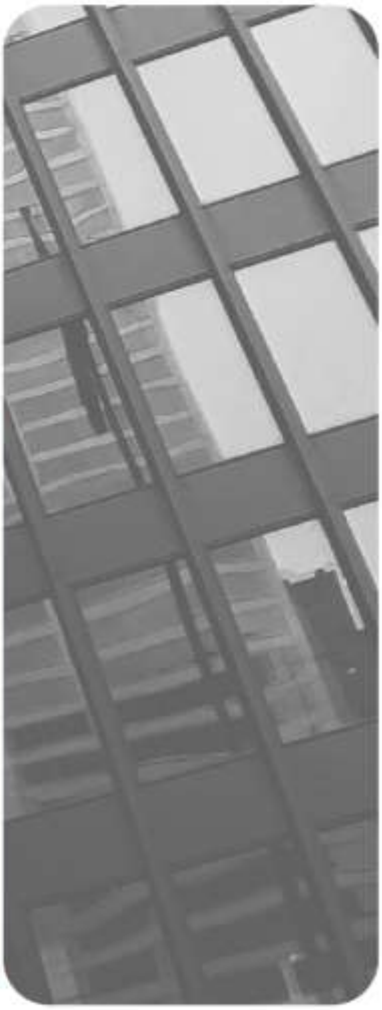

D3.2 Proposed set of user-centred and effective overall and partial indicators, including SRI

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Introduction to U-CERT

Under the Energy Performance of Buildings Directive (EPBD), all EU countries have established independent energy performance certification systems supported by independent mechanisms of control and verification. These Energy Performance Certification (EPC) schemes have stood in the past as one of the most important sources of knowledge on the energy performance (EP) of the European building stock. However, there are still several barriers to overcome towards a widely supported and successful implementation of the EPCs as effective tools to support the revised EPBD [1]. One of the main obstacles is users' understanding and acceptance of EPCs, nowadays held back by the lack of user-friendliness, reliability – and therefore lack of credibility – and cost effectiveness. Another barrier is that some implementations of the certification and assessment schemes seem to be not fully compliant with EU legislation, which is necessary to instil trust in the market and to incite investments and to support decision making, both on new energy efficient buildings as on deep renovation. Moreover, EPCs often fail in evaluating the impact of innovative technical solutions on buildings energy performances. Current calculation methods used in EPCs typically do not enable realistic prediction of performances of innovative technologies, so that building designers and EPCs assessors are led to miscalculate or even discard daring design options, thus hindering their market uptake.

Since 2017, there is a new opportunity as the EPCs can rely on the new set of EPB standards for their assessment methodology. These standards address the afore-mentioned challenges by proposing a holistic and modular approach. In principle, this modular approach can enable a step-by-step implementation, starting with the overarching EPB standard and other key modules. However, there is still a clear need for guidance and support with respect to the structure of the set of EPB standards and the application of individual standards or clusters of standards, both on a local and a national level. The standards and technical reports provide a lot of information, but based on the feedback received so far, it appears difficult to find or recognize the information that is searched for. Information must be made accessible and applicable for the Member States (MS) to support them in their investigation on how the EPB standards can be used.

Summarizing, current practices and tools of EPB Assessment and certification applied across Europe, clearly face several challenges. To meet them they should become more reliable, by being compliant with EU legislation and facilitating convergence of EPCs across EU. They also should become more user-friendly, by offering support in decision making; and more cost-effective, increasingly reflecting the smart dimension of buildings and ensuring a technology neutral approach.

In this context is where the U-CERT project is developed.

Executive Summary

The U-CERT project is focused on introducing a next generation of user-centred EPCs to value buildings in a holistic and cost-effective manner by means of five measurable objectives:

- Stimulating and enabling the co-creation and implementation of the new generation of EPC Schemes with a wide based support.
- Enhancing the new certification schemes to be more practical, reliable, understandable, and desirable by a holistic and user-centred approach.
- Making the new certification schemes easily accessible for a wide range of users and stakeholders by the services of the EPB Center.
- Providing evidence of applicability and usefulness developed schemes by testing the U-CERT approach in selected cases.
- To foster the EU-wide uptake by motivating and activating EU interest groups and national certifying and standardization bodies.

Stimulating and enabling the co-creation and implementation of the new generation of EPC Schemes with a wide based support; enhancing the new certification schemes to be more practical, reliable, understandable and desirable by a holistic and user-centred approach; and making the new certification schemes easily accessible for a wide range of users and stakeholders by the services of the EPB Center are Work Package (WP) 3's main contribution to U-CERT.

The general fitting of WP3 within the Work Packages of the U-CERT project is depicted in Figure 1.

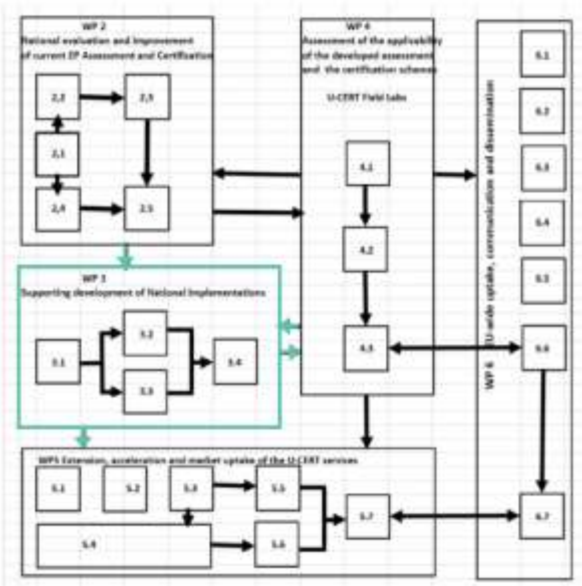

Figure 1. Synergies between Work Packages within U-CERT. Source: U-CERT's GA

As stated in U-CERT's Grant Agreement (GA), *"the objective of WP3 is that U-CERT will use and strengthen the services of the EPB Center to assist the eleven involved Member States in the process of drafting the national implementation of the Energy Performance Assessment and Certification, including application of the M/480 results and the integration of the Smart Readiness Indicator with a holistic end user centric approach".*

Thus, WP3 tasks are strongly intertwined with the tasks from other WPs. Task 2.3 provides valuable findings in relation to the quality of user experience regarding EPCs. The review and analysis of holistic indicators for measured data and quantification of effects of EPCs developed in Task 2.4 yields relevant inputs for the design of next generation EPC indicators. All of it considering Task 3.1's design of the choices to be made in the selection of EPB Standards towards the U-CERT EPB Assessment and Certification Scheme. It is within this context that this deliverable about **Task 3.2: Development of a set of user-centred and effective overall and partial indicators, including SRI** is completed. As exposed in Task 4.1, some of the indicators included in this value proposition will be tested on U-CERT case studies, others are only listed since they require further tool development.

Definitions

The underlying document uses certain concepts which may be unfamiliar to the public and for EPB assessors without deep knowledge of the EPB standards.

For deeper knowledge of the terms and definitions used in the scope of energy performance calculations, refer to EN ISO 52000-1 section 3 [2], EN ISO 52016-1 section 3 [3], and EN ISO 52018-1 section 3 [4].

Also, refer to [5] for the latest definitions on energy performance of buildings.

Introduction

Next generation energy performance (EP) assessment and certification schemes should value buildings in a holistic and cost-effective manner across several complimentary dimensions. Thus, U-CERT is focused on including added value indicators and criteria based on a holistic user-centred perspective. In particular **indicators to support decision making by end-users on deep renovation**. Similar efforts are also undertaken by U-CERT's sister projects[1].

Previous endeavours within U-CERT, mainly Task 2.3 [6] and Task 2.4 [7], provided relevant findings regarding future energy performance assessments and certification schemes.

In addition, the experts of U-CERT's partner, EPB Center [8][9][10], have led the development of key EPB standards in the field of **EPB indicators**:

- EN ISO 52003-1. Energy performance of buildings - Indicators, requirements, ratings and certificates - Part 1: General aspects and application to the overall energy performance [11].
- EN ISO 52018-1. Energy performance of buildings - Indicators for partial EPB requirements related to thermal energy balance and fabric features - Part 1: Overview of options [4].

And the accompanying two technical reports containing a justification and explanation, [12] and [13] respectively.

Lastly, U-CERT's consortium is aware of the key findings made by the most relevant and recent H2020 initiatives; namely, ALDREN[2], CEN-CE[3], Triple A-reno[4], among others. Thus, U-CERT, being a Coordination and Support Action (CSA), will learn from such outcomes and will build upon them when possible.

All these sources of information will be leveraged towards the **proposal of a set of user centred and effective overall and partial indicators**. These indicators will serve to check compliance with normative EP requirements, given that the current main goal of Energy Performance Certificates (EPCs).is to provide an EP value for a building under standard conditions and use. Furthermore, additional informative indicators will be included in the EPC with a view of increasing their holisticness and user-friendliness, also with a view of allowing to leverage measured data.

This deliverable is only focused in selecting relevant indicators for next-generation EP Assessment and Certification schemes. The specifics concerning the calculation and assessment methodology are out of the scope of this document. Refer to Deliverable 3.1 [14] for further details.

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[1] See more on U-CERT sister projects at https://u-certproject.eu/epc-sister-projects/.

[2] More information at: https://aldren.eu/

[3] More information at: https://www.cen-ce.eu/

[4] More information at: https://triplea-reno.eu/

Indicators

The indicators proposed by U-CERT cover many dimensions (i.e., energy performance, smart readiness; Indoor Environmental Quality and cost). A core idea behind U-CERT is that the information contained in EPB Assessments and, specially for the application of EPCs, should be leveraged to the highest extent as possible. Thus, rather than overload EPB Assessments with additional analysis, the philosophy is to define EPB elements and indicators in a way that can be further exploited by complementary assessments and supporting tools. This is very much in line with the connection with digital building logbooks.

On the one hand, U-CERT aims to avoid exaggerating the number of indicators related to requirements with a view to nor overburdening EPB assessors and final users. On the other hand, U-CERT shall not limit the useful information offered simply for the sake of having more compact outputs. Thus, the project proposal is to make an explicit difference between indicators related to **requirements**, others of **informative** nature, which can be part of U-CERT value proposition or rather represent a connection with additional voluntary assessments. The indicators can also be referred to the whole building (i.e., **overall indicators**), to a part of the building (i.e., **partial indicators**), which, in turn, can be referred to a single element, or to a combination of elements. Moreover, the indicators and their visual representation in the EPC should be designed to achieve the objectives pursued for buildings in general (e.g., energy efficiency, indoor environmental quality, digitalisation, and connectivity), and, specifically, for existing buildings (i.e., deep renovations).

The **overall indicators** represent a comprehensive view of the building. They allow for design freedom, provided certain limitations are fulfilled. They could be regarded as an "outer" limitation, a maximum that should not be exceeded. The **partial indicators** at **elemental** level constitute the most specific assessment and focus on a single item. They are the basis from which the design is built. They could be regarded as an "inner" limitation, a minimum that should always be fulfilled. When a **combined** partial indicator is defined, a certain design freedom is created in the region between the elemental and the combined indicator. These concepts are illustrated in Figure 2. The "design freedom" is represented by the diagonal line pattern.

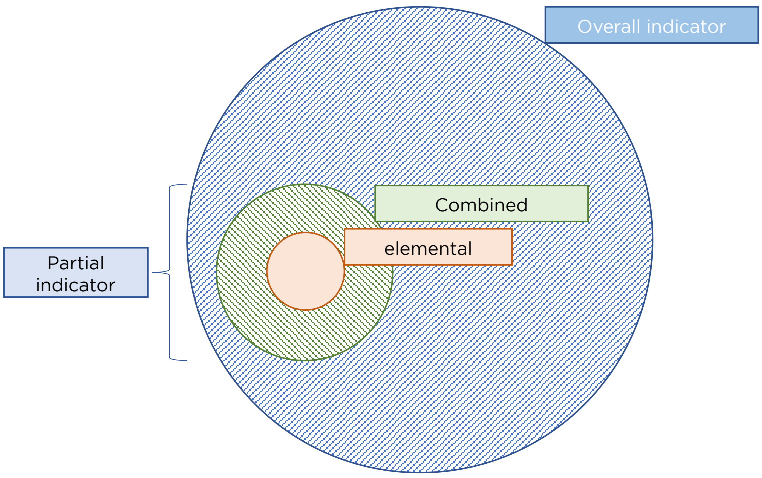

Figure 2. Graphical representation of overall and partial indicators

For example, in a new building, the features of a window may need to meet certain elemental requirements (i.e., glazing thermal transmittance), while also, as part of the envelope, may be required to contribute to meeting certain combined requirements (i.e., overall envelope thermal transmittance). Furthermore, as building element it should also play its part in reaching a given overall requirement (i.e., overall non-renewable primary energy). Thus, all three conditions should be fulfilled, meaning that meeting the elemental requirements is not a guarantee of meeting the combined nor the overall requirements.

Depending on the **application** (e.g., energy performance certificate, building permit, permit to use, etc.) of EPB assessment, some indicators may be applicable or not. Moreover, they may rely on calculations or measurements.

This document constitutes a proposal, which could serve as the **basis for an EU-harmonized set of EPB indicators and Energy Performance Certificate design.** It should serve as guidelines for Member States towards defining more user centred and effective EPB Assessments and Certification Schemes. The provisions from the proposal of EPBD recast [5] have been considered.

