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P. 4.1
Handbook to measure and evaluate a group of Social Quality indicators

Project: New Evaluation Method for Homes of Social, Sustainable and Energy Efficient Interest – Architecture for Climate- in the Sudoe Territory (ARCAS)

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Executive summary

This handbook presents the methodology for calculation of the social quality indicators of the ARCAS project. It consists of three main sections. The first one presents the calculation methods for the energy poverty indicators - 10% indicator, the LHIC indicator, the 2M and the Index for Vulnerable Homes - that will be assessed in the scope of the project. The methods also include the distinctive data collection techniques and data sources that can be used in the three different national contexts within the ARCAS project.

The second section of the handbook is constituted by the calculation of the indoor air quality using the TAIL index, highlighting the devices to be used and the experimental set-up protocol to be applied for the measurements.

The last section presents the concluding remarks and recommendations.

Glossary

Energy poverty: following EPOV, is "the inability of a household to access socially and materially necessitated levels of energy services in the home".

Energy services: Energy services at home are those functions performed using energy, which are means to obtain or facilitate desired end services, such as heating, cooling and cooking.

Equivalised disposable income: the economic resources available to a standardised household.

Energy carrier: following the definition in ISO 13600, an "energy carrier is either a substance or a phenomenon that can be used to produce mechanical work or heat or to operate chemical or physical processes". Energy carriers include electricity and heat as well as solid, liquid and gaseous fuels. They serve as intermediate in the energy supply chain between primary energy sources and end-use services. In that sense, an energy carrier is a transmitter of energy.

The following acronyms are used within this evaluation report:

CI	Comfort Indicator (IVH)
DHW	Domestic Hot Water needs
EnI	Energy Indicator (IVH)
EP	Energy Poverty
EPOV	Energy Poverty Observatory
EU	European Union
EU-SILC	European Union Statistics on Income and Living Conditions
2M	High share of energy expenditure in income indicator
LIHC	Low Income High Costs indicator
IAQ	Indoor Air Quality
QALY	Quality-adjusted life years
IVH	Index of Vulnerable Homes
MPI	Monetary Poverty Indicator (IVH)
M/2	Low absolute energy expenditure indicator
N_W	Heating needs
N_S	Cooling needs
OECD	Organisation for Economic Co-operation and Development
TAIL	Thermal, Acoustic, Indoor environment, Luminosity indicator
VOC	Volatile Organic Compounds

1. CONTEXT

1.1. The ARCAS Project

The objective of the ARCAS project is to develop an assessment and design methodology aimed at the renovation of buildings and groups of multifamily housing buildings of social interest, to address energy poverty and promote sustainable renovation, energy efficiency and healthy indoor environments in the SUDOE territory. The project is based on the integration of three research axes:

AXIS 1 - Energy autonomy - efficiency

AXIS 2 - Social quality - energy poverty

AXIS 3 - Air quality - health

As a result of this integration, the work in the project is developed to determine the optimal relationship between the three mentioned axes and obtain the best energy efficiency while maintaining the social quality and well-being of citizens.

ARCAS is based on the use of similar climatology in the South Atlantic region for the development of a tool that allows, through key indicators, the design of building architecture based on maximizing energy efficiency, air quality and thus promoting social welfare, making use of the best available techniques, including renewable energy sources.

This project combines efforts to develop strategies and measures that facilitate the development of policies, at national, regional and local governments scale, for the renovation of multifamily housing buildings with great autonomy and energy efficiency (axis 1), with healthy air quality for building occupants (axis 3) and reducing energy poverty, which is so important in many European countries (axis 2).

ARCAS results and outcomes will be applicable and reproducible in the public and private institutions participating in the project and will be especially useful for professional associations, manufacturers, and builders and for national, regional and local public administrations.

The Action Plans that will be developed in an integrated manner on the three axes of the research project by ARCAS beneficiaries, in collaboration with ARCAS associated partners constitute a key element that will ensure the transfer of knowledge to the entire SUDOE territory, as well as the future sustainability of the ARCAS methodology.

From a methodological point of view, the project is structured in different Work Packages (WP). In a first phase, the indicators that will be used in the ARCAS methodology are defined. These indicators are proposed within the first four Work Packages, as well as the specifications and protocols for their quantification. Those four Work Packages are specifically:

WP 1 - Climate indicators selection
WP 2 - Selection of energy efficiency indicators in residential buildings
WP 3 - Selection of indicators on best technologies available in renewables
WP 4 - Selection of social quality indicators

In WP 5, the ARCAS methodology will be developed and implemented in a computer tool. Therefore, it is essential that the indicators selected in the previous WPs can be measurable and evaluable, in addition to being compatible with their application to different types of residential buildings and in different countries.
The methodology will be validated in WP 6. For this, a set of demonstration buildings will be selected. As selection criteria, buildings that include a casuistic representative of the three axes considered and the three countries of the consortium will be sought.
WP 7, WP 8 and WP 9 encompass the part of the project that can be considered as the capitalization part. More specifically, in WP 7, the ARCAS certification procedure will be detailed, generating a series of guides for project owners, and other relevant actors that will audit ARCAS projects. This work will be carried out in coordination with the associated partners of the project. As for WP 8, this group of tasks has as its main objective the training of professionals, and to achieve it, a training program will be defined to train professionals in the application and certification of the ARCAS method, and a pilot program will be provided training in professional institutions that belong to the ARCAS project value chain. Finally, in WP 9, strategies will be developed to establish new sustainability, energy efficiency and social quality policies in the renovation of multifamily buildings of social interest. This includes, amongst others, proposals for renovation policies, financing models and criteria to prioritize interventions. For that, the indicators defined in WPs 1 to 4 will be used and will be carried out in coordination with the public administrations and private organizations associated with the ARCAS project.

Specifically in WP 4 – Selection of social quality indicators – Energy Poverty and Indoor air Quality, the main objective is to identify and select appropriate variables and indicators related to social quality, in particular related to interconnected issues such as energy poverty and health that will be applied in the ARCAS assessment method. In this context, two secondary objectives can be identified:
1. Characterization of energy poverty indicators according to the context of the European Social Policy adapted to the SUDOE territory. Individual and aggregated indicators will be considered, with particular focus on those directly related to the scale of intervention of the project. Some key factors that should be considered are energy vulnerability, family income levels and energy prices.
2. Selection of indicators related to indoor air quality. Air quality is a cross-cutting aspect with strong effects on occupants' health. Additionally, with the current regulations that

promote airtightness, ventilation and air quality, these indicators represent an important percentage of the final energy consumption of the home. This study was included in this WP due to its impact on the health and comfort of building users.
This handbook is dedicated to present the methodology to measure and evaluate the group of social quality indicators, composed of energy poverty indicators and air quality indicators for the ARCAS methodology, in relation to the necessary adaptations and methods and sources for data acquisition, instrumentation and equipment for the use of indicators.