Applicability to building situation

Although the indicators proposed may be the same regardless the building situation (e.g., new building, buildings that have undergone major renovations, existing building, etc.), the numerical benchmark should adapt accordingly, and considerations of Clause 9 in EN ISO 52003-1 should be considered when deciding the benchmarks, and its strictness. The definition of each indicator's benchmark is out of the scope of the document, in Deliverable 4.3 [15] additional information about the differences between each U-CERT partner country can be found.

Three main differences regarding the building situation can be defined: namely, shallow-medium renovations in existing buildings, deep renovations in existing buildings, and newly constructed buildings. The requirements they should meet can be defined in an incremental manner:

- **Shallow-medium renovations**. The elements renovated should abide by the applicable elemental partial indicators. So, items that are completely fully replaced by new components or products must have great energetic quality.
- **Majorly renovated buildings**. If building components are modified to a certain degree, apart from the elemental partial indicators certain combined partial indicators may also apply. Moreover, with a view to giving flexibility and design freedom to deep renovations, the possibility of abiding by the combined partial indicators while not meeting certain elemental indicators could be considered.

  What should always be considered is that partial interventions in existing buildings should not block or lock-in future interventions towards reaching the deep renovation potential. The requirements in terms of indicators should be designed with that in mind.
- **New buildings**. It is the greatest opportunity to reach cost-effective high energy efficiency. Thus, the requirements should be most ambitious, not just covering overall energy performance indicators, but also meeting the minimum partial indicators at elemental and combined level.

In light of the foreseen recast of the EPBD [16] with regards to minimum energy performance requirements for existing buildings, this could be included as a fourth item. For instance, the latest EPBD recast proposal [5] mandates worst performing public buildings (G-rated) to reach, at least, class F by 2027, and class E by 2030 at the latest. Residential buildings are to reach a minimum class F by 2030, and E by 2033 at the latest.

Area for the specific indicators

For all the indicators expressed per m², the surface considered should be the *reference floor area* as defined in Deliverable 3.1.

Assessment type dependency

According to Table UU.8 and UU.9 under EN ISO 52000-1 in Deliverable 3.1, a basic distinction can be made when dealing with EPB Assessments depending on whether they are **calculated** or **measured**. A more detailed definition can be seen in Table 1.

Table 1. EPB Assessment types. Adapted from [2].

Type	Building situation	Use	Climate	Example of application
Calculated	Design for new construction	Standard	Standard	Energy Performance Certificate; check compliance with EPB requirements; obtain a building permit
		Project	Project	Tailored assessment
	As built existing building	Standard	Standard	Energy Performance Certificate; check compliance with EPB requirements; obtain a permit to use
		Actual	Actual	Tailored assessment (e.g., energy audit)
	Design for renovation	Standard	Standard	Energy Performance Certificate; check compliance with EPB requirements;
		Project	Project	Tailored assessment
		Actual	Actual	Tailored assessment
Measured	As built existing building	Actual	Actual	Tailored assessment
		Standard	Standard	Energy Performance Certificate; check compliance with EPB requirements; obtain a permit to use

The calculated assessment can be applicable to all building situations. In the **design for a new construction**, the calculations can be arranged to represent standard use and climate, or other project conditions. The first option is usually preferred when dealing with official EPB assessments, whereas the second option is always available for any other tailored analysis. Similarly, when having an existing building, standard or actual conditions can be applied to calculations representing the **as built** status. In the case of **design for renovation**, the calculated EPB assessments can reflect standard conditions, usually applicable for checking requirements or fulfilling regulatory obligations; or project conditions, which can be related to actual building use. The latter of special relevance when envisioning tailored-to-actual use renovation roadmaps. In contrast, the measured assessment is only applicable to **as built existing buildings** since they require having access to metered data. However, such measurements can be normalised to reflect standard conditions or left as measured to represent actual building use and climate influence and as such to be compared with a tailored calculation.

In the following sections, the difference between Calculated EPB Assessment and These indicators could be arranged in some sort of factsheets to be easily compared and/or merged with information coming from other repositories (e.g., databases, Eurostat, etc.) or sources (e.g., building and systems inspections, etc.).

Renovation potential

With a view to nudging renovation actions, EPB Assessments of existing buildings ought to reflect the potential change in indicators should the building or its technical systems be improved. Thus, the indicators exposed in section Calculated EPB Assessment should be recalculated representing the foreseen status of the building after each proposed renovation scenario. The potential should be calculated aiming for deep renovation, while considering the option of staged deep renovation The change in the partial indicators could be made explicit, along with a detailed estimation of the cost of each renovation action, and the complete renovation scenario.

Measured EPB Assessment is going to be maintained, explicitly stating the applicability of the proposed indicators in each case.

Calculated EPB Assessment

The calculated EPB Assessment under standard conditions and standard weather data is often referred to as asset performance, and it is the most widely used for regulatory applications. This is the focus of this section, given the main application is the generation of U-CERT EPC. However, the indicators proposed could also be of relevance when dealing with tailored EPB Assessments.

Calculated EPB Assessments can be referred to the building as a whole and on specific parts. The indicators should be the result of performing building EP assessments following U-CERT guidelines recommendations. Refer to Deliverable 3.1 for details on the calculation methodology. Note that it is possible to calculate EPB assessments not intending to represent an asset performance. In that case there are certain choices made in Deliverable 3.1 that ought to be changed (e.g., use conditions, weather data, etc.) with a view of representing a tailored assessment rather than a standardized or asset assessment.

For the selection of energy performance indicators, the guidelines established in [17] and Annex H of ISO 52000-1 [2] regarding *nearly zero energy buildings* are considered. Also Deliverable 2.2 from the ALDREN project [18].

The following items should be covered:

- Energy needs.
- Technical Building Systems efficiency.
- Renewable energy contribution.

Although the previous items are all part of the overall building energy performance, U-CERT's indicators proposal should enable individual assessment of each of them separately. It would go against the *"energy efficiency first principle"*[5] to allow for compensation between a very poor building envelope with highly efficient technical building systems, or great renewable energy production on site. Despite the previous elements being covered and fulfilled separately, there is also the need of defining main indicator(s) assessing the overall energy performance.

Principle assumed presence of systems

According to Deliverable 3.1, the choice for U-CERT in EN ISO 52000-1 Table UU.19 is *presence of system*. This decision falls in line with the objective of representing in the EPB Assessment the actual equipment present in the building and enables to couple thermal discomfort to the energy performance calculation. Thus, when the present system cannot meet the required thermal load, some degree of discomfort is generated as expressed in Figure 3.

[5] More at: https://ec.europa.eu/energy/topics/energy-efficiency/targets-directive-and-rules/energy-efficiency-first_en

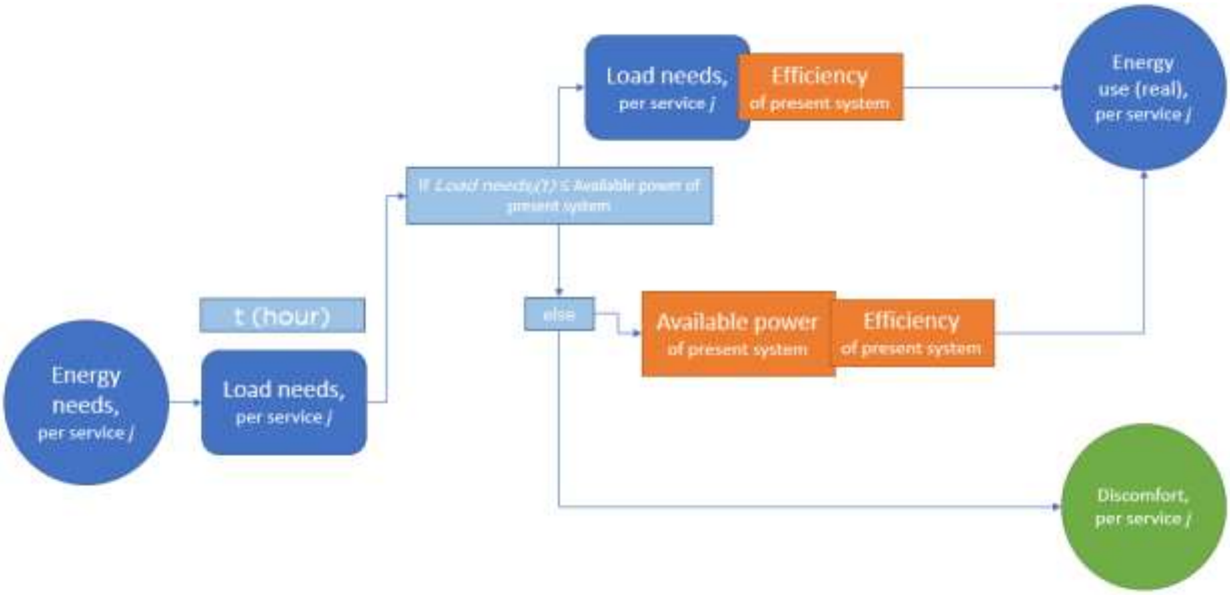

Figure 3. Energy performance assessment with presence of system principle.

However, U-CERT aims at producing an asset assessment with a main EP indicator, which shall be comparable between buildings and ought to have a rating according to a certain EP scale. For several buildings to be compared, there is a need to establish a comparable rating under the premise that comfort conditions are maintained. Thus, exclusively for the EP rating, the main EP indicator should be calculated with the *assumed system* principle following the scheme illustrated in Figure 4.

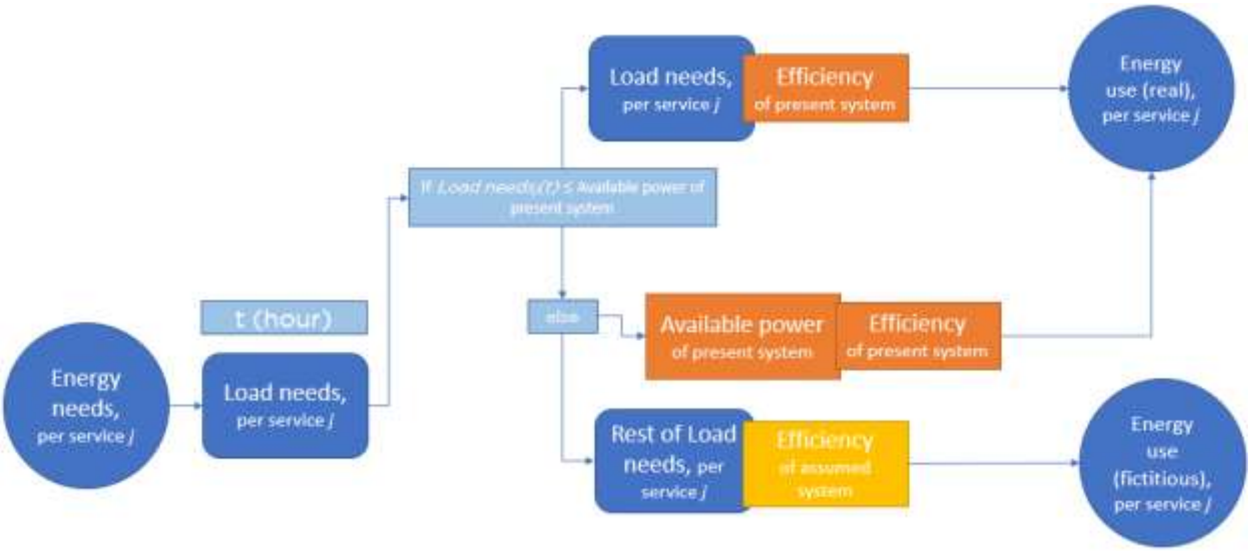

Figure 4. Energy performance assessment with assumed system principle.

The *assumed system* principle would only be used with a view of placing a given building in the EP scale, after generating the EP rating linked to the EPC. Thus, restricted to the energy performance certificate application in Table UU.2 of EN ISO 52000-1.

The definition of the *assumed system* is out of the scope of this document.

Overall EP indicators

The **overall energy performance indicators** selected to be included in U-CERT are:

- Basis for EP requirements:
  An effort has been made to define a proper set of overall energy performance indicators as basis for EP requirements, aiming to obtain the pursued objectives without overburdening designers. The following are U-CERT's proposal, although Member States could decide otherwise.
  - **Overall non-renewable primary energy use [kWh/m^2] [kWh].** Calculated according to H5 in Annex H in ISO 52000-1 [2]; thus, considering compensation between different energy carriers and the effect of exported energy.
    This indicator assesses the final global impact the energy performance of the building has. An excess consumption during certain moments during the year may be balanced by surplus of energy in others. **It constitutes the main EP indicator**. This is in line with ALDREN project [18].
  - **Overall total primary energy use [kWh/m^2] [kWh]**. Calculated according to H4 in Annex H in ISO 52000-1 [2]; thus, not considering compensation between different energy carriers nor the effect of exported energy.
    This indicator assesses the total primary energy the building requires to operate according to the energy needs, technical building system efficiency and renewable contribution to the onsite energy use. It seeks to prevent buildings to balance a poor envelope and inefficient systems with oversized renewable generation.
  - **Summer thermal comfort [K·h].**
    This indicator serves to account for overheating during the cooling period. It refers to the amount of (weighted) occupation hours the temperature is above a certain reference temperature. The source for the definition of the reference temperature can be found in Deliverable 3.1.
  - **Winter thermal comfort. [K·h].**
    This indicator serves to account for underheating during the heating period. It refers to the amount of (weighted) occupation hours the temperature is below a certain reference temperature. The source for the definition of the reference temperature can be found in Deliverable 3.1.
  - **Domestic Hot Water thermal comfort [K·h].**
    This indicator serves to check that sanitary hot water is provided, when there is demand, at a certain minimum reference temperature.
- Informative:
  - **Overall non-renewable primary energy use [kWh/m^2] [kWh].** Calculated according to H4 in Annex H in ISO 52000-1 [2]; thus, not considering compensation between different energy carriers nor the effect of exported energy. This indicator is also compliant with Level(s).
  - **Overall renewable primary energy production [kWh/m^2] [kWh].** Considering the whole onsite renewable primary energy production, regardless of whether consumed onsite or exported to the grid.
  - **Overall renewable primary energy use [kWh/m^2] [kWh].** The portion of the previous indicator compensating the energy demanded by the uses considered in the assessment.
  - **Overall equivalent CO_2 emissions [kg/m^2].** Calculated following H5 in Annex H in ISO 52000-1 [2]; thus, considering compensation between different energy carriers and the effect of exported energy.
  - **Renewable electricity generation by onsite PV [kWh/m^2] [kWh].**

- Renewable electricity generation by onsite wind turbines [kWh/m²] [kWh].
- Renewable electricity generation by onsite CHP [kWh/m²] [kWh].
- Renewable electricity from onsite PV self-used [kWh/m²] [kWh].
- Renewable electricity from onsite wind turbines self-used [kWh/m²] [kWh].
- Renewable electricity from onsite CHP self-used [kWh/m²] [kWh].
- Renewable electricity exported to non-EPB uses by onsite PV [kWh/m²] [kWh].
- Renewable electricity exported to non-EPB uses by onsite wind turbines [kWh/m²] [kWh].
- Renewable electricity exported to non-EPB uses by onsite CHP [kWh/m²] [kWh].
- Renewable electricity exported to the grid by onsite PV [kWh/m²] [kWh].
- Renewable electricity exported to the grid by onsite wind turbines [kWh/m²] [kWh].
- Renewable electricity exported to the grid by onsite CHP [kWh/m²] [kWh].
- Energy needs per service [kWh/m²].
    - Heating.
    - Cooling.
    - Domestic Hot Water (DHW).
    - Humidification and Dehumidification.
    - Mechanical Ventilation.
    - Lighting.
      For the case of the lighting, the metric proposed would be the Daylight Autonomy (DA). Thus, the indicator of the lighting energy needs would be the percentage of the occupied hours of the year when artificial lighting is needed, because daylight alone can't meet the minimum illuminance threshold [19].
- Energy use per system service and energy vector [kWh/m²] [kWh].
    - Heating.
    - Cooling.
    - DHW.
    - Humidification and Dehumidification.
    - Mechanical Ventilation.
    - Lighting.

The way the indicators are defined allows for the generation of additional ones as a combination of these elemental.

Partial EP indicators

For the partial indicators, no distinction is made from U-CERT on whether to consider them as **basis for EP requirements** or as **informative**. These indicators cover **physical and technological** elements, which could have strong connection with building and system inspections.

A note stating the connection with elements addressed by the Smart Readiness Indicator[6] (SRI) can be found as well in the following subsections. This is in line with the philosophy stated in section Indicators of designing EPB Assessments and

[6] More information on the Smart Readiness Indicator at: https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/smart-readiness-indicator/sri-explained_cs

Certification Schemes in a way that their individual elements can be further leveraged for additional complementary assessments.

Envelope performance indicators

The **envelope performance indicators** selected to be included in U-CERT are the following:

- Per opaque envelope construction.
  - Thermal transmittance [W/(m²·K)];
  - Colour outside layer;

  Additionally, a description of the layered materials should be included. It should cover (from outer to inner element), at least:
  - Name of the material;
  - Thickness of the material;
  - Conductivity of the material.

  Other features, such as density or specific heat may also be included.
- Per window/skylight:
  - Thermal transmittance (U-value) [W/(m²·K)][7];
  - Opening control (e.g., manual or fixed windows, open/closed detection to act on HVAC, based on sensor data, etc.)
    Link with DE-2 code in SRI calculation (version 3).
  - Solar shading of glazings:
    - Presence;
    - Technology (e.g., awning, blinds, shutters, etc.);
    - Control (e.g., manual, motorized, automation based on sensor data, combined control with HVAC, predictive control, etc.)
      Link with DE-1 and DE-4 codes in SRI calculation (version 3).
  - Solar shading potential [%], according to ISO 18292 [20];
  - Glass thermal transmittance [W/(m²·K)];
  - Glass solar factor [-];
  - Frame thermal transmittance [W/(m²·K)];
  - Frame colour or absorptance.
  - Air permeability class, according to EN 12207.

  Additionally, a description of each representative window/skylight should be included.
- Thermal bridges, per type of junction (e.g., corner, slab-façade, pillar, etc.):
  - Linear thermal transmittance Ψ [W/K].
  - Length [m].
- Air leakage:
  - Air change rate at 50Pa [1/h].

  This indicator should be measured by means of a Blower Door test according to EN 13829 [21] whenever possible, and its value should be included in the calculations.

Technical Building Systems performance indicators

Continuing with the infrastructure present in the building, the **technical building systems** per service also provide valuable information about the energy performance of the building, as a whole.

- Technical Building Systems per service or combination of services:

[7] For a protruded product like a skylight: based on the daylight opening.

Additionally, to the categories presented below, a general description of the installation should be included.

- Service or services linked to the system.
- Rated general installation efficiency [%].
- Generation:
    - Technology (e.g., conventional boiler, condensing boiler, air-to-air heat pump, electric heater, etc.);
    - Energy carrier;
    - Rated power input [kW];
    - Effective rated output [kW];
    - Rated efficiency [%];
    - Renewable contribution (if applicable);
    - Metering type;
    - Control type (e.g., on-off control; control according to fixed priority list; control according to dynamic priority list; control according to dynamic priority list and predicted information; control according to dynamic priority list, predicted information and external signals).
      Link with Heating-1c, Heating-2a, Heating -2b, Heating-2d, Heating-4, DHW-2b, Cooling-1c, Cooling-1f, Cooling-2b, Ventilation-2c, Ventilation-2d, Ventilation-3 codes in SRI calculation (version 3).
- Storage:
    - Capacity [m^3].
    - Control (e.g., continuous storage operation, scheduled storage operation, load prediction-based storage operation, flexible control according to external signals, etc.).
      Link with Heating -1f, DHW-1a, DHW-1b, DHW-1d, Cooling-1g codes in SRI calculation (version 3).
- Distribution:
    - Typology of circuit (e.g., two-pipe, four-pipe, recirculation, etc.);
    - Insulation of pipes;
      Further detail may be included.
    - Circulation device (e.g., pumps, fans, etc.).
      Further detail may be included.
    - Control (e.g., on-off control, multi-stage control, variable speed circulation device control based on internal signals or on external signals).
      Link with Heating -1d, Cooling-1d, Ventilation-1c codes in SRI calculation (version 3).
- Emission:
    - Technology (e.g., radiators, heated floor, fancoils, etc.);
    - Control (e.g., central automatic control, individual room control, individual room control with communication between controllers and to BACS, individual room control with communication and occupancy detection).
      Link with Heating -1a, Heating-1b, Cooling-1a, Cooling-1b, Ventilation-1a codes in SRI calculation (version 3).
- Reporting of performance (e.g., central reporting of KPIs, historical data, forecasting and/or benchmarking, predictive management, and fault detection, etc.).

Link with Heating -3, DHW-3, Cooling-3, Ventilation-6 codes in SRI calculation (version 3).

The aim is to characterize the main elements of the Heating, Cooling, DHW, Humidification & Dehumidification, and Mechanical Ventilation technical systems.

With respect to Lighting, the following may apply:

- Technology (e.g., LED, dichroic, fluorescent, etc.).
- Overall rated power [W];
- Control (e.g., manual, sweeping extinction signal, automatic detection, etc.).

Link with Lighting-1a, Lighting-2 codes in SRI calculation (version 3).

If there is a certain service which lacks technical building system, it should be explicitly mentioned.

Renewable electricity production performance indicators

U-CERT proposes including the following indicators about **renewable electricity production**.

- Photovoltaics:
  - Technology (e.g., monocrystalline, etc.).
  - Installed peak power [kWp].
  - Rated efficiency [%].
  - Orientation [°].
  - Inclination [°].
  - Possibility to export electricity to the grid.
  - Inverter type (e.g., central inverter, power optimizer + inverter, or microinverters).
  - Reporting of performance (e.g., current generation data, actual values and historical data, performance evaluation including forecast and/or benchmarking, predictive management, and fault detection, etc.).

    Link with Electricity-2 codes in SRI calculation (version 3).
- Wind turbine:
  - Technology.
  - Installed peak power [kWp].
  - Rated efficiency [%].
  - Possibility to export electricity to the grid.
  - Reporting of performance (e.g., current generation data, actual values and historical data, performance evaluation including forecast and/or benchmarking, predictive management, and fault detection, etc.).

    Link with Electricity-2 codes in SRI calculation (version 3).
- CHP:
  - Technology.
  - Installed peak power [kWp].
  - Nominal efficiency for thermal and power generation.

    Link with Electricity-2 codes in SRI calculation (version 3).
- Storage:
  - Technology (e.g., dedicated battery storage, dedicated thermal energy storage, etc.).
  - Installed peak capacity [kWh].

- Control (e.g., direct storage of on-site production, controlled based on grid signals, optimising the use of locally generated electricity, possibility to feed back into the grid, etc.).
  Link with Electricity-3 codes in SRI calculation (version 3).
- Reporting of performance (e.g., current state of charge, actual values and historical data, performance evaluation including forecast and/or benchmarking, predictive management, and fault detection, etc.).
  Link with Electricity-11 and Electricity-12 codes in SRI calculation (version 3).

In the case the building or building unit is connected to an energy community or district heating/cooling network it should also be made explicit.

Smart Readiness

The Smart Readiness refers to the capability of buildings or building units to adapt their operation to the needs of the occupant, also optimizing energy efficiency and overall performance, and to adapt their operation in reaction to signals from the grid.

However, the SRI assessment may cover a wider scope than EPB Assessments. For instance, the SRI has certain domains that transcend the services generally considered in EPB Assessments; for instance, electric vehicles. Furthermore, there are certain impact categories that may exceed the purpose of Asset EPB Assessments; such as, convenience or information to occupants. With a view of showcasing the number of additional indicators that the complete SRI Assessment would represent, the results the SRI are presented next:

- Overall score.
- Impact scores:
  - Energy savings on site;
  - Flexibility for the grid and storage;
  - Comfort;
  - Convenience;
  - Wellbeing and health;
  - Maintenance and fault prediction;
  - Information to occupants;
  - Total.
- Domain scores:
  - Heating;
  - DHW;
  - Cooling;
  - Controlled ventilation;
  - Lighting;
  - Dynamic envelope;
  - Renewable generation & Storage;
  - EV charging;
  - Monitoring & control;
  - Total.

Such indicators are, in turn, obtained after assessing certain elemental characteristics of each domain.

The fully-fledged SRI assessment could be regarded as a parallel analysis to be included as an annex in EPB Assessments and Certification schemes. ALDREN's European Voluntary Certificate (EVC) goes in this direction [18]. U-CERT is aware that the complete inclusion of SRI as independent from EPB Assessments could represent too much extra work for EPB assessors further hindering the uptake of next generation EPCs. However, if smoothly integrated in the EPB Assessment process, added value could be given to EPCs, while not overburdening assessors. U-CERT's identification of the overlapping elements between SRI and EPB Assessment can be found in Table 2.