2. INTRODUCTION

ARCAS project is concerned with obtaining affordable and sustainable energy renovation interventions in social housing contexts in the SUDOE region. One of the project's focuses is related to the consideration of social quality indicators in the scope of the methodology used to assess renovations in these challenging contexts. For the ARCAS project, the social quality dimension is closely related to energy poverty and indoor air quality.

Energy poverty is a growing problem in Europe. It is a multidimensional and complex societal problem closely related to households' inability to meet their energy needs. It is estimated that this problem in the European territory affects between 30 to 120 million people (EPOV, 2020). This has substantial economic, political, social and health implications, and there is evidence that it is likely to increase during financial crises. Tackling the problem is therefore urgent and relevant for Europe.

There is a significant number of research studies and institutions addressing the problem in Europe at different scales (e.g. Horta et al., 2019; Sánchez-Guevara Sánchez et al., 2020). Additionally, it should be highlighted that several countries and cities have developed strategies specifically addressing the issue of energy poverty.

Although there is no common definition for energy poverty in Europe, the complexity and multidimensionality of the problem are widely recognized both on definitions and on proposed indicators. To be considered in the ARCAS methodology, indicators should meet several requirements. One of the most important is the need for easy and affordable, but rigorous, measurability for the parameters composing the indicator.

Being energy poverty a very complex and multidimensional problem, there is the need in WP4 to find a balance between the complexity achieved in the methodology and the accuracy while measuring the problem. The choice of indicators should also consider the context and the scale to be addressed within the scope of the project, as well as data availability.

Building ventilation and the quality of the indoor environment have been at the centre of the discussions of energy efficiency since there are significant energy losses due to air renovation and infiltrations. On the other hand, indoor air quality affects not only the social aspects of the dwellings, but also health and well-being. There is a recognized need for considering indoor air quality in sustainable assessment methods to ensure that occupants health are not disregarded in the pursuit of improved energy efficiency and carbon neutrality in the building sector.

Three main sections constitute this handbook. The first section is dedicated to the energy poverty indicators that will be tested for integration in the ARCAS methodology. The second section is dedicated to the indoor air quality indicator and the experimental setup necessary for adequate measurements. The last section presents the concluding remarks and recommendations.

3. ENERGY POVERTY

3.1. ENERGY POVERTY INDICATORS FOR THE ARCAS METHODOLOGY

The work described in report 4.1.1 – Report on Energy Poverty Indicators – resulted in identifying and selecting an energy poverty definition and a range of indicators that are suitable for the analysis being pursued in the ARCAS project.

The definition adopted in this project is intended to be open and broad to embrace the different national contexts considered in the analysis. Additionally, the adopted definition also considers that, although heating needs are, in general, the main issue in these contexts, the project also aims to consider future climates where indoor conditions could suffer significant differences. In this context, the definition proposed for the energy poverty assessment in the ARCAS project follows the EU Energy Poverty Observatory (EPOV) definition, where energy poverty can be defined as the “inability of a household to access socially and materially necessitated levels of energy services in the home” (EPOV, 2020).
Concerning the indicators, since the general methodology of the multicriteria analysis that will be used in the ARCAS project is yet to be developed, various indicators were indicated in report 4.1.1., as suitable for further testing in the methodology (Table 1).

An important question that was considered for the selection relates to the need for adaptability to the different national contexts within the scope of the project and the flexibility to use both measurements and calculations from numerical simulations.
The following indicators selection (Table 1) assumes that, although providing a simplistic perspective of the problem, expenditure-based indicators can give a very objective overview of an energy poverty situation. This objectivity can be crucial in the framework of the development of multicriteria analysis. There is also the question that, in the scope of the ARCAS project, a very particular context – social housing buildings - is going to be analysed. In this context, the lack of economic availability of resources to pay for energy services is determinant and therefore, this type of indicators is considered adequate.

Table 1 - Proposed indicators to be tested in the ARCAS methodology

Indicators	**Definition**	**Thresholds**
10%	The indicator establishes a direct relationship between the net income and the energy expenditure of a household	10% of net income spent on energy
High share of energy expenditure in income (2M)	This indicator shows whether the share of energy expenditure in household income is more than double the national average share	Income< equivalised income Expenditure> more than twice the national share
Low Income, High Costs (LIHC)	The indicator considers both household income and the energy expenditure in housing. The indicator allows identifying if the household has an energy expenditure above the national median and also the relation between the household income and the official poverty threshold after the energy expenditure	Income <poverty threshold Expenditure>national median
Index of Vulnerable Homes	This composite indicator combines a monetary poverty indicator (using available net income), an energy indicator (comparing the energy consumption associated with the building characteristics with the median energy	Pre-defined levels of vulnerability

Indicators	Definition	Thresholds
	consumption associated with the building typology in the area of study) and a comfort indicator (using indoor temperature data) as well as an indicator of health-related quality of life of the household.	

Three expenditure indicators were proposed in this context – the 10% indicator, the Low Income, High Costs (LIHC) indicator and the 2M indicator, together with a more detailed composite indicator – the Index of Vulnerable Homes.

The 10% indicator is an objective indicator that establishes a very direct relationship between the household's net income and its expenditure on energy. The simplicity and objectivity of this indicator can make sense in the scope of the multicriteria assessment methodology under development, which involves the calculation of other complex indicators.

On the other hand, the Low-Income High Costs indicator (LIHC) allows identifying whether the household has an energy expenditure above the national median, but also the relation between the household income and the official poverty threshold after the energy expenditure, which, in the context being analysed, can be particularly useful and insightful.

Finally, the 2M indicator presents another perspective taking into account equivalised income, which considers the relative size of households, which is an important factor for the economic stability of a household in a social housing context.

The selection of indicators also considered that, depending on the complexity of data collection and method of multicriteria assessment, the multidimensionality of energy poverty can also be useful and necessary to capture in the ARCAS methodology. In this case, it was proposed the use and testing of a composite index.

The index to include in the ARCAS methodology should be, preferably, a composite metric that can make use of other indicators being collected in the scope of the methodology (e.g. energy efficiency indicators) and that takes into account dimensions that are important for the project, such as energy efficiency and health.

In this context, an adaptation of the Index of Vulnerable Homes was proposed, since it uses a monetary indicator, an energy indicator and a comfort indicator (all of which can be measured or simulated in the scope of the project), as well as a quality-of-life indicator.

3.2. METHODOLOGY FOR CALCULATION OF ENERGY POVERTY INDICATORS IN THE ARCAS PROJECT

This section details the methods for calculating the proposed indicators. The methods will be presented by increasing the level of complexity of the indicators, starting with the indicator considered the less complex.
In general, the literature concerning the use of the proposed indicators suggests a wide range of data to be used. Examples include average values, aggregated data at the country level, or direct measurements at the household level.
The analysis to be carried out in the ARCAS project focuses on the household and ultimately the neighbourhood level, and therefore, both the calculation methods and the data sources must be consistent with this objective.
The methodology could be applied using three different approaches regarding the ARCAS project: 1) Using direct measurements or calculations for the households. 2) Using public data sources that reflect the national context being analysed. 3) Combining the two previous approaches, where some direct measurements and metrics are available while others have to be inferred from public databases. The methods indicated in the following subsections consider that these three perspectives can be used to calculate the indicators.