Table 2. Synergies between SRI and U-CERT EPB Assessment

SRI Assessment – Method B (Version 3)			Referenced by U-CERT Partial indicators
Domain	Code	Service group	
Heating	Heating-1a	Heat control - demand side	X
Heating	Heating-1b	Heat control - demand side	X
Heating	Heating-1c	Heat control - demand side	X
Heating	Heating-1d	Heat control - demand side	X
Heating	Heating-1f	Heat control - demand side	X
Heating	Heating-2a	Control heat production facilities	X
Heating	Heating-2b	Control heat production facilities	X
Heating	Heating-2d	Control heat production facilities	X
Heating	Heating-3	Information to occupants and facility managers	X
Heating	Heating-4	Flexibility and grid interaction	X
Domestic hot water	DHW-1a	Control DHW production facilities	X
Domestic hot water	DHW-1b	Control DHW production facilities	X
Domestic hot water	DHW-1d	Control DHW production facilities	X
Domestic hot water	DHW-2b	Control DHW production facilities	X
Domestic hot water	DHW-3	Information to occupants and facility managers	X
Cooling	Cooling-1a	Cooling control - demand side	X
Cooling	Cooling-1b	Cooling control - demand side	X
Cooling	Cooling-1c	Cooling control - demand side	X
Cooling	Cooling-1d	Cooling control - demand side	X
Cooling	Cooling-1f	Cooling control - demand side	X
Cooling	Cooling-1g	Cooling control - demand side	X
Cooling	Cooling-2a	Control cooling production facilities	X
Cooling	Cooling-2b	Control cooling production facilities	X
Cooling	Cooling-3	Information to occupants and facility managers	X
Cooling	Cooling-4	Flexibility and grid interaction	X
Controlled ventilation	Ventilation-1a	Air flow control	X
Controlled ventilation	Ventilation-1c	Air flow control	X
Controlled ventilation	Ventilation-2c	Air temperature control	X
Controlled ventilation	Ventilation-2d	Air temperature control	X
Controlled ventilation	Ventilation-3	Free cooling	X
Controlled ventilation	Ventilation-6	Feedback - Reporting information	X
Lighting	Lighting-1a	Artificial lighting control	X

Lighting	Lighting-2	Control artificial lighting power based on daylight levels	X
Dynamic building envelope	DE-1	Window control	X
Dynamic building envelope	DE-2	Window control	X
Dynamic building envelope	DE-4	Feedback - Reporting information	X
Electricity	electricity-2	Feedback - Reporting information	X
Electricity	electricity-3	DER - Storage	X
Electricity	electricity-4	DER- Optimization	-
Electricity	electricity-5	DER - Generation Control	-
Electricity	electricity-8	DSM- Storage	-
Electricity	electricity-11	Feedback - Reporting information	X
Electricity	Electricity-12	Feedback - Reporting information	X
Electric vehicle charging	EV-15	EV Charging	-
Electric vehicle charging	EV-16	EV Charging - Grid	-
Electric vehicle charging	EV-17	EV Charging - connectivity	-
Monitoring and control	MC-3	HVAC interaction control	-
Monitoring and control	MC-4	Fault detection	-
Monitoring and control	MC-9	TBS interaction control	-
Monitoring and control	MC-13	Feedback - Reporting information	-
Monitoring and control	MC-25	Smart Grid Integration	-
Monitoring and control	MC-28	Feedback - Reporting information	-
Monitoring and control	MC-29	Override control	-
Monitoring and control	MC-30	Single platform that allows automated control & coordination between TBS + optimization of energy flow based on occupancy, weather, and grid signals	-

Thus, when performing the U-CERT EPB Assessment, certain SRI elements could be automatically defined, leaving the remaining categories to be addressed in a dedicated manner.

U-CERT has selected the items from the SRI with direct link with the proposed EPB Assessment and Certification Scheme. They have been referenced in each individual element in section Partial EP indicators. Thus, enabling that a partial automatic definition of the SRI can be done while performing the EPB Assessment. U-CERT envisions the inclusion of the fully-fledged SRI assessment in the form of a dedicated annex in U-CERT EPCs.

Future developments may work on the integration of the information required for the complete SRI assessment as features of building components and systems present in digital building logbooks or digital twins, hence easing the EPB Assessment process.

The relevance of the SRI is that it relies on a qualitative assessment, which provides indications on the existing infrastructure in the building enabling digitalization and control. Thus, appealing to specific elements in the building, most of which the user can self-assess regardless of whether the building is existing, majorly renovated or newly constructed. At the current state of development, there is a Method A and a Method-B, which intend to be addressed for final users and EPB experts, respectively. Thus, the philosophy of the SRI seems to fall in line with U-CERT user-centric considerations.

Indoor Environmental Quality

Enhanced comfort and indoor environmental quality (IEQ) have proven to be relevant trigger points towards building renovation [22]. People may be prone to intervene in the building under the premise that the IEQ is improved. The recent COVID-19 pandemic has only confirmed that.

In the scope of U-CERT, several methodologies for the inclusion of IEQ in EPB Assessments and Certification Schemes have been studied. The Triple-A reno Combined Label methodology includes interesting elements, however the supporting digital tool created[8] is intended to be a support to EPB Assessments, rather than a fine proposition for the inclusion of IEQ indicators in EPB calculations. The ALDREN TAIL Index is a modular approach to integrate health and well-being into an EVC for hotels and offices. The methodology is detailed in the project's Deliverable 4.2 [23], allows to rely on calculations or measurements, and it covers the items listed in Table 3.

Table 3. ALDREN TAIL Comfort and IEQ indicators [20]

Category	Indicator
Thermal	Dry-bulb temperature TAIL Index
Acoustics	Noise level TAIL Index
IEQ	CO_2 level TAIL Index
	Ventilation TAIL Index
	Relative Humidity TAIL Index
	Mold TAIL Index
	Benzene TAIL Index
	Formaldehyde TAIL Index
	Radon TAIL Index
	PM 2.5 TAIL Index
Visual	Illuminance TAIL Index

There are indicators that are related to others listed as relevant for U-CERT; namely, under the thermal category (see section Overall EP indicators). However, including the complete ALDREN TAIL may be excessive for EPB Assessments and Certification Schemes, given that performing the calculations under certain guaranties would represent an extra work for EPB Assessors. Thus, U-CERT's point

[8] For access to Triple-A reno Combined Performance Label digital tool, refer to: https://engine.triplea-reno.eu/label

of view with regards to ALDREN TAIL is that although it is very valuable information, it should be left to be voluntary, like for the complete SRI. In the scope of U-CERT, the IEQ Compass [24] has also been studied reaching similar considerations.

ALDREN recently published a proposal for thermal score, which was included in ALDREN's EVC. All the details can be found in ALDREN's Deliverable 2.2 [18]. This integration of IEQ indicators in EPB Assessments and Certification Schemes is aligned with U-CERT.

U-CERT decision with respect to including IEQ indicators in EPB Assessments and Certification Schemes is to use the discomfort indicators listed in section Overall EP indicators, along with the thermal score defined by ALDREN's Deliverable 2.2 [18].

Cost

In EN ISO 52000-1's Annex B a weighting factor is foreseen for the energy cost. However, U-CERT considers that for an Asset EPB Assessment, introducing a cost indicator may be counterproductive. This is because the Asset EPB Assessment represents the calculated EPB performance under standard conditions and standard weather data. Thus, any cost indicator that builds on such theoretical energy calculations won't provide meaningful information to both final users and EPB experts, who would tend to compare the cost indicator with the information present in the energy invoices.

A calculated cost indicator could be meaningful if it were performed under tailored conditions, rather than standardized. If the EPB Assessment were configurated to reflect the actual use conditions (e.g., thermostatic setpoints, control strategies, occupant behaviour, etc.) and under actual weather influence, - tailored-to-actual conditions- then the cost indicator could be closer to reflect the actual energy expenditure. Moreover, it could be valuable to use it as baseline model for the ideation of tailored renovation roadmaps.

Summary of indicators

To sum up, the indicators to be included in U-CERT's calculated asset EPB Assessment and EPC are the ones listed in Table 4.

Table 4. Indicators related to U-CERT's Calculated EPB Assessment and Certification Scheme

Category	Indicators	U-CERT EPB Assessment and Certification Scheme		Recognized as complementary to any EPB Assessment
		Included	Left as voluntary	
Energy Performance	Overall EP indicators	X	-	-
	Partial EP indicators	X	-	-
Smart Readiness	SRI	X	-	-
IEQ	ALDREN Thermal score	X	-	-
	ALDREN TAIL	-	X	-
	Triple-A reno Combined Label	-	-	X
Cost	Cost	-	-	-

These indicators could be arranged in some sort of factsheets to be easily compared and/or merged with information coming from other repositories (e.g., databases, Eurostat, etc.) or sources (e.g., building and systems inspections, etc.).

Renovation potential

With a view to nudging renovation actions, EPB Assessments of existing buildings ought to reflect the potential change in indicators should the building or its technical systems be improved. Thus, the indicators exposed in section Calculated EPB Assessment should be recalculated representing the foreseen status of the building after each proposed renovation scenario. The potential should be calculated aiming for deep renovation, while considering the option of staged deep renovation The change in the partial indicators could be made explicit, along with a detailed estimation of the cost of each renovation action, and the complete renovation scenario.

Measured EPB Assessment

There is growing interest in implementing measurement based EPB assessments as valid options for in use buildings. The concept is very appealing, given it would allow to transition from static and often time-consuming calculated EPCs to dynamic and low-cost EPB Assessments, which could even be leveraged for continuous maintenance purposes. This evolution of EPCs is often referred to as **Operational EPB Assessment**. This is of special relevance given the massive wide-scale rollout of electricity smart meters in the EU [25]. The gas smart meters are lagging a bit behind, and their development is not as widespread but rather focused on specific countries (i.e., France, Ireland, Italy, Luxembourg, and The Netherlands). The results from the ethnographic research performed in U-CERT under Deliverable 2.3 [26] were unequivocal as far as final user interest on this evolution of EPCs.

However, the implementation of measurement based EPB assessments requires recognised methodologies, and currently there is only one CEN Standard dealing with it. It is the EN 15378-3. Energy performance of buildings. Heating and DHW systems in buildings. Part 3: Measured energy performance [27]. The fact of not having standardised methodology to rely on when approaching whole-building measurement-based EPB Assessments is a barrier for its widespread implementation in EPB Assessments and Certification Schemes. Unlike energy audits, official EPB Assessments and Certification schemes should produce comparable results under standardised conditions. Thus, the main challenges for establishing measurement based EPB Assessments are:

- service separation (i.e., unless there are dedicated meters per each service included in the assessment, there is need to separate EPB uses from non-EPB uses and to enable use normalisation and weather standardisation),
- use normalisation (i.e., measured data is implicitly influenced by actual user behaviour and building use) and
- weather standardisation (i.e., measured data is implicitly affected by actual climate and period, if different from full year).

It is worth mentioning that the indicators that will result from the measured EPB Assessment cannot ensure the checks and balances of the performance assessment (i.e., minimum temperature of DHW, etc.) as in the calculated option. The added value of measured EPB Assessments is their capacity of generating low-cost massive EPCs, which logically will have less indicators than the calculated alternatives.

An important limitation of measured EP assessment is that it will be incapable to predict the effect of energy reducing measures (i.e., deep renovation).

Overall EP indicators

The **overall energy performance indicators** selected to be included in U-CERT are the following, with analogous considerations for each indicator as in the case of Calculated EPB Assessment:

- Basis for EP requirements:
  - **Overall non-renewable primary energy use [kWh/m^2].**
  - **Overall total primary energy use [kWh/m^2].**
- Informative:
  - **Overall non-renewable primary energy use [kWh/m^2].**
  - **Overall renewable primary energy production [kWh/m^2].**
  - **Overall renewable primary energy use [kWh/m^2].**
  - **Overall equivalent CO_2 emissions [kg/m^2].**
  - **Renewable electricity generation by onsite PV [kWh/m^2].**

- Renewable electricity generation by onsite wind turbines [kWh/m^2].
- Renewable electricity generation by onsite CHP [kWh/m^2].
- Renewable electricity from onsite PV used [kWh/m^2].
- Renewable electricity from onsite wind turbines used [kWh/m^2].
- Renewable electricity from onsite CHP used [kWh/m^2].
- Renewable electricity exported to non-EPB uses by onsite PV [kWh/m^2].
- Renewable electricity exported to non-EPB uses by onsite wind turbines [kWh/m^2].
- Renewable electricity exported to non-EPB uses by onsite CHP [kWh/m^2].
- Renewable electricity exported to the grid by onsite PV [kWh/m^2].
- Renewable electricity exported to the grid by onsite wind turbines [kWh/m^2].
- Renewable electricity exported to the grid by onsite CHP [kWh/m^2].
- Energy use per system service and energy vector [kWh/m^2];

Note that the only indicators that can be directly produced with the measured EPB Assessment are those related to energy delivered, produced, and exported, or any other derived from them (i.e., CO_2 emissions). Thus, there is a general information loss, and some indicators simply cannot be obtained, or, to obtain them additional high-level metering equipment should be in place (e.g., temperature sensors, presence detectors, etc.), which defeats the purpose of low-cost measurement based EPB Assessments and Certification Schemes. It is worth mentioning that in the measured EPB Assessment methodologies procedures can be designed to infer some non-energy parameters, like in [27] under the energy signature method, where the indoor temperature is estimated as an output indicator.

It is important to take into consideration the following statement from EN 15378-4:2017. *"An operational rating attempt on a system that was not designed or upgraded to support operational rating will seldom meet the quality requirements for the validity of the standardized operational rating"* [13].

Partial EP indicators

No partial indicators can be obtained as part of measured EPB Assessments. However, the same indicators listed for calculated EPB Assessments could be obtained through inspection or visit to the building. Moreover, if EPCs are coupled with technical building or technical system inspections, these information gaps could be filled.

U-CERT's decision with regards to partial indicators in measured EPB Assessments is to leave them as voluntary.

Smart Readiness

Smart Readiness will not be part *per se* of a measurement based EPB Assessment, but rather having greater smart readiness in certain areas would enable dynamic and even remote measured EPC.

In the case that the partial EP indicators proposed for the calculated EPB assessment are included, then the semi-automatic assessment of SRI could also be performed. In any case, the SRI could be integrated in measured EPB Assessments as a parallel and separate analysis.

U-CERT's decision with regards to SRI in measured EPB Assessments is to leave it as voluntary.

Indoor Environmental Quality

All the considerations stated in section Calculated EPB Assessment would apply for measurement based EPB Assessments. For all the procedures analysed, the input data to assess IEQ can come from simulated values or from actual measurements.

U-CERT's decision with regards to IEQ indicators in measured EPB Assessments is to leave them as voluntary.

Cost

The inclusion of cost indicators is of outmost relevance, given that economic aspects are at the centre of many energy renovations. Here the most reliable source of information are the energy invoices, and there is only one indicator proposed:

- **Overall energy cost per energy carrier** [€].

This indicator is purely based on actual measurements, although the normalization procedures of measured EPB Assessment methodologies may be applied to cost indicators, hence obtaining a standardized equivalent.

U-CERT's decision with regards to cost indicators in measured EPB Assessments is to include them, clearly stating whether they respond to standardised use and weather, or whether they reflect actual conditions.

Summary of indicators

To sum up, the indicators to be included in U-CERT's measured asset EPB Assessment and EPC are the ones listed in Table 5Table 4.

Table 5. Indicators related to U-CERT's Measured EPB Assessment and Certification Scheme

Category	Indicators	U-CERT EPB Assessment and Certification Scheme		Recognized as complementary to any EPB Assessment
		Included	Left as voluntary	
Energy Performance	Overall EP indicators	X	-	-
	Partial EP indicators	-	X	-
Smart Readiness	SRI	-	X	-
IEQ	ALDREN Thermal score	-	X	-
	ALDREN TAIL	-	X	-
	Triple-A reno Combined Label	-	-	X
Cost	Cost	X	-	-

These indicators could be arranged in some sort of factsheets to be easily compared and/or merged with information coming from other repositories (e.g., databases, Eurostat, etc.) or sources (e.g., building and systems inspections, etc.).

Calculated vs Measured

In the previous sections, the details with respect to indicators and content of calculated and measured EPB assessments have been described. As exposed in Table 1, each type of assessment is subject to certain limitations. For newly constructed buildings and for designs for renovation, calculated EPB Assessments are the only option. With regards to existing buildings, both types of assessments could be used. Additional considerations exist, given that detailed calculated EPB assessments tend to require quality information to model the building (e.g., project information, envelope description, technical specifications of systems, blueprints, etc.), which may be in accessible in the case of new constructions, being hardly ever present for the case of existing buildings. Moreover, calculations may offer the flexibility to be performed under various set of conditions, resulting in standardised assessments, while allowing for the possibility to perform tailored analysis. Contrarily, measurements always reflect actual conditions and require methodologies to adapt the data to be fit for standardised EPB assessments. Such standardisation procedures are not yet developed to cover the whole building. Further, renovation roadmaps can't be established with measured EPB assessments since projections cannot be simulated without some kind of energy model.

The interrelation between the different types of EPB assessments, during any building's lifecycle is illustrated in Figure 5.

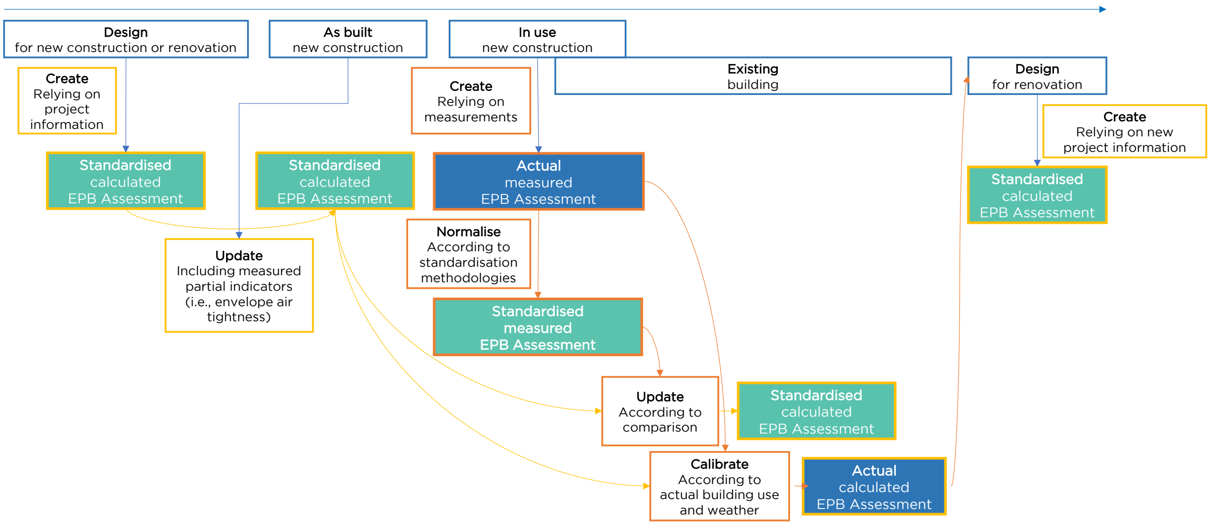

Figure 5. Interrelation of EPB Assessment types during a building's lifecycle

At the beginning, the design for a new construction shall generate a **standardized calculated EPB assessment** to fulfil the normative requirements (e.g., check compliance with EPB requirements, obtain a building permit, issue the EPC, etc.). Once the building is constructed, such EPB assessment can be updated to reflect the final as built conditions and can also include further definition of partial indicators that could require punctual measurements. For in use or existing buildings, the available measurements can generate **actual measured EPB assessments**, which according to standardisation methodologies could be normalised into **standardised measured EPB assessments.** Through the comparison of the existing calculated EPB assessment and both measured EPB assessments, an updated **standardised calculated EPB assessment** could be obtained reducing the performance gap (i.e., following ALDREN's Deliverable 2.3 [28], for instance) and an **actual calculated EPB assessment**, which would be calibrated to behave as a digitalisation of the real building. Such calculated EPB assessment tailored-to-actual conditions could be used to design a renovation roadmap adapted to actual building use. The use of such tailored assessments, in lieu of standardised ones, prevents the selection of sub-optimal renovation measured and the exaggeration of payback period[29][30][31]. In the end, when facing the design for a renovation, the process would start again.

Thus, by comparing calculated and measured EPB assessments, the complete lifecycle process of the analysing the energy performance of a building can be enhanced. Moreover, the calculated EPB assessment can be validated [5].

Refer to Annex C for a protocol related to the definition of the actual calculated EPB Assessment.

Performance gap

The coexistence of two approaches to EPB Assessments, a calculated and a measurement-based, raises the question of their similarity in the results. When performing such comparison, it is important to be aware of what is being compared with what, to extract meaningful conclusions. A schematic representation is shown in Figure 6. The most interesting comparison perhaps is when the tailored conditions reflect the actual status of the building performance.

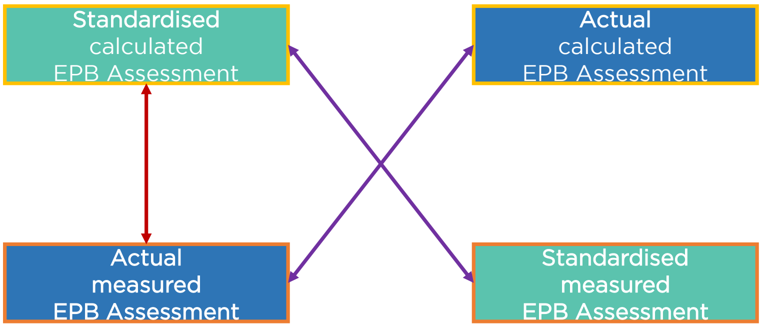

Figure 6. Comparison between calculated and measured EPB Assessments

Certain issues must be considered, such as the assessment period (i.e., typically a year) and the assessed object (i.e., the building, the technical systems, the EPB uses, etc.) should coincide. Of utmost importance is the determination of the reference area for the EP indicators. For instance, *"a space category that is formally allocated as inhabitable space should [...] be assumed to be an inhabitable area, [...] if this space is in practice regularly occupied (and its energy consumption is measured)"* as stated in EN ISO 52000-2 section 6.2.2.2 [12].

With a view of assessing the sensitivity and robustness of the EPB calculation under different use conditions, indicators showing the gap of calculations could also be generated.

For each service, a comparison will be presented between the energy use per energy carrier calculated under standardised/tailored weather and use conditions, and the equivalent measured values.

Energy GAP per service (i) and energy vector (j).

$$GAP_{i;j} = \frac{E_{usei;j}(Calculated_k) - E_{use;i;j}(Measured_l)}{E_{usei;j}(Measured_l)} \cdot 100$$

Being:

- $E_{usei;j}(Calculated_k)$: The calculation of the final energy use for the service *i*, and the energy vector *j*, under *k* conditions (i.e., standardised or tailored).
- $E_{use;i;j}(Measured_k)$: The actual measured final energy use for the service *i*, and the energy vector *j*, under *l* conditions (i.e., standardised or tailored).

In the case that $k = l$ (the purple lines in Figure 6), the indicator points to actions for the energy model calibration. In the case of $k = standard$ and $l = actual$ (the red line in Figure 6), the GAP indicator provides the following information, which could prove relevant for fault detection in management activities in in-use buildings:

- $GAP_{i;j} < 0$. The measured energy use in the service *i* is higher that the calculated value.
  Although such difference could be due to the actual weather being harsher than the one assumed in the calculated conditions, it could also point to careless energy use by the user.
- $GAP_{i;j} \approx 0$. The measured energy use in the service *i* is equal to that the calculated value.
  Thus, energy is used accordingly to the standard use.
- $GAP_{i;j} > 0$. The measured energy use in the service *i* is lower that the calculated value.
  Although such difference could be due to the actual weather being milder than the one assumed in the calculated conditions, it could also point to under-use of energy or even undeclared energy poverty.

Note that different use patters could seriously affect the comparison.

In case of a low value of the denominator a meaningless extreme GAP value would occur. In that case it is advised to ignore the GAP value ("not relevant") or to combine the service with a related other service. For instance: in case of low energy use for cooling compared to heating, heating, and cooling could be combined.

Needless to say, that, the different elements within the whole U-CERT EPC scheme may not be applicable to all buildings in all situations. Some points from section 6.2.4 in EN ISO 52000-2, are worth reproducing here:

- *"For new buildings, the measured energy indicator is not available.*
- *For existing buildings which are rented or sold, the way the building is managed could change and the measured energy indicator could change as a result.*
- *In existing public buildings where there is no change in ownership, the measured energy indicator can be a measure of the quality of the management and can be used to motivate building operators and users.*
- *For managers of buildings, a measured energy indicator can be easily obtained from data often stored in their information systems*
- *Measured energy indicator and standard calculated energy indicator do not necessarily include the same energy uses*[9] *"* [11].

[9] Additional considerations regarding the comparison between calculated and measured EP can be found in section 8 in EN ISO 52000-2 [12].

Energy Performance Certificate

The Energy Performance Certificate constitutes the main document for the communication of the energy performance in buildings to final users. It represents a normalised EPB performance under standardised use conditions and climate, although it can include additional information as exposed in current EPBD [1], and in its foreseen modifications [16].

As written in U-CERT's Grant Agreement (GA) regarding EPC *"one of the main obstacles is users' understanding and acceptance of EPCs, nowadays held back by the lack of user-friendliness [...]"*. In this section of the document, a proposal for a more user-friendly EPC is presented.

Previous endeavours within U-CERT, mainly Task 2.3 [6] and Task 2.4 [7], showed the following main findings regarding future energy performance certification schemes.

Regarding Task 2.3, it was found that they should:

- Make **energy more intuitive** and **influence behaviour** of building users. Indicators covering *health*, *safety*, *convenience*, *well-being,* and *comfort* should be leveraged;
- Accommodate a wide scope of use by offering **several levels of complexity of user interface** (e.g., for different types of users);
- In combination with **digitalisation**, EPCs could adopt a **modular design**, hence being tailored to different needs and expectations.

In relation to Task 2.4's findings, they should:

- Differentiate between newly constructed buildings and major renovations, and existing buildings.

Aware of these findings, the U-CERT scheme is structured in a way that aims to provide **flexible energy diagnostics**, depending on the type of user (e.g., expert, and non-expert) and the type of building (e.g., new, or majorly renovated and existing building).

U-CERT's EPC constitutes a repository of all the indicators mentioned above and complementary voluntary information. However, EPCs still face the everlasting dilemma of having to be meaningful to **expert users** (e.g., architects, engineers, etc.) and to **non-expert users** (e.g., building owners, tenants, etc.), while also being useful to policy makers, given they represent a crucial tool to monitor building stock energy efficiency and effectiveness of supporting policy, among others. U-CERT's contribution to solving this crossroads is to adapt the content to the user receiving the information, with a view to making EPCs more user-friendly. For this specific endeavour, the findings from Deliverable 2.3 [6] will be specially considered.

Figure 7. Illustration of U-CERT's flexible approach to user type.

The basic information should be made accessible to **non-expert users**, while explicitly labelling the more complex information as only relevant to **expert users**. Thus, building users will not be discouraged by not understanding some of the parameters and indicators that very often are included in most EPCs. The underlying philosophy is to avoid using complex terminology (e.g., non-renewable primary energy, thermal transmittance, coefficient of performance, etc.) and very technical units (e.g., kWh/m^2, W/m^2·K, etc.) that fail to communicate the pursued objective, which is to boost energy efficiency in buildings, especially, existing buildings.