3.2.1. 10% Indicator

The **10% indicator** establishes a direct relationship between the net income and the energy expenditure of a household. It uses the following formulation to assess energy poverty situations, according to equation 1.

*Annual household energy expenditure/ annual household net income * 100 < 10%* (1)

3.2.1.1. Calculation and collection of parameters for the 10% indicator

The 10% indicator should be calculated using the following rationale:

1. Calculation of net income for the household
2. Calculation of energy expenditure
3. Generation of the ratio between the previous parameters

To obtain the net income, it is recommended that at least the occupational status of the households is known: the number of people employed, unemployed, retired, with social benefits, etc. Since the ARCAS project focuses on low-income contexts such as social housing neighbourhoods, it is proposed to adopt the respective national minimum values foreseen for these occupational statuses, multiplied by the number of people classified in each. Alternatively, if regional or local specificities are sought to be important for the assessment, direct consultation can be used. Finally, if none of this data is available, the national minimum wage multiplied by the number of adult cohabitants can be adopted.
Regarding the net income, it should be estimated using Equation 2.

Net income = (Non-taxable income + Taxable income) – (national insurance (or social security) payable+ income tax payable) (2)

The data sources indicated in Table 2 can be consulted regarding incomes in the different national contexts.

Table 2 – Data sources for national incomes in the different countries being addressed in the ARCAS project

National context	Data Source for Income
France	www.insee.fr, www.onpe.org
Portugal	www.pordata.pt[1]
Spain	www.mites.gob.es[2]

The energy expenditure should be estimated, when possible, using the energy needs stated in the Energy Performance Certificates (EPC) of the building. This method of obtaining the energy needs, not only accommodates the local specificities of the three participating countries, as it follows the calculation methods defined in the legislation, but also allows for an objective comparison between buildings and takes into account the achievement of minimum comfort conditions for users. Additionally, this approach links the Energy Poverty indicator to the quality of the envelope and the equipment used.
If an EPC is not available, the energy needs should be calculated using the same methodology and procedures as the ones foreseen by each country's legislation, which can be done by using dynamic or steady-state calculations for simulating the energy performance of the building. Finally, as an alternative, directly measuring household

[1] https://www.pordata.pt/Portugal/Sal%C3%A1rio+m%C3%ADnimo+nacional-74-7892
[2] https://www.mites.gob.es/es/Guia/texto/guia_6/contenidos/guia_6_13_2.htm

energy consumption using power meters or querying energy bills to obtain historical data could also be used, but only if indoor comfort temperatures and all other minimum conditions required by the regulations are met.

The energy performance should relate to the energy demand associated with the typical use of the building, which includes energy used for space heating and cooling, domestic hot water, lighting, and ventilation, taking as a reference the standardized temperature threshold defined in each national thermal regulation. The numerical model used should consider, inter alia, the physical characteristics of the buildings (e.g., thermal transmittance coefficient of the envelope), internal gains of the dwelling, and the type of heating and cooling system used.
After the estimation of the energy needs, the energy expenditure should be calculated considering the different energy vectors in use in the building and the current prices of the different energy carriers for each national context, including applicable fees.

3.2.2. 2M Indicator

The 2M indicator is a relative indicator. This indicator shows whether the share of energy expenditure in household income is more than double the national average share, according to equation 4.

share of (equivalised) energy expenditure on income/ national share > 2 (4)

The national share is a median value that can change over time (as a result of policies or other external factors, e.g., the confinement in 2020/2021 in consequence of the COVID 19 pandemic) and would also cause a variation of the threshold value. However, the national share serves as a useful reference for the effort being made in terms of household disposable income. When using this indicator, it should be highlighted that if a household consumes less energy, this may not be captured by this indicator. In these cases, a variation of the indicator should be used. This variation is designated as M/2 – Low absolute energy expenditure. The M/2 presents the share of households whose total energy expenditure is below half the national median, or in other words, abnormally low. This is particularly important due to the social housing context being analysed in the ARCAS project and because this kind of situation (i.e. under consumption) was already identified in some countries, such as Portugal.

3.2.2.1. Calculation and collection of parameters for the 2M and M/2 indicator

The indicators 2M and M/2 should be calculated using the following rationale:

1. Calculation of the share of (equivalised) energy expenditure
2. Calculation of (equivalised) disposable income for each household
3. Generation of the comparison between the previous parameters and the national share

For the calculation of energy expenditure, the preferred methods will include direct measurement of the consumption of the household using power meters or through consultation of household energy bills for historical data.
If no measured data is available, energy expenditure should be calculated from the energy performance simulations of the household. These calculations should include the energy necessary for space heating and cooling and domestic hot water needs using, as a reference, the standard temperature thresholds defined in thermal regulations in each national context. Lighting consumption and appliance use should also be included if available. The numerical model used should consider the physical characteristics of the buildings (e.g. thermal transmittance coefficient of the envelope), occupancy and internal gains of the dwelling and the type of heating and cooling system used. Both dynamic and steady state calculations can be used to calculate the energy needs, preferably in line with what is considered an established method in the different national contexts.

After the estimation of the energy needs, the energy expenditure should be calculated considering the different energy vectors in use in the building and the current prices of the different energy carriers for each national context, including applicable fees.

Disposable income should be calculated from direct consultation of the household or through the use of statistical data. If the occupational status of the households is known (the number of people employed, unemployed, retired, with social benefits, etc.), and because the ARCAS project focuses on low-income contexts such as social housing neighbourhoods, the net income can be calculated by multiplying the respective national minimum values foreseen for these occupational statuses by the number of people classified in each of them. Finally, if none of this data is available, the national minimum wage multiplied by the number of adult cohabitants can be adopted.
To be used through consultation, disposable income should consider the formulation in equation 6:

Disposable income = net income – housing costs (6)

The approach used for calculating the relative burden of energy expenditure and disposable income utility regarding the 2M (and the M/2) is through an equivalisation of the values. The rationale for using this approach is clearly explained in several sources (e.g.(Anyaegbu, 2010; Chanfreau & Burchardt, 2008)) and that specific household needs do not increase proportionately with the addition of a new member. For example, the need for indoor space or electricity will not be three times higher for a household with three persons than for a household consisting of only one person. Using this perspective, disposable income utility will also be expected to decline with more persons in a household. This proportion is normally weighted through the use of equivalence scales. In this case, the factors considered are the size of the household in terms of the number of persons and their age (making the distinction between adults and children).

To account for household differences concerning the relative burden of energy expenditure and relative utility of disposable household income, it is suggested, in the scope of the project ARCAS, to use the OECD modified equivalence scale. According to this scale, each member of the household is first given an equivalence value (OECD, 2020):

- 1.0 to the first adult;
- 0.5 to the second and each subsequent person aged 14 and over;
- 0.3 to each child aged under 14.