Therefore, non-expert users will only be given information in accessible terms, such as visual scales or percentages referred to known concepts. (according to Table A.4 of Annex A in [2]). This dual results presentation is aligned with the latest EPBD recast proposal [5].

General information

Apart from the information specifically related to the EPB assessment, there is complementary data that should be present. Note that there are contents the applicability of which depends on the building situation:

- **Contextual information**.
  - Issue date;
  - Reference to EPC protocol (incl. version)
  - Link to EPC database;
  - Software used.
- **Identification of the assessed building**.
  - Building name;
  - Address;
  - Municipality;
  - Postal Code;
  - Region;
  - Country;
  - Reference (e.g., cadastre).

  An image of the assessed building should also be included.
  - **Identification of the assessment type** (drop-down option according to Table A.2 of Annex A in [2]).
    - Building situation (e.g., existing building, existing building to be renovated, new building).

      Just in the case of existing buildings:
    - Year of construction of original building;
    - Description of interventions since then.
  - **Identification of the object type** (drop-down option according to Table A.3 of Annex A in [2]).
  - **Identification of the building category** (drop-down option according to Table A.4 of Annex A in [2]).

    Clarify which building categories, in the case of mixed-use buildings.
  - **Identification of the building reference area** (drop-down option according to Tables A.20-22 of Annex A in [2]).
- **Identification of the EPB assessor**.
  - Full name and ID;
  - Company name and ID;
  - Address;
  - Municipality;
  - Postal Code;
  - Region;

- Country;
- Email;
- Phone.

In the case of existing buildings, a description of the tests, checks and inspections performed by the EPB assessor should be included, along with the date in which they took place.

Indicators

The indicators to be included in EPCs are the ones presented in section Indicators. Note that different types of EPB Assessments had different selection of applicable indicators, as exposed in Table 4 and Table 5

Scales

A partial or overall numeric indicator does not yet automatically reveal the quality of the building with respect to that feature. Great expertise is required to judge whether a single numerical indicator represents good or poor quality and performance. This can be the case of EPB experts, but definitely cannot be assumed for non-expert users Thus, the indicator needs to be compared to reference values to judge (rate) the good or poor performance of the feature under consideration.

In the next subsections, scales are going to be presented for three of the four categories of indicators included in U-CERT (i.e., energy performance, smart readiness, indoor environmental quality, and cost).

Energy Performance scale

The main indicator is the overall energy performance of the building. According to Overall EP indicators, for the application of the energy performance certificate, the Overall non-renewable primary energy use. Calculated according to H5 in Annex H in ISO 52000-1 [2]; thus, considering compensation between different energy carriers and the effect of exported energy. By comparing the value of the main indicator against one or more reference values, the energy performance is rated on a scale. See UU.4 section of EN ISO 52003-1 in Deliverable 3.1 for more detail. A graphical representation is used to present the rating in a user friendly, intuitively clear way.

In EN ISO 52003-1 [11] different options are given for the EP scale and the graphic representation. Such options can be chosen at national or regional level. Also, alternative national options can be chosen while still being in line with this EPB standard. The reason for such flexibility was that European and further international harmonization is the aim, but this could not be forced upon countries (top down) without further gaining more experience (bottom up). However, since the publication of that standard a convergence can be noticed, in particular in international projects around this theme, in particular in ALDREN that further worked out the recommendations from the Energy Voluntary Certification project more in detail, for office buildings and hotels [18]. The EPC Recast[10] project will continue along the same lines, focusing on the residential building sector.

It is proposed that for U-CERT some of the recommendations from ALDREN [18] are adopted.

[10] More information at: https://epc-recast.eu/

Rating

The U-CERT choice is the method given in EN ISO 52003-1 with the single reference point. For this, the provisions on energy performance certificates from [5] have been considered.

In this method:

- The performance scale ranges from Class A to Class G.
  The Class A should represent a *"zero emission building"* [5], and the Class G "*shall include the 15% worst-performing buildings in the national building stock"* [5].
- Subclasses may be defined to expand the classes, for instance class A may be expanded with A+, A++, A+++. U-CERT proposition is to define A+ Class.
- The boundaries of the classes are based on a nonlinear scale: ($Y = \sqrt{2}^{n-n_{ref}}$)
- The energy performance reference, *EP*$_{ref}$, shall be placed at the boundary between two classes, for instance classes 4 and 5 (n_{ref} = 4).
  The value of n_{ref} in formula ($Y = \sqrt{2}^{n-n_{ref}}$) determines the position of the reference, *EP*$_{ref}$, on the scale. The choice of the boundary, n_{ref}, is subject to a (national or regional) choice in Table A.6 (normative template) of EN ISO 52003-1, with an informative default choice given in Table B.6. The U-CERT choice is n_{ref} = 4.
- For U-CERT the class A upper boundary is set to n=1: EP≤0,35 *EP*$_{ref}$, with the upper boundary for A+ set to EP=0.

See illustration in Figure 8.

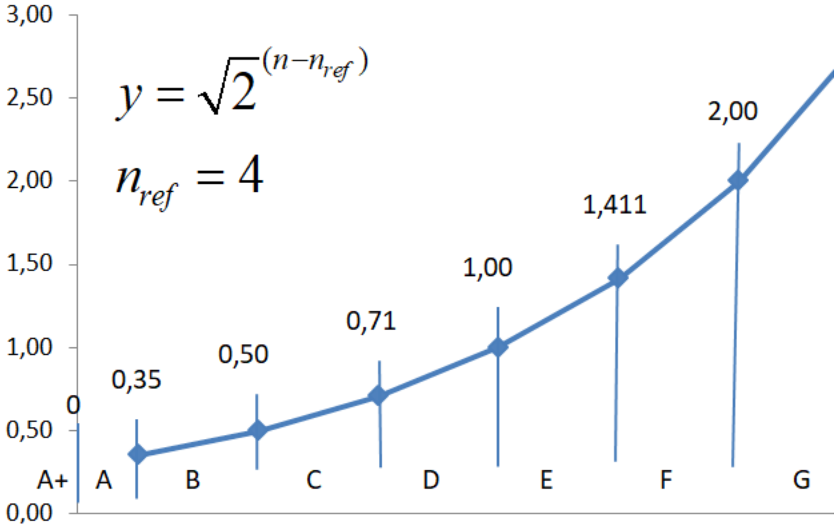

Figure 8. Illustration of the class boundaries (from CEN ISO/TR 52003-2, adapted)

CEN ISO/TR 52003-2 [12] provides more background information on this method.

The reference values

A proper **value of the single reference point** at the boundary between class D and E is the average for the building stock. This corresponds to the energy performance reached by a certain percentage, for instance approximately the median value (50 %), of the national or regional building stock. Again, this is a choice in Table A.6 (template) with informative default choice in Table B.6. of EN ISO 52003-1.

The reference value, however, is not defined by U-CERT. National values should be in line with EC Recommendation 2016/1318 [17]. Further details will be given in Deliverable 4.3, but the discrepancies between U-CERT partner countries calculation methodologies made impossible any kind of harmonisation between each national reference value.

The references for the rating of the overall energy performance may be a fixed value or a variable value, tailored to specific individual building characteristics. Notably by means of the formula approach or the notional reference building approach, as described in Clause 8 of EN ISO 52003-1. A variable value reference (a function) may be necessary for reasons of cost-optimal performance (see Clause 9 of EN ISO 52003-1). For the same reason, different reference values need to be defined for classes of buildings belonging to different categories, (e.g., single family houses, apartment blocks, offices, education buildings, hospitals, hotels and restaurants, sport facilities, wholesale and retail trade service buildings, and other types).

Mixed buildings

According to EN ISO 52003-1, when a given building belongs to different categories (mixed building, e.g., education + sport), one shall either

– Option 1: define a reference for each building category separately, or
– Option 2: define the reference value as an area weighted average of the reference values for each building category.

This choice has not yet been made in U-CERT. The first option implies that the calculated energy performance is assessed separately for the different building parts (with all the implications on the partial indicators and certificate as well). Therefore, option 1 seems not an evident approach, while option 2 seems quite elegant. But information needs to be gathered on the choices made in this respect in the EU Member States. Again, this is directly linked to the way the national or regional energy performance requirements are set.

Graphical representation

The proposed U-CERT graphical representation is in line with EN ISO 52003-1 and -apart from minor details in layout and text- equal to the default choice given in Table B.7 of the standard.

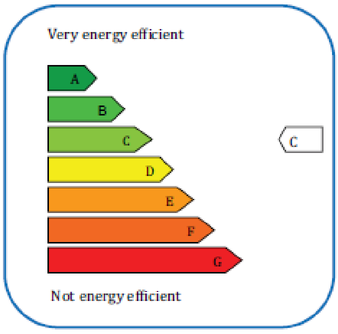

Figure 9. Default model for the graphical representation of the energy rating (11.3.2 in EN ISO 52003-1)

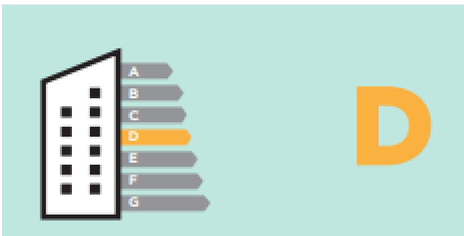

Figure 10. U-CERT proposal for Energy Performance scale

Thermal comfort scale

It is proposed that for U-CERT also the recommendations from ALDREN are adopted with respect to the addition of a rating/score of the thermal comfort. The complete methodology can be found in [18], and an extract of the steps are presented next.

1. The **hourly external dry-bulb air temperature** and the **internal operative temperature** for each zone are obtained.
2. The occupancy hours are divided into three seasonal periods according to the **mean external dry-bulb air temperature**, calculated from the previous 3 days according to formula B.1 in EN ISO 16798-1:2019 [32].
    - Winter for values equal or less than 10°C;
    - Summer for values equal or more than 15°C
    - Spring/Fall for values between 10°C and 15°C.
3. For each season and based on the **internal operative temperature** of each zone, the hours within each IEQ category are obtained. Then the percentage of occupancy hours inside each IEQ category excluding all better categories can be obtained.
4. For each season, and zone, the **thermal comfort score** could be calculated based on the percentage of occupancy hours in each IEQ category excluding all better categories. For this, the formula ALDREN proposed was the one defined by [33].
5. For each season a single score is obtained by the weighted average of all the thermal zones considered. Also, a weighted average of the thermal score is obtained for the building.
6. Each thermal comfort score is placed in the scale defined by ALDREN:
    - First class (the best), for scores below or equal to 2;
    - Second class, for scores above 2 and below or equal to 2.5;
    - Third class, for scores above 2.5 and below or equal to 3;
    - Fourth class (the worst), for scores above 3.

Analogous scores could be defined by other comfort parameters defined by [32], as referred in Deliverable 2.4.

Graphical representation

An exemplary visual representation of the thermal score to be adopted by U-CERT is shown in Figure 11.

Thermal environment
for standard use (1=best, 4-worse)

Season	Occupied hours	Score
Winter	1218	1.9
Summer	738	2.8
Spring/Fall	501	2.7
Overall thermal comfort		**2.3**

Figure 11. Illustration of the reporting of thermal comfort [18]

Season	Occupied (h)	Score
Winter	[Value]	1.9
Summer	[Value]	2.8
Aut./Spring	[Value]	2.7
Total:	[Value]	2.5

Figure 12. U-CERT proposal for Thermal comfort scale

Smart Readiness scale

The Smart Readiness calculation tool [34] available at the time of writing this document contains the option of having several weighting factors for each of the considered elements, as exposed in the final report [35]. U-CERT's decision is to maintain the default proposed factors.

As a result, a global SRI score and three partial ones are obtained.

Graphical representation

For the representation of the SRI, the final report [35] proposes several option for visual representation. U-CERT's decision is to maintain the overall score as well as the partial ones, so the final selection will be aligned with Figure 14.

Figure 13. Visual examples of SRI score [35]

Figure 14. Visual examples of SRI domain indicators [35]

U-CERT EPC report

In this section, a tentative proposal of the U-CERT EPC report is presented. As it was mentioned, there is a specific subset of information proposed to be explicitly presented to **non-expert users** in a user-friendly manner. The rest is presented to the **expert users**. The way of presenting this information could be via a **reduced EPC report** and an **extended EPC report**. The itemisation of the elements present in U-CERT EPC reports for calculated and measured EPB Assessments are presented in Table 6 and Table 7, respectively.