The values obtained from the equivalence scale will be added to give a total equivalence value. For instance, a value of 2 for a particular household would suggest that the household would need twice the income of a single person household to meet a comparable standard of living.
As stated, if direct data is not available, statistical general data can be used. The country's equivalised disposable income is accessible in the EU statistics on income and living conditions (EU-SILC)[3].

Finally, the national median share for energy expenditure is accessible in the different countries in the sources identified in Table 3.

Table 3 - Data sources for national share of energy expenditure in the different countries being addressed in the ARCAS project

National context	**Data Source for National Share of Energy Expenditure (per capita)**
France	www.insee.fr
Portugal	www.ine.pt[4]

[3] https://ec.europa.eu/eurostat/web/microdata/european-union-statistics-on-income-and-living-conditions

[4] https://www.ine.pt/xportal/xmain?xpgid=ine_tema&xpid=INE&tema_cod=1611&xlang=pt

Spain	www.ine.es[5][6]

3.2.3. Low Income and High Costs Indicator

The Low-Income High Costs indicator allows identifying if the household presents an energy expenditure above the national median share and the relation of the household income to the official national poverty threshold (after the energy expenditure). Therefore, it can be considered a dual indicator in the sense that it measures not only the extent of the problem but also its depth (Annual Fuel Poverty Statistics in England, 2020 (2018 Data), n.d.). Figure 1 presents a graphical interpretation of the indicator, where the shaded area indicates the zone where energy poverty is considered. The figure also highlights what is known as the fuel poverty (or energy poverty) gap, which accounts for the additional costs that would make the household out of an energy poverty situation. Although useful to understand the effect of energy prices, for example, the fuel poverty gap will not be addressed in the ARCAS project.

Similarly to the 2M indicator, the Low-Income High Costs indicator presents a relative metric since it compares the situation of households with national income thresholds and national median energy share. Regarding the figure and the indicator, it is also worth highlighting that its use is useful to understand the dynamics of changing energy poverty risk situations. For example, those households that are situated in the bottom right-hand quadrant also have high energy costs. Still, their relatively high incomes allow for the necessary balance for them not to be considered energy poor in the light of the LIHC indicator. Households in the top right-hand quadrant present both high incomes and low energy costs (e.g. due to high energy efficiency, for example) and are not considered to be in an energy poverty situation. Households in the top left-hand quadrant have low incomes. Still, they have relatively low energy costs (i.e. not surpassing the threshold of the national median share due to, e.g. living in a high energy efficient dwelling) and are also not considered to be in energy poverty.

[5] https://www.ine.es/dynt3/inebase/es/index.htm?padre=3777&capsel=3821

[6] Disaggregated by autonomous communities - https://www.ine.es/dynt3/inebase/es/index.htm?padre=3856&capsel=3857

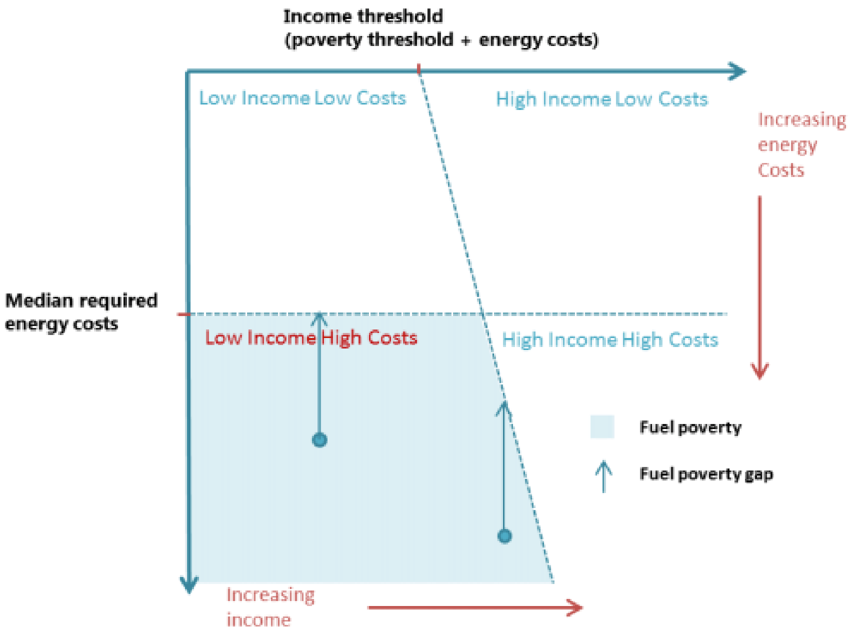


*Figure 1 – LIHC indicator (source:(*Annual Fuel Poverty Statistics in England, 2020 (2018 Data)*, n.d.))*

3.2.4. Calculation and collection of parameters for the LIHC indicator

The indicator LIHC should be calculated using the following rationale:

1. Calculation of the share of (equivalised) energy expenditure
2. Calculation of (equivalised) disposable income for each household
3. Generation of the comparison between the previous parameters, the national share and the national poverty threshold

For the calculation of energy expenditure, the preferred methods will include direct measurement of the consumption of the household using power meters or through consultation of household energy bills for historical data.
If no measured data is available, energy expenditure should be calculated from the energy performance simulations of the household. These calculations should include the energy necessary for space heating and cooling and domestic hot water needs using, as a reference, the standard temperature thresholds defined in thermal regulations in each national context. Lighting consumption and appliance use should also be included if

available. The numerical model used should consider the physical characteristics of the buildings (e.g. thermal transmittance coefficient of the envelope), occupancy and internal gains of the dwelling and the type of heating and cooling system used. Both dynamic and steady-state calculations can be used to calculate the energy needs, preferably in line with what is considered an established method in the different national contexts.

After the estimation of the energy needs, the energy expenditure should be calculated considering the different energy vectors in use in the building and the current prices of the different energy carriers for each national context, including applicable fees.

The use of numerical simulations to calculate energy expenditure should be applied with a clear understanding of the limitations of this approach, namely in terms of associated uncertainty and discrepancies to measured values.

Disposable income should be calculated from the consultation of the household or through the use of statistical data. If the occupational status of the households is known (the number of people employed, unemployed, retired, with social benefits, etc.), and because the ARCAS project focuses on low-income contexts such as social housing neighbourhoods, the net income can be calculated by multiplying the respective national minimum values foreseen for these occupational statuses by the number of people classified in each of them. Finally, if none of this data is available, the national minimum wage multiplied by the number of adult cohabitants can be adopted.
To be used through consultation, disposable income should consider:

Disposable income = net income (after taxes) – housing costs (8)

To account for household differences concerning to the relative burden of the energy expenditure and the relative utility of disposable household income, it is suggested to use the modified OECD equivalence scale in the scope of the project ARCAS. According to this scale, each household member is first given an equivalence value (OECD, 2020):

- 1.0 to the first adult;
- 0.5 to the second and each subsequent person aged 14 and over;
- 0.3 to each child aged under 14.