Table 6. Indicators related to U-CERT's Measured EPB Assessment and Certification Scheme

Calculated EPB Assessment	Reduced	Extended
Existing building or new building		
General information	X	X
Main EP rating in scale	X	X
Thermal comfort rating in scale	X	X
Smart Readiness in scale	X	X
Overall EP indicators	-	X
Partial EP indicators	-	X
SRI report	-	X
ALDREN Thermal score report	-	X
Voluntary indicators as annexes	-	X

Renovation potential		
per each renovation action		
Description of renovation action	X	X
Main EP rating in scale	X	X
Thermal comfort rating in scale	X	X
Smart Readiness in scale	X	X
Cost of renovation action	X	X
Overall EP indicators	-	X
Partial EP indicators	-	X
SRI report	-	X
ALDREN Thermal score report	-	X
Voluntary indicators as annexes	-	X
for the complete renovation scenario		
Description of renovation scenario	X	X
Main EP rating in scale	X	X
Thermal comfort rating in scale	X	X
Smart Readiness in scale	X	X
Cost of renovation scenario	X	X
Overall EP indicators	-	X
Partial EP indicators	-	X
SRI report	-	X
ALDREN Thermal score report	-	X
Voluntary indicators as annexes	-	X

Table 7. EPC report content for Measured EPB Assessments

Measured EPB Assessment	Reduced	Extended
Existing building or new building		
General information	X	X
Main EP rating in scale	X	X
Thermal comfort rating in scale (if performed)	X	X
Smart Readiness in scale (if performed)	X	X
Overall EP indicators	-	X
Partial EP indicators (if performed)	-	X
SRI report (if performed)	-	X
ALDREN Thermal score report (if performed)	-	X
Voluntary indicators as annexes	-	X

Graphical representation

For a graphical representation of U-CERT's EPC report refer to Annex A, for the Calculated EPB Assessment, and Annex B, for the Measured EPB Assessment.

They are presented as a static document in the annexes. However, the itemization of the U-CERT EPCs' content aims to lay the foundation for a further digitalization of EPCs, link with databases and integration into digital building logbooks. This is in line with the proposal EPBD recast of 2021 [5].

EPC databases

Energy Performance Certificates pose the most important source of knowledge on the energy performance of the European building stock. Improving EPCs' quality is as important as creating tools to leverage their full potential. This is the case of EPC databases.

U-CERT's user-centred and effective EPB indicators have been created with a view to more easily integrating valuable information in EPC databases. Among the content from U-CERT EPC reports listed in **¡Error! No se encuentra el origen de la referencia.** and Table , the ones conveying information about **overall performance** (e.g., overall EP indicators, Smart Readiness Indicators, Indoor Environmental Quality and Cost) and **building characterisation infrastructure** (e.g., envelope performance indicators, technical building systems performance indicators and electricity production performance indicators) provide the most value.

The current EU Buildings Database [36] includes many indicators, classified by country and years. Among all the available aggregated indicators, the following on building characterisation infrastructure are greatly related to U-CERT's:

- **Building shell performance**, divided into residential and non-residential for the following sub-items:
    - Air tightness;
    - U-value building envelope;
    - U-value external walls;
    - U-value floors;
    - U-value of doors;
    - U-value of roofs;
    - U-value skylight;
    - U-value windows.
- **Technical building systems**, offering information about the number of systems and their share:
    - Space heating;
        - Boilers;
        - Heat pumps;
        - Solar heating system;
        - Stove, fireplace;
        - Heating system;
        - Fuel used;
        - Other systems.
    - Water heating;
        - Fuel used;
        - Boiler types.
    - Space cooling;
        - System type.
    - On-site energy generation;
        - Energy generation;
        - Renewable energy.
    - Lighting;
        - CFL;
        - Incandescent lamps;
        - Halogen;
        - LED;
        - TL;
        - Other lamps;

These indicators can be directly linked with U-CERT's partial EP indicators in a way that EPCs following U-CERT's proposed structure could automatically feed European databases.

In [36], there are other indicators dealing with building overall performance, such as:

- Energy consumption, divided per service, and providing metrics on energy use per building type and per area:
    - All end-uses;
    - Space heating;
    - Water heating;
    - Space cooling;
    - Lighting.
- Certification:
    - Total EPCs;
    - EPCs per year;
    - Compliance;
    - Voluntary certification.

These indicators are aligned with U-CERT's overall EP indicators. Thus, similarly to partial EP indicators, U-CERT EPCs could populate European databases as they are issued and registered. Moreover, additional valuable indicators proposed by U-CERT, such as the SRI, IEQ or cost could also be included.

The proposal of U-CERT indicators is tentative. In the event of further digitalisation of EPB Assessments and Certification Schemes, data from EPCs could be included without limits, which may trigger additional products and services.

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I. Annex A. EPC report. U-CERT Calculated EPB Assessment

This section contains the EPC report resulting from U-CERT's Calculated EPB Assessment, both in its expert and non-expert version. It can be found at the end of the document.

II. Annex B. EPC report. U-CERT Measured EPB Assessment

This section contains the EPC report resulting from U-CERT's Measured EPB Assessment, both in its expert and non-expert version. It can be found at the end of the document.

III. Annex C. Protocol for more user-centric EP calculation

This protocol constitutes a concrete method for a Calculated EPB Assessment under actual use. This protocol is meant as a first step towards a more realistic and more user centred energy performance calculation.

To be able to describe the steps concretely, the protocol has been designed for a specific theoretical calculation. Since all energy performance calculation methods that are used for the EPB Assessments differ among the Member States [15], the ISO 52016-1 standard [3] has been followed. This standard offers an physics-based Resistance-Capacitance (RC) model that allows for a fully-dynamic simulation of the energy use and the indoor temperature in buildings with different level of complexity, on an hourly basis. In addition, the standard offers the monthly method as a quasi steady-state alternative for the hourly method. We choose as a use case to work out the protocol for the hourly method in ISO 52016-1, as an example of how this could work in national hourly energy performance methods. This is in line with U-CERT's choice in Deliverable 3.1.

Introduction

Despite their high potential to accurately predict the energy dynamics in buildings, RC models seem to underperform in practice. This is not so much caused by the RC models itself, but mainly due to the fact that some of **the most influential parameters that the model needs to take in as inputs are often hard to determine or measure**. An important example is the behaviour of the occupants (e.g., interaction with windows and with settings of HVAC facilities) which is challenging to predict and in energy performance methods are usually covered with fixed values or fixed time series. Although ISO 52016-1 clearly identifies how the occupant behaviour fits in the energy balance questions, and ISO 52016-1 itself might not prescribe fixed user behaviour values, for the energy performance label fixed values and times series are used [37]. These fixed user behaviour values can cause a significant deviation in model outcomes compared to the actual energy use. In addition, making the energy certificate more user-centred includes going from fixed behaviour values towards taking into account actual user behaviour. Not only to reduce the gap, but calculations based on actual use are better equipped to estimate the effect of measures [37]: if energy saving measures are suggested based on the theoretical calculations, the selection of these measures is sub-optimal and the payback time will on average be much longer than expected (e.g. [30], [31], [29]).

Assumptions in the method about user behaviour are known as the most important cause of the gap between theoretical and actual energy performance. Therefore we will focus the protocol on bringing these assumptions a bit closer to reality. Since this is a first step, the protocol limits to behavioural aspects that are relevant in the heating season in a moderate to cold climate. We also limit this use case to houses, since the behavioural aspects in non-residential buildings are very different.

It should be noted that, in addition to the occupant behaviour, there might be significant uncertainties in building-related factors; such as infiltration, ventilation and thermal bridges if sufficient information about the buildings and the installation is not available. A possible solution would be to estimate such parameters via model calibration, an approach that has not been presented in ISO 52016. Model calibration serves to reduce the building-related uncertainties. It is described in section Model calibration as an optional part which can be used if there is sufficient data available on the energy used in the building.

Moreover the Standard mainly focuses on a one-zone model, or thermally uncoupled multi-zone models, while under certain circumstances using a thermally coupled multi-zone model is necessary to reach an acceptable accuracy. Therefore the protocol will also contain a section on how to extend a one-zone RC model of ISO 52016-1 into a thermally coupled multi-zone model.

The goal of this report is to improve the predictive power of the RC model in ISO 52016 by providing a protocol which aims to mitigate the above-mentioned challenges. The report is organized as follows. The protocol is organized in four separate subsections. The data collection protocol, with a focus on characterizing occupants behaviour via questionnaires, is outlined in section Data collection protocol - occupants' behaviour. Translation of occupants data to model input describes how the collected data on occupants behaviour can be transformed in a way which can be inputted to the RC model of ISO 52016-1. Section Model construction and zoning focuses on the model construction, describing how and under which circumstances a one-zone model should be replaced by a thermally coupled two-zone model. Section Model calibration discusses the optional model calibration process and the estimation of the uncertain parameters. Finally, section Concluding remarks gives some concluding remarks.

Protocol

This chapter describes the protocol for improving the accuracy of model calculations for ISO 52016-1. The procedures described in the first 3 sections are indispensable parts of the protocol and shall be performed sequentially. The section on model calibration is optional and might be performed if sufficient measured data is available, and if the discrepancy between the model predictions and the measurements exceeds an acceptable tolerance.

As mentioned in the introduction, this protocol is designed for calculations of the heating season in a moderate to cold climate. This means that the focus lies on the important user behaviour factors related to the heating season.

Data collection protocol - occupants' behaviour

This chapter describes the procedure to obtain information on occupants' behaviour. The source of information can be questionnaires and monitoring data. In case the information is obtained from questionnaires, several alternatives are presented when applicable (i.e., detailed, simple and basic) depending on the level of details required in characterizing the occupant behaviour. Which level of detail is used is up to the user of the protocol. In principle, a higher level of detail gives a higher level of accuracy. However, there is always a trade off with the time it takes for filling in the questionnaire and the quality of the provided data if too much is asked or the questions are too difficult to fill in. To improve the quality of questionnaire data, it is suggested to ask occupants to fill in the questionnaire on their heating season behaviour in the heating season.

Occupants presence

Information on occupants' presence is obtained from questionnaires.

- Detailed questionnaire:
  - Number of occupants that use (e.g., live, visit or work) the building is provided.
  - The schedule of the presence of each occupant is provided in Table III-1.

Table III-1. Presence schedule of each occupant

Time	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
6.00-9.00							

9.00-13.00							
13.00-18.00							
18.00-23.00							
23.00-6.00							

- Simple questionnaire:
  - Number of occupants that use the building is provided.
  - The time intervals in **¡Error! No se encuentra el origen de la referencia.¡Error! No se encuentra el origen de la referencia.** can be merged into larger intervals, and the days grouped into weekdays and weekend.
- Basic questionnaire:
  - Number of occupants that use the building is provided.
  - Instead of providing **¡Error! No se encuentra el origen de la referencia.**, each occupant identifies on what days they work or perform other activities outdoor, how many hours per day on average they spend out of the building during the weekdays, and whether or not they spend most of weekend at home.

Setpoint profiles for heating systems

Information on the heating setpoint is obtained from questionnaires.

- Detailed questionnaire:
  - for each of the controlled heating systems, the setpoint schedule in a typical winter week is provided in Table III-2.

Table III-2. Schedule of the setpoint for heating systems for every day of a typical winter week

Time	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
6.00-9.00							
9.00-13.00							
13.00-18.00							
18.00-23.00							
23.00-6.00							

- Simple questionnaire:
  - Only the typical schedules for a week day and a weekend day is provided in Table III-3.

Table III-3. Schedule of the setpoint for heating and ventilation systems for a typical winter weekday and weekend

Time	6.00-9.00	9.00-13.00	13.00-18.00	18.00-23.00	23.00-6.00
Setpoint values (weekday)					
Setpoint values (weekend)					

- Basic questionnaire:

  The occupants indicate their preferred values for the daily setpoints during the day when occupants are present, during the day when occupants are away, and during the night.

Terminal heating unit

It is assumed that the living area is always heated when the thermostat is high; this is, the terminal heating unit (THU) valves in the living room are opened. The occupants indicate in the questionnaire whether the terminal heating unit in the main bedroom and the other bedroom(s) (if applicable) are often on. Also, the approximate floor area of each bedroom is also required. In the case the living area is not always heated when the thermostat is high, it could also be included in Table III-4.

Table III-4. State of terminal heating unit in bedrooms

Room	THU often on	Floor area (m^2)
Main bedroom		
Other bedroom #1		
Other bedroom #2		

If the building has an attic, it is also indicated whether the attic is heated or not.

This information is required to determine whether or not a two-zone model should be used. More information can be found in section Model construction and zoning.

Interaction with windows

This information is needed only if the method to calculate the ventilation flows explicitly takes the window positions into account. Otherwise this section shall be ignored. ISO 52016-1 refers to EN 16798-7 [38] for the calculation of ventilation flows, in which indeed window positions are taken into account.

The information about interaction of occupants with the windows is obtained from questionnaires.

- Detailed questionnaire
  - For a typical winter day the time intervals during which each window is fully open or ajar is indicated in Table III-5.

Table III-5. Occupants' interaction with each window in a typical winter day

Room	Hours window fully open	Hours window ajar
Livingroom		
kitchen		
Bathroom		
Bedroom #1		
Bedroom #2		
Bedroom #3		

- Simple questionnaire
  - Instead of Table III-5, the occupants answer the following questions:
    1. In a typical winter day, how many hours do you open the windows in your living area during the day?
    2. Do you keep the windows in your bedroom partially open during the night?
    3. How many hours do you open the windows in your bedroom during day?

Shading devices

If the building is equipped with external shading devices, information about the use of these devices is provided in a questionnaire.

- The occupants indicate which windows are equipped with shading devices.
- The occupants also indicate how many days per week on average they use the shading devices in the winter period, and to what purpose.
- If such information is not available, it is assumed that the shading devices are not used during winter.