The values obtained from the equivalence scale will be added to give a total equivalence value. For instance, a value of 2 for a particular household would suggest that the

household would need twice the income of a single person household to meet a comparable standard of living.
Equivalised disposable income by country is accessible in the EU statistics on income and living conditions (EU-SILC)[7].

The national share for energy expenditure is accessible in the different countries in the sources indicated in Table 4. In Table 5, data sources for national poverty thresholds are detailed.

Table 4 - Data sources for national share of energy expenditure in the different countries being addressed in the ARCAS project

National context	Data Source for National Share of Energy Expenditure (per capita)
France	www.insee.fr
Portugal	www.ine.pt[8]
Spain	www.ine.es[9][10]

Table 5 - Data sources for national poverty thresholds in the different countries being addressed in the ARCAS project

National context	Data Source for National Poverty Thresholds
France	https://onpe.org
Portugal	www.pordata.pt[11]
Spain	www.ine.es[12]

3.2.5. IVH Indicator

The index of Vulnerable Homes (IVH) can be applied to assessing an individual household scale by combining four indicators. It combines a monetary poverty indicator (using

[7] https://ec.europa.eu/eurostat/web/microdata/european-union-statistics-on-income-and-living-conditions
[8] https://www.ine.pt/xportal/xmain?xpgid=ine_tema&xpid=INE&tema_cod=1611&xlang=pt
[9] https://www.ine.es/dynt3/inebase/es/index.htm?padre=3777&capsel=3821
[10] Disaggregated by autonomous communities - https://www.ine.es/dynt3/inebase/es/index.htm?padre=3856&capsel=3857
[11] https://www.pordata.pt/Portugal/Limiar+de+risco+de+pobreza-2167
[12] https://www.ine.es/jaxiT3/Datos.htm?t=9964

available net income), an energy indicator (comparing the energy consumption of the specific building with the average energy consumption of a typical building in the region under study), a comfort indicator (using indoor temperature data) and a health-related quality of life indicator of the household. A hierarchy of vulnerability levels is established by combining the different indicators' values with the quality-of-life thresholds. The result is a multidimensional index related to technical and social aspects, providing a holistic assessment and identifying which variables require improvement to alleviate energy poverty situations. The indicator presented here is adapted from [8].

3.2.5.1. Calculation and collection of parameters for the IVH indicator

The indicator should be calculated using the following rationale:

1. Calculation of the Monetary Poverty indicator
2. Calculation of the Energy indicator
3. Calculation of the Comfort indicator
4. Determination of the Quality-of-Life values
5. Application of the pre-defined levels of vulnerability

The monetary poverty indicator (MPI) of the IVH is calculated following equation 9:

$$MPI = NI/T \qquad (9)$$

Where, NI is the net income and T is the poverty threshold.

The calculation of Net Income should consider the formulation of equation 10:

$$Net\ Income = (I+B) - (HE+OE) \qquad (10)$$

Where, I = household Income minus the energy expenses, B = social benefits, HE = Housing costs (rent or mortgage), OE = other additional housing expenditures such as expenses derived from degenerative diseases, mobility and disabled persons living in the household.

The poverty threshold to be considered here is related to the national poverty thresholds. If no threshold is defined at the national level, the value of 60% of the median equivalised disposable income in each region according to Eurostat statistics should be considered. For this indicator, a household is considered to be in a monetary poverty situation if its net incomes fall below the set threshold (MPI < 1.00).

The national poverty threshold is accessible in the different national contexts in the sources indicated in Table 6.

Table 6 - Data sources for national poverty thresholds in the different countries being addressed in the ARCAS project

National context	Data Source for National Poverty Thresholds
France	https://onpe.org
Portugal	www.pordata.pt[13]
Spain	www.ine.es[14]

In what concerns the energy indicator (EnI) of the IVH, it intends to evaluate whether the energy demand of the dwelling corresponds to the standard situation for the building typology and respective location. It is calculated according to equation 11:

$$EnI = EC/MEC \qquad (11)$$

Where:

EC is the energy demand. It should be estimated, when possible, using the energy needs stated in the Energy Performance Certificates (EPC) of the building. If an EPC is not available, the energy needs should be calculated using the same methodology and procedures as the ones foreseen by each country's legislation, which can be done by using dynamic or steady-state calculations for simulating the energy performance of the building. Finally, as an alternative, directly measuring household energy consumption using power meters could also be used, but only if indoor comfort temperatures and all other minimum conditions required by the regulations are met.

The energy performance should relate to the energy demand associated with the typical use of the building, which includes energy used for space heating and cooling, domestic hot water, lighting, and ventilation, taking as a reference the standardized temperature threshold defined in each national thermal regulation. The numerical model used should consider, inter alia, the physical characteristics of the buildings (e.g., thermal transmittance coefficient of the envelope), internal gains of the dwelling, and the type of heating and cooling system used.

MEC can be drawn from national studies addressing average values of a specific type of buildings, if existent, or in the absence of these, the national median share of energy expenditure can be used.

[13] https://www.pordata.pt/Portugal/Limiar+de+risco+de+pobreza-2167

[14] https://www.ine.es/jaxiT3/Tabla.htm?t=9964&L=0

The national share for energy expenditure is accessible in the different countries in the sources indicated in Table 7.

Table 7 - Data sources for national share of energy expenditure in the different countries being addressed in the ARCAS project

National context	**Data Source for National Share of Energy Expenditure (per capita)**
France	www.insee.fr
Portugal	www.ine.pt[15]
Spain	www.ine.es[16][17]

The EnI indicator is admissible if the result is below the energy threshold (EnI < 1.00). It is not adequate if EnI > 1.00.

The Comfort Indicator (CI) in this index is based on the adaptive approach for thermal comfort assessment. It evaluates the number of hours in which living spaces are out of the comfort range considered in the standards such as ASHRAE standard 55-2017 (ANSI/ASHRAE, 2017) and EN 16798-1:2019 [10]. Three comfort categories are defined, depending on the context and building typology under analysis. In particular, the calculation of the CI should be compatible and in line with the methodology described for the %HI-II Indicator (Percentage of hours that the dwelling is within the comfort range conditions) detailed in Deliverable 2.2 - Report on Methodology for the evaluation of Energy Efficiency and Sustainability Indicators. It should also be consistent with calculations for comfort defined in Deliverable 4.4 – Report on Air Quality assessment methodology.

Calculations for determining CI should follow standard EN 16798-1:2020, where the optimal comfort temperature (Tc) is calculated through equation 12 (ANSI/ASHRAE, 2017):

$$Tc = 0.33 \times Tpma + 18.8 \qquad (12)$$

where Tc is the acceptable upper operative temperature, and Tpma is the prevailing mean outdoor temperature of the previous 7 days.