Appliances use

The appliance use can be directly estimated from the electricity use data, assuming that the electricity is not used for heating. Only a fraction of the used electricity is turned into heat. A typical value of 90% is assumed (note that the value of 90% is an expert best guess, based on some use cases where is estimated how much of

the electricity used is released in the building and how much is leaving the building via the sewer (e.g., washing machine, dish washer etc)).
If electricity is used for heating the following procedure can be applied:

- Use at least data on monthly level
- Calculate the average electricity use per month outside the heating season.
- Use this value (times 90%) as the internal heat gain from appliances for every month.

Translation of occupants data to model input

Collected data on occupants behaviour should be converted to hourly timeseries for the whole simulation period. These hourly timeseries replace the default values that are used normally in standardised calculated EPB Assessments. The procedure to determine a more realistic hourly timeseries for a typical week is described below. The timeseries of this typical week can be repeated for the whole calculation period, or divided into typical weeks per season.

Occupants presence

Occupants presence is used to calculate a value for the internal heat gain from people that represents actual building use.

- If the detailed or simple questionnaire is used the information in Table III-1 is directly converted to hourly occupancy timeseries for each occupant.
- If the basic questionnaire is used, for each occupant a daily profile distinguishing between weekdays and weekends is first created based on the occupant's answers to the specified questions. This profile is then converted to a hourly occupancy timeseries.
- The people gain is then calculated by summing the occupancy timeseries of all occupants multiplied by a typical value of 70 W [39].

Setpoint profiles for heating systems

- If the detailed or simple questionnaire is used the information in Table III-2 and Table III-3 is directly converted to an hourly setpoint timeseries.
- In case the basic questionnaire is used, a weekly setpoint profile is formed based on the combination of the provided answers and the occupant presence. The presence of all occupants is combined as follows:
    - For each hour between 7:00h and 23:00h, when nobody is present, the setpoint is used 'when occupants are away during the day'.
    - For each hour between 7:00h and 23:00h, when one or more occupants are present the setpoint is used 'when occupants are present during the day'.
    - For each hour between 23:00h and 7:00h the setpoint is used that the occupants use 'during the night'.

Interaction with windows

- If the detailed questionnaire is used, the information in Table III-5 is directly converted to hourly timeseries of the position of each window with open=1, ajar=0.5 or closed=0.
- If the simple questionnaire is used, the following assumptions are made to generate the window position timeseries:
    - Based on the answer to question 1, it is assumed that the window(s) in the living area are opened every day in the middle of the day, for the duration of time given in the questionnaires.
    - If the answer to question 2 is positive, it is assumed that the window(s) in the bedroom are set to the ajar position during the night periods.

- o Based on the answer to question 3, it is assumed that the window(s) in the living area are opened every morning, for the duration of time given in the questionnaires

The procedure above is needed only if the method to calculate the ventilation flows explicitly takes the windows positions into account. Otherwise questionnaire data on interaction with the windows shall be ignored/not asked. In case Calculation Method 1 in EN 16798-7 is applied, the hourly timeseries for the positions of the windows shall be used as windows' opening fractions.

Shading devices

If shading devices are used, a threshold on the solar radiation is used to determine when shading is applied. If the solar radiation on a certain window exceeds this threshold, it is assumed that the shading is closed and it will remain closed as long as the solar radiation is higher than 70% of the calculated threshold[1]. This will result in a hourly timeseries for the state of the shading devices. To determine the appropriate threshold, the following procedure is performed:

1. The solar radiation on each window is calculated at each hour of the simulation period.
2. A set of thresholds are chosen. For each threshold in the set, and for each day in the simulation period, it is checked whether the solar radiation on one or more windows exceeds the threshold value during one or more hours on that day. If this happens it is assumed that the shading devices were used on that day.
3. Following step 2, the number of days in which the shading devices were used is calculated for all the chosen thresholds.
4. Based on step 3 a table is created which relates each value of the threshold to the fraction of days (in terms of number of days per week) in which the shading devices have been activated during the simulation period.
5. A suitable threshold is chosen from the table, so that the frequency of use of shading devices during the simulation period matches the frequency indicated in the questionnaire.

Appliances use

<u>If no electricity is used for heating</u>, the average hourly electricity use is calculated from available data and multiplied by a typical factor 90% to represent a constant value for the appliances heat gain. If hourly data is available, that can be used directly (after multiplying it with the factor of 90%). Otherwise a constant average hourly value can be used per available data period.

<u>If electricity is used for heating</u>, the following procedure can be applied:

- Use at least data on monthly level
- Calculate the average electricity use per month outside the heating season.
- Use this value (times 90%) as the internal heat gain from appliances for every month.

Note: The energy use for heating per month can be assessed by subtracting the average electricity use calculated above.

Model construction and zoning

Depending on the type of the building and the state of the terminal heating units different modelling approaches are considered:

[1] There have been a lot of studies done on the triggers for solar shading use, with very different outcomes. So underpinning any value is not easy. The use of solar shading in the heating season for residential building in cold to moderate climates is not that big. If people think this is more important, than it might be better to extend the questionnaire on this aspect to get better actual shading use input.

1 The building is an apartment (all rooms are at the same floor). In this case, it is assumed that there is a uniform temperature over the apartment. Therefore a one-zone model is considered and no setpoint correction is applied.

2 The building is a multi-story house. In this case, one might expect more temperature division over the floors, depending on the amount of rooms that are heated. Therefore, in this case, the fraction of the area of the first floor plus attic (if applicable, see the Note below) which is heated is calculated. The value of the heated area fraction determines the zoning of the model:

   a. If the heated area fraction is larger than 75%, a one-zone model is chosen and it can be assumed that the whole area is heated; this is the terminal heating unit's valves are open and heating is provided conform the setpoint schedule.

   b. Otherwise a two-zone model is chosen, where the first zone includes the living room and is assumed to be heated; this is the terminal heating unit's valves are open and heating is provided conform the setpoint schedule. The second zone includes the rest of the building and is assumed to be unheated (i.e., free floating). If precise geometric information on the individual zones is not available, the average floor-to-roof height is calculated, and the horizontal plain which cuts the height in half is used to divide the building (i.e. the interior space as well as the bounding walls) into two parts, each corresponding to one of the zones. An exchange conductivity U_{exch} is used to model the heat exchange between the two zones. An initial value of $5\,W$ per squared meter of floor area is assumed [40], which can be refined during the calibration process (see section Model construction and zoning). If the area of the construction between the two zones is unknown, the area can be estimated by averaging the ground floor area and the roof area. The energy balance equation at the zone level, as given in ISO 52016-1, should be replaced by two coupled equations as follows, one for each zone:

$$\left[\frac{C_{\mathrm{int};z1}}{\Delta t} + \sum_{\substack{eli=1\\ z1}}^{eln} \left(A_{eli} \cdot h_{\mathrm{ci};eli}\right) + \sum_{\substack{vei=1\\ z1}}^{ven} H_{\mathrm{ve};vei;t} + H_{\mathrm{tr;tb};z1} + U_{exch}\right] \cdot \theta_{\mathrm{int;a};z1;t} - \sum_{\substack{eli=1\\ z1}}^{eln} \left(A_{eli} \cdot h_{\mathrm{ci};eli} \cdot \theta_{\mathrm{pln};eli;t}\right) - U_{exch} \cdot \theta_{\mathrm{int;a};z2;t}$$

$$= \frac{C_{\mathrm{int};z1}}{\Delta t} \cdot \theta_{\mathrm{int;a};z1;t-1} + \sum_{\substack{vei=1\\ z1}}^{ven} \left(H_{\mathrm{ve};vei;t} \cdot \theta_{\mathrm{sup};vei;t}\right) + H_{\mathrm{tr;tb};z1} \cdot \theta_{\mathrm{e;a};t} + f_{\mathrm{int}} \cdot \Phi_{\mathrm{int};z1;t} + f_{\mathrm{sol}} \cdot \Phi_{\mathrm{sol};z1;t} + f_{\mathrm{H/C}} \cdot \Phi_{\mathrm{HC};z}$$

$$\left[\frac{C_{\mathrm{int};z2}}{\Delta t} + \sum_{\substack{eli=1\\ z2}}^{eln} \left(A_{eli} \cdot h_{\mathrm{ci};eli}\right) + \sum_{\substack{vei=1\\ z2}}^{ven} H_{\mathrm{ve};vei;t} + H_{\mathrm{tr;tb};z1} + U_{exch}\right] \cdot \theta_{\mathrm{int;a};z2;t} - \sum_{\substack{eli=1\\ z2}}^{eln} \left(A_{eli} \cdot h_{\mathrm{ci};eli} \cdot \theta_{\mathrm{pln};eli;t}\right) - U_{exch} \cdot \theta_{\mathrm{int;a};z1;t}$$

$$= \frac{C_{\mathrm{int};z2}}{\Delta t} \cdot \theta_{\mathrm{int;a};z2;t-1} + \sum_{\substack{vei=1\\ z2}}^{ven} \left(H_{\mathrm{ve};vei;t} \cdot \theta_{\mathrm{sup};vei;t}\right) + H_{\mathrm{tr;tb};z2} \cdot \theta_{\mathrm{e;a};t} + f_{\mathrm{int}} \cdot \Phi_{\mathrm{int};z2;t} + f_{\mathrm{sol}} \cdot \Phi_{\mathrm{sol};z2;t},$$

Where the subscripts $z1$ and $z2$ are used to denote the properties related to the first and the second zones respectively. In particular $\theta_{\mathrm{int;a};z1;t}$ and $\theta_{\mathrm{int;a};z2;t}$ refer to the internal air temperatures in the first and the second zones at time t. The terms containing U_{exch} couple the temperature dynamics in the two zones. The definition of other variables is given in ISO 52016-1. The term $f_{\mathrm{H/C,c}} \cdot \Phi_{\mathrm{HC};z2;t}$ does not appear in Equation III-2 as the second zoon is assumed to be unheated.

Note: If the building has an attic, it is included in the model only if it is considered as a part of thermal envelope. Otherwise the attic is not included in the second zone.

Model calibration

Model calibration against measured data can be used to estimate uncertain model parameters and to reduce the discrepancy between model predictions and the measured data. In this section the procedure to estimate the residual loss and the exchange coefficient between the zones is described. The procedure can be easily generalized to estimate other parameters. Caution is required, however, if model calibration involves a large number of uncertain parameters, as the procedure might yield unrealistic estimations due to overfitting.

Note: The calibration procedure is optional, and can be ignored, for instance if the deviation of the model predictions from the measurements are within the acceptable range.

Data for model calibration

If the building is heated by gas (or another source not being electricity):

- Data on gas usage (or other source, except electricity) is required. The lowest required resolution is per month. The average gas use in the summer period is subtracted from the data to obtain the energy use for space heating.
- Energy use data with higher temporal resolution and data on hourly indoor temperature (if available) are optional, but can improve the model calibration process and can lead to more accurate model predictions.

If the building is heated by electricity:

- Data on electricity usage is required. The lowest required resolution is per month. The average electricity use in the summer period is subtracted from the data to obtain the energy use for space heating.
- Energy use data with higher temporal resolution and data on hourly indoor temperature (if available) are optional, but can improve the model calibration process and can lead to more accurate model predictions.

Model calibration procedure

To capture the uncertainty in model parameters such as thermal conductivities of the constructions, air infiltration and contribution of thermal bridges, as well as the ventilation through open windows, a term of the form

$$H_{res}\left(\theta_{\mathrm{e;a};t} - \theta_{\mathrm{int;a};zi;t}\right), \qquad \text{Equation III-3}$$

is added to the energy balance equation of the zone(s). In Equation III-3, $\theta_{\mathrm{e;a};t}$ represents the outdoor air temperature at time t, $\theta_{\mathrm{int;a};zi;t}$ is the internal air temperature in zone i at time t, and H_{res} is the residual loss coefficient which is estimated via model calibration.

If a two zone model is considered, the heat exchange between the two zones is represented by

$$U_{exch}\left(\theta_{\mathrm{int;a};z1;t} - \theta_{\mathrm{int;a};z2;t}\right), \qquad \text{Equation III-4}$$

according to Equation III-1 and Equation III-2.

The residual loss H_{res} and the exchange coefficient (if included in the model) can be estimated via model calibration by minimizing the least square penalty which calculates the sum of squared differences between the model predictions and the measurements. denoting the measured energy for heating during month j by E_j, and the predicted energy for the same month with the particular choice of H_{res} and U_{exch} by $\hat{E}_j|_{H_{res},U_{exch}}$, the least square penalty can be written as

$$\mathbf{LS}(H_{res}, U_{exch}) = \sum_j \left(E_j - \hat{E}_j|_{H_{res},U_{exch}}\right)^2, \qquad \text{Equation III-5}$$

where the sum in Equation III-5 runs over all the months for which the data is available. The minimization of the least square penalty can be performed using a variety of commercial and open-source software programs which offer multiple functionalities for nonlinear optimization. Examples are scipy.optimize.least_squares function in Python and fmincon function in MATLAB.

Concluding remarks

When the energy performance calculation is done using more realistic timeseries for the user behaviour related to heating of the building (as described in sections Data collection protocol - occupants' behaviour and Translation of occupants data to model input) and a multi-zone model is applied, when appropriate (as described in section Model construction and zoning), we expect that the difference between the calculated performance and the actual energy use is decreased.

The deviation will reduce the difference further if the optimization procedure (conform section Model calibration) is performed.

Note that a worked-out example of a use case will be added to the chapter in a later stage.

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