[15] https://www.ine.pt/xportal/xmain?xpgid=ine_tema&xpid=INE&tema_cod=1611&xlang=pt

[16] https://www.ine.es/dynt3/inebase/es/index.htm?padre=3777&capsel=3821

[17] Disaggregated by autonomous communities - https://www.ine.es/dynt3/inebase/es/index.htm?padre=3856&capsel=3857

CI is considered "admissible" if the thermal comfort of 80% acceptability threshold (Tc ± 3.5 °C) is surpassed. When this condition is not met, the household is considered to be in a vulnerable situation. Similarly to the energy indicator, data can be obtained either from direct measurements (for detailed methodologies concerning the temperature measurement, please refer to Deliverable D2.2.1) or numerical energy simulation. In the latter case, the numerical model used should consider the physical characteristics of the buildings (e.g. thermal transmittance coefficient of the envelope), occupancy and internal gains of the dwelling. Both dynamic and steady-state calculations can be used, preferably in line with what is considered an established method in the different national contexts.

The IVH also considers an indicator concerning Quality of Life – Quality-Adjusted Life Years (QALY), which establishes the relationship between the quality of life and the health of occupants. It can be defined as "a measure of a person's length of life weighted by a valuation of their health-related quality of life" (Phillips, 2009). QALY scale is organized from 0 to 1, being the latter what represents the best condition possible. In the case of the indicator presented here, the QALY is calculated using the 'European Quality of Life-5 Dimensions' (EQ-5D) questionnaire and the EQ-5D-5L Index Value Calculator (EUROQOL, 2020). For the calculations regarding the benefits for health through energy efficiency improvements, previous studies were taken as reference (e.g. [13]).

Instead of obtaining a single objective result from the assessment of the household's vulnerability, the Index of Vulnerable Homes is organized around levels of vulnerability, assuming the multidimensionality of the problem of energy poverty in the integration of the various indicators composing the index. The crescent four levels of vulnerability (Table 8) are adapted from the original study that developed the index (Castaño-Rosa et al., 2020) and are presented as a possibility for integrating the ARCAS methodology. The proposed levels can be further adapted to better suit the development of ARCAS multicriteria analysis.

Table 8 – Pre-defined levels of vulnerability for IVH index

Level of Vulnerability	**Variables**			
1	MPI: No Monetary Poverty	EnI: Admissible	CI: Admissible	QALY: 0.91
2	MPI: No Monetary Poverty	EnI: Inadmissible	CI: Admissible	QALY:0.85
3	MPI: Monetary Poverty	EnI: Inadmissible	CI: Admissible	QALY:0.62
4	MPI: Monetary Poverty	EnI: Inadmissible	CI: Inadmissible	QALY:0.48

4. INDOOR AIR QUALITY

4.1. TAIL INDEX

This index was developed to promote renovation operations and the quality of renovations. This index is intended to be used before and after renovations. It proposes to note four categories of comfort with a colour code ranging from green (good quality) to red (poor quality) (Figure 2), referenced by the four letters of the acronym:

- T for «Thermal comfort»;
- A for «Acoustic comfort»;
- I for «Indoor air quality»;
- L for «Luminous comfort».

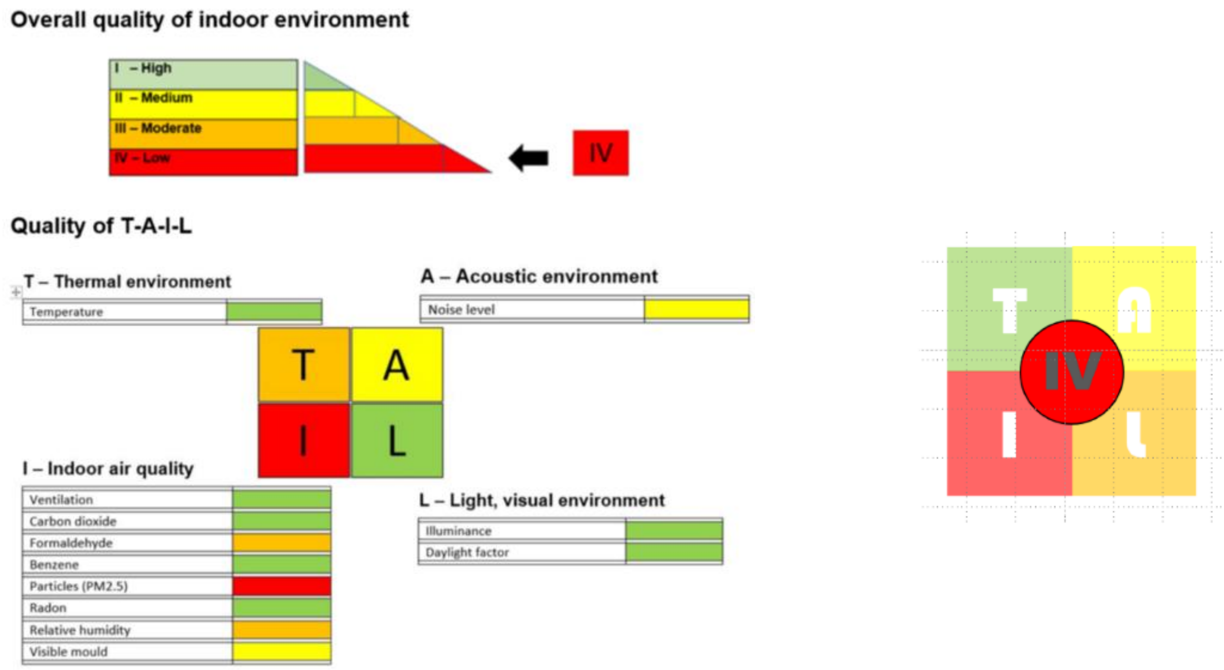


Figure 2: Examples of graphic representations of the TAIL index (Wargocki et al., 2019

An overall score out of four is also indicated and aggregates the four categories. The lower the number, the better the IAQ. This system is in accordance with the NF EN 16798-1 (2019) standard, which deals with indoor ambient settings for thermal ambience, indoor air quality, lighting and acoustics.
According to the ARCAS tool, just thermal comfort and indoor air quality could be measured.

4.1.1. General Process

The general measurement methodology consists of four steps, as shown in Figure 3. Data collection in one or more weeks of monitoring depends on the type of target molecules in the indoor air. The TAIL indicator is generally used for hotels and offices but can be adapted for residential applications (i.e. taking into account different occupancy scenarios).

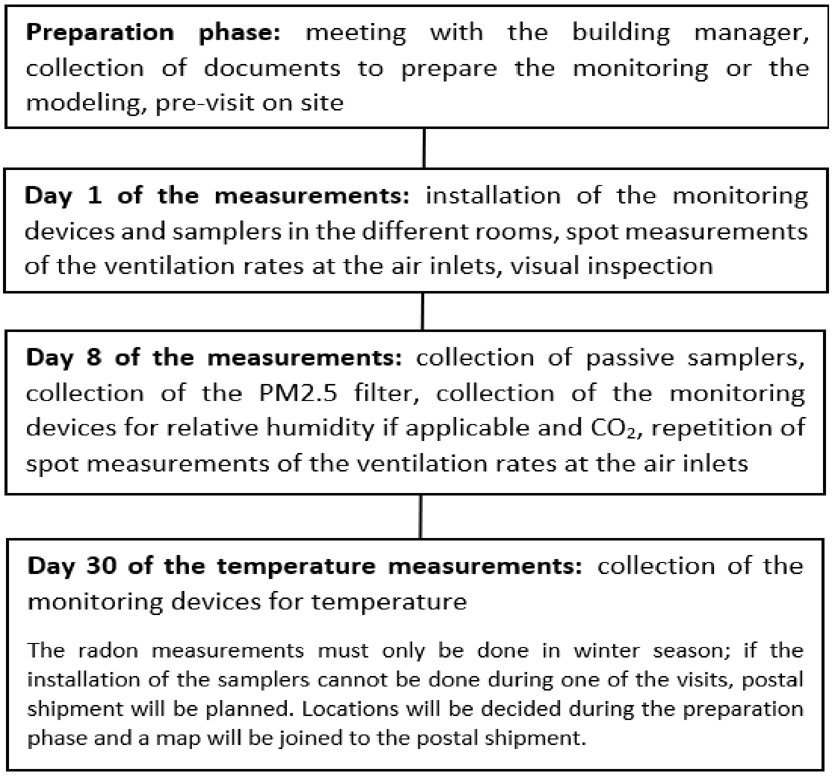


Figure 3: General overview of TAIL process

4.2. GENERAL RECOMMENDATIONS

Several criteria should be fulfilled in the context of the experimental protocol:

1. The minimum total area covered by all the measuring sensors should be at least the living room and the most used bedroom;
2. The choice of monitored locations should consider temperature, relative humidity, CO_2 and VOCs (formaldehyde and benzene) in the living room and

bedroom. Particle Matters can be measured in the living room only. Radon should be measured in the compartment closest to the ground;

3. Ideally, samplers and data loggers should be placed in the middle of the room, at a height comparable to the level of the respiratory tract and at least 1m away from the walls. They should also not be exposed to heat sources, direct solar radiation or draughts.

4.3. DETAILED PROTOCOL FOR INDOOR AIR QUALITY EVALUATION

Indoor Air quality is evaluated based on the following parameters: the emissions of carbon dioxide (CO2), particle matters (PM2.5), formaldehyde, benzene, radon, relative humidity, ventilation rate, and the visible mould. The different ranges of values delimitating the categories for each component (from I to IV) are detailed separately in the Excel Sheet mentioned previously in the D4.3 Report.

The next part aims to present the experimental set-up and protocol used for each component as discussed in the ALDREN (Alliance for Deep RENovation in Buildings) project in compliance with NF EN 16798-1 and NF EN 16798-2 (2019), to have a global experimental approach applied on residential buildings.

4.3.1. Carbon dioxide parameter (CO_2)

Table 9 : CO_2 experimental set-up

CO_2 Parameter (EN 16798)	
Assessment method	**Experimental set-up**
- On-line measurements - Measurements period for seven consecutive days with a time interval from 1 min to 10 min. - Data covering occupancy periods shall be used (between 19h and 7h in the weekdays, the whole day on weekends). - An additional measurement of outdoors CO_2 concentrations is recommended; else, 400 ppm can be considered. - The CO2 concentration should fall within the indicated range. The range can be exceeded by no more than 5% of the time concerning concentration levels set by the next higher category and by no more than 1 % of the time concerning concentrations set by the following higher category.	Calibrated Fourier Transform infrared (FTIR) sensors with accuracy of at least ±50 ppm   *Figure 4: Infrared sensors and data recorder interface*

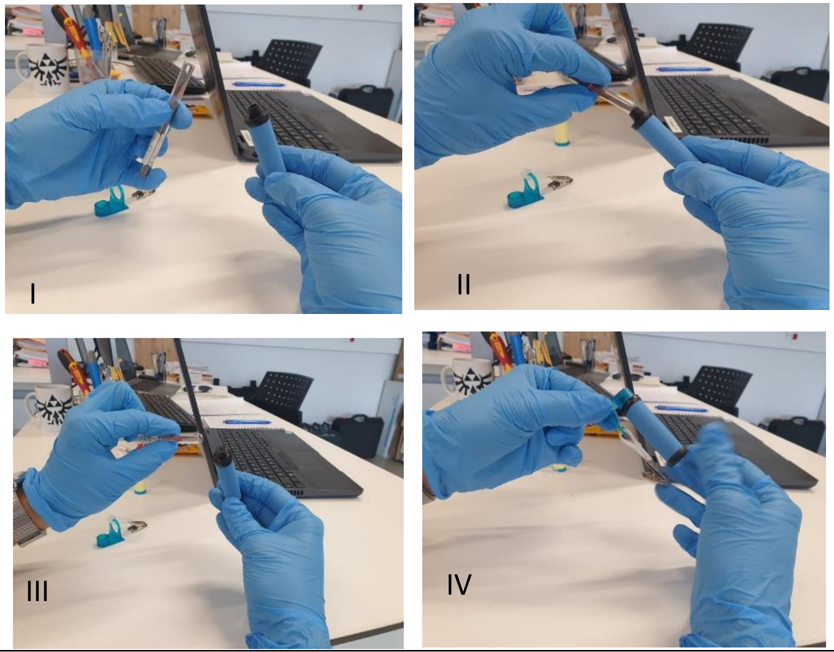
4.3.2. Particle Matters ($PM_{2.5}$)

Table 10 : $PM_{2.5}$ experimental set-up

$PM_{2.5}$ Parameter (CEN-EN 12341)	
Assessment method	**Experimental set-up**
- On-line measurements - Measurements period for seven consecutive days. - Data covering occupancy periods shall be used (between 19h and 7h in the weekdays, the whole day on weekends). - An additional measurement of outdoor $PM_{2.5}$ concentration is recommended; else, refer to ambient air quality monitoring station data. - It is recommended to perform measurements in the most two critical periods of the year with respect to the outdoors temperatures (in winter and summer) leading to a mean value used in order to establish the real category of $PM_{2.5}$ emissions.	Gravimetric method (weighing a Teflon filter) must be preferred but measurements using calibrated optical counters could be done. Same protocol could be applied on PM_{10}.    *Figure 5: Active methods used for $PM_{2.5}$ measurements*

4.3.3. Formaldehyde and benzene

Table 11 : Formaldehyde and benzene experimental set-up

Formaldehyde (ISO 16000) and benzene Parameters (ISO 16017)	
Assessment method	**Experimental set-up**
- The experimental set-up for formaldehyde and benzene are quite similar. - Passive measurements covering a period of seven consecutive days. - For benzene, an additional measurement of outdoor concentration is recommended; else, refer to ambient air quality monitoring station data. - It is recommended to perform measurements in the most two critical periods of the year with respect to the outdoors temperatures (in winter and summer) leading to a mean value used in order to establish the real category of formaldehyde and benzene emissions.	Measurements using passive samplers and permeation tubes with a different porosity for each type of formaldehyde (blue permeation tube) or benzene (yellow permeation tube) with Radiello® system for example (see pictures).   *Figure 6: Passive samplers and steps of the set-up*

4.3.4. Radon

Table 12: Radon experimental set-up

Radon Parameter (ISO 11665)	
Assessment method	**Experimental set-up**
- Passive measurements covering a period of two months and applied during winter only. - Relevant only for the radon-prone areas and construction areas with ground floor. - Two different locations, at the ground floor, will be instrumented with dosimeters, depending on the type of studied apartments (social housing) or just one inhabited room in an individual apartment.	Measurements using passive dosimeters.  *Figure 7: Example of a dosimeter used for radon measurements*

4.3.5. Ventilation rate (outdoor air supply)

Table 13: Ventilation rate measurements

Ventilation Parameter (EN 16798)	
Assessment method	**Experimental set-up**
- Measurements are to be applied in no naturally ventilated buildings. - Two measurements have to be done (one at the onset and the second at the end of the mechanical supply and exhaust). - Airflow rates of all the inlets and outlets of the studied room should be measured using calibrated flow hoods. - The number of persons and the surface of the room should be known - The mean value of airflow rate (of the inlet and outlet) should be calculated per person or per m^2 and then compared to the recommended range according to the type of use of the room	Measurements using a calibrated flow hood (for constant flowrate) or a micromanometer based on differential pressure (for variable flowrate).  I  II *Figure 8: Example of a calibrated flow hood (I) and a micromanometer (II)*

4.3.6. Indoor relative humidity

Table 14: Relative humidity measurements

Relative Humidity Parameter	
Assessment method	**Experimental set-up**
- In case the sensor used permits to monitor temperature simultaneously, measurements have to be applied for one month. Otherwise, data recording should be done during seven consecutive days at a time-interval ranging from 1 to 10 min. - Data corresponding to the occupancy hours is considered. - Hourly outdoor relative humidity is recommended to be known: it could be measured directly or taken from the nearest ambient measuring station. - A maximum deviation of 5 % with the normal range is accepted, or a 10 % deviation for a time period less than 1 % of the total occupancy periods.	Measurements using calibrated sensors with a maximum deviation of ± 5 %. It could measure at the same time the indoor temperature and CO_2 concentrations.  *Figure 9: Different types of calibrated sensors for relative humidity measurements*

4.3.7. Visible mould

Table 15: Mold inspection

Visible Mold Parameter	
Assessment method	**Experimental set-up**
Instrumented rooms should be inspected by a qualified expert or simulations should be done to determine potentiality of mould. - Critical locations enhancing mould growth should be identified based on the surface relative humidity values delivered by the simulations - The areas witnessing mould appearance should be measured in cm^2 in order to attribute the appropriate index category according to the boundaries defined.	On-site inspections only require a visual assessment by a qualified person.  *Figure 10: Example of mold growth on walls surface*

4.4. DATA ANALYSIS

The collected data via the previous measurements is gathered through an Excel sheet, so that for every studied criterion, a distribution from category I to category IV can be attributed (the categories boundaries are defined based on the components concentrations). Therefore, once every sub-index is defined, a global TAIL indicator can be deduced.

Table 16 and 17 summarize the different criteria used to categorize dwellings in thermal and IAQ environments.

Table 16: synthesis of the classification criteria for the thermal environment for TAIL index.

Parameter	Season	Mecanic conditioning				No mecanic conditioning			
		Cat I	**Cat II**	**Cat III**	**Cat IV**	**Cat I**	**Cat II**	**Cat III**	**Cat IV**
Air temperature (°C)	Heated	21-23	20-24	19-25	Other	21-23	20-24	19-25	Other
	Not heated	23,5-25,5	23-26	22-27	Other	<$0{,}33T_m+20{,}8$ >$0{,}33T_m+15{,}8$	<$0{,}33T_m+21{,}8$ >$0{,}33T_m+14{,}8$	<$0{,}33T_m+22{,}8$ >$0{,}33T_m+13{,}8$	Other

T_m : average outdoor slippery temperature.

Table 17: synthesis of the ranking criteria for the IAQ for TAIL index.

Parameters	Office			
	Cat I	**Cat II**	**Cat III**	**Cat IV**
CO_2 concentration (ppm)	<550	<880	<1350	Other
Minimum ventilation rate	10 $L.s^{-1}.p^{-1}$ or 2 $L.s^{-1}.m^{-2}$	7 $L.s^{-1}.p^{-1}$ or 1,4 $L.s^{-1}.m^{-2}$	4 $L.s^{-1}.p^{-1}$ or 0,8 $L.s^{-1}.m^{-2}$	2,5 $L.s^{-1}.p^{-1}$ or 0.6 $L.s^{-1}.m^{-2}$
Dampness (%)	>40%	30-40%	10-30%	<10%
Moisture (visual control)	Aucune	<400 cm^2	<2500 cm^2	>2500 cm^2
Benzene ($\mu g.m^{-3}$)	<2	2-5		>5
Formaldehyde ($\mu g.m^{-3}$)	<30	30-100		>100
Particles – $PM_{2.5}$ ($\mu g.m^{-3}$)	<10	10-25		>25
If possible : moving average 8h $PM_{2.5}$ ($\mu g.m^{-3}$)	Always <15 $\mu g.m^{-3}$	Exceed 15 $\mu g.m^{-3}$ once / week	Exceed 15 $\mu g.m^{-3}$ 2-3 times / week	Other
Radon ($Bq.m^{-3}$)	<100	100-300		>300

5. CONCLUSIONS

Energy poverty is increasingly recognized as a problem to be addressed in Europe. There is a need to identify the issue at different scales and investigate different levels of interventions.

This report builds on a previous identification and selection of energy poverty indicators to be tested and integrated into the methodology of the ARCAS project - the 10% indicator, the Low-Income High Costs indicator, the 2M indicator and the Index of

Vulnerable Homes. The report details the methods, tools and data sources that should be used to calculate the proposed indicators to provide a common, objective and simplified approach that can be used in the three countries participating in the ARCAS project – France, Portugal and Spain. Regarding the ARCAS project, it is foreseen to calculate the indicators of energy poverty using three different approaches:

1) Using direct measurements, energy bills consultation, calculations or data from the EPC for the households;

2) Using public data sources that reflect the national contexts;

3) Combining the two previous approaches, where some direct measurement and metrics are available while others have to be inferred from public databases.

The report also distinguishes the action areas the project will focus on for testing the methodology, namely regarding energy poverty alleviation.

Due to the importance of indoor air quality for sustainable renovation of multifamily buildings in social housing contexts, this report also presents the experimental setup to evaluate an indoor air quality sub-index - the TAIL indicator. This indicator is in accordance with the directives and protocol of the ALDREN project. Different types of emissions are selected and studied separately. Examples of several equipment used for the measurements of the emissions are proposed in each case. TAIL directives concerning the measurements procedures are detailed and adapted according to the occupancy scenarios of residential buildings.

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