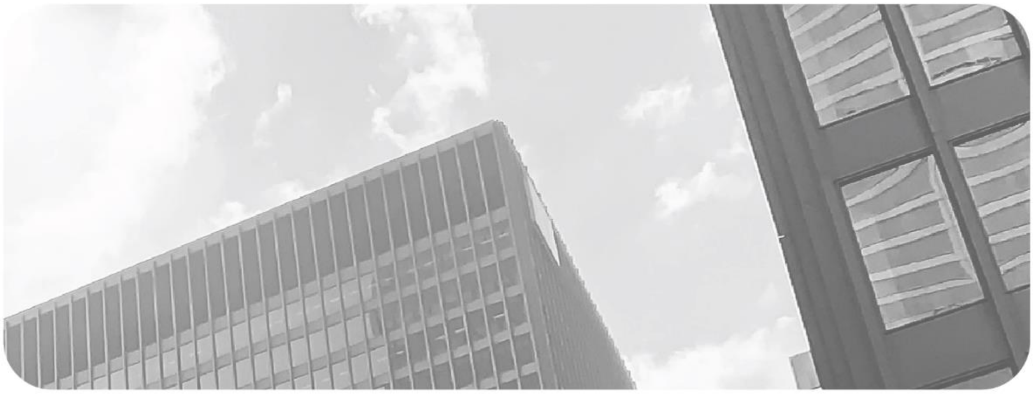
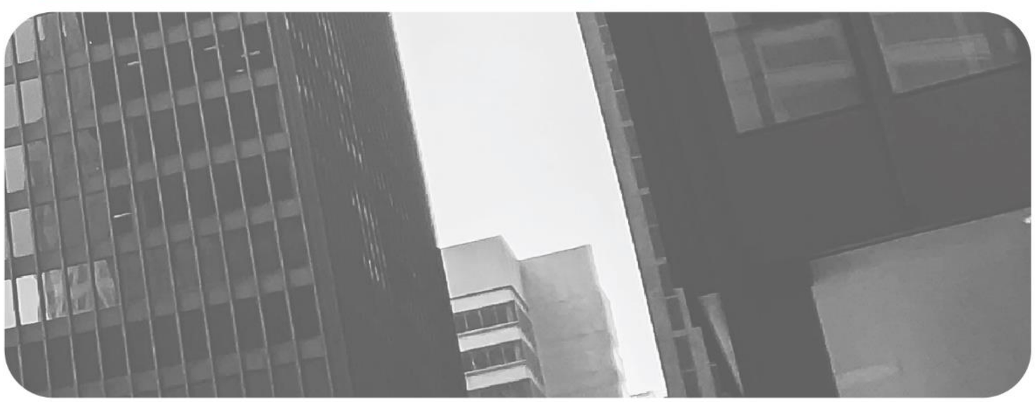


D2.4 Building performance indicators based on measured data for holistic EPCs



U-CERT
User-Centred Energy Performance Assessment and Certification

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List of abbreviations used in this document

DR: Draught Rate

EPBD: Energy Performance of Buildings Directive

EPC: Energy Performance Certification/Certificate

HVAC: Heating, ventilation and air conditioning

IEQ: Indoor Environmental Quality

IAQ: Indoor Air Quality

MS: EU Member State(s)

PD/PPD: Percentage of People Dissatisfied

SRI: Smart Redlines Indicator

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Executive summary

In the current implementation of EPCs, the assessment focus is purely on the energy consumption data of buildings. Furthermore, for existing buildings, they are often made at a low cost and not in alignment with actual energy consumption of the building. For new buildings and major renovations, the EPCs are generally calculated during the design process of the building when all design documentation is available but is utilized only for the aspects minimally required by the EPBD. The aim of this deliverable is to outline performance indicators that could be implemented in the framework of next generation EPCs.

Within the EPC framework, the problem is not the availability of performance indicators, but with the assessment effort required (cost and level of qualification necessary) for these indicators. There are plenty of privately developed voluntary certification schemes readily available both locally and internationally, such as LEED, BREEAM and Green Star, but these are typically targeted at interested investors and developers and are not suitable for bulk EPCs. Only the data that is easily available can justifiably introduced to EPCs either as direct complementary input or as a performance indicator. This deliverable proposes two different development paths - one for existing buildings and one for new buildings and major renovations. Two categories of complementary indicators to energy are proposed – IEQ and Power indicators.

IEQ indicators cover parameters such as room temperature, air flow, air velocities, CO_2 levels and HVAC system noise. In new buildings and major renovations, it would require only some small additional access to design documentation and increased competence of the assessor. For example, additional design information about air distribution and air quality is needed, as draught complaints are one of the most common complaints about the indoor environment in modern non-residential buildings. However, the design documentation of the building must anyhow state the design criteria of the indoor environment parameters. If all the calculation and simulation reports that prove the compliance to the design criteria are presented with the design documentation, then the assessment effort of IEQ for certification is reasonably justified.

For existing buildings, generally only limited information is available in the design documentation, or in some cases the design documentation might not be complete or not available. The IEQ assessment then would require on-site measurements, inspections and monitoring, this procedure is described in detail.

Currently, there is no power or flexibility data of the building systems presented in the EPCs. Proposed power indicators would describe peak and typical loads of the building on electricity, district heating and cooling grids and networks. This interacts with the Smart Readiness Indicator framework, where grid flexibility, power shifting and demand-response are important assessed parameters. Power indicators can be implemented for existing buildings as well, under the assumption that hourly metering data is available or retrofitted to the existing system.

Introduction

To meet the goal of a holistic next generation of EPCs, preliminary research is needed to list which are and how are calculated the most popular indicators in the plethora of voluntary certification schemes available on the market (e.g. health, productivity, market value). These aspects will underpin the development of methods for including measured data in an interactive EPC that would enable an evidence-based decision-making process and facilitate the delivery of renovation triggers. Moreover, based on existing research, the consortium will identify the possible effects that next generation EPC indicators could have on the improvement of the holistic performance of buildings (e.g. does a good EPC ranking affect the market value of a building?, which indicator is most relevant for triggering action?). These findings will guide the selection of the shortlist of indicators to be proposed in the next generation EPCs.

Existing building certification schemes

The effects of exponential growth in resource consumption has been explored and contested for many decades. It is generally accepted that BREEAM (Building Research Establishment Environmental Assessment Method) is the world's first **green building rating tool** and was established in 1990. Many similar schemes have since been developed with varying numbers of assessed parameters and levels of detail, such as LEED and Green Star, see Figure 1 below. These are voluntary schemes that attempt to rate or reward relative levels of compliance or performance with environmental requirements and goals. These rating schemes assess the performance of buildings in categories such as building materials, energy efficiency, water efficiency, waste management, land use and ecology, management, pollution, IEQ (Indoor Environmental Quality), location, innovation in design, emissions, and many other categories. Theses schemes can be applied to different types of buildings, e.g. new and existing buildings, residential and non-residential buildings and address different criteria, e.g. energy performance only or wider sustainability schemes.

These voluntary schemes find varying levels of use in different EU member states. Reasons for limited implementation include high costs of international schemes, lack of market demand and unawareness of the advantages and value that the schemes offer. In member states with low uptake, the schemes are mainly used by international investors and developers that operate in multiple countries and regions where the certification is seen as lucrative.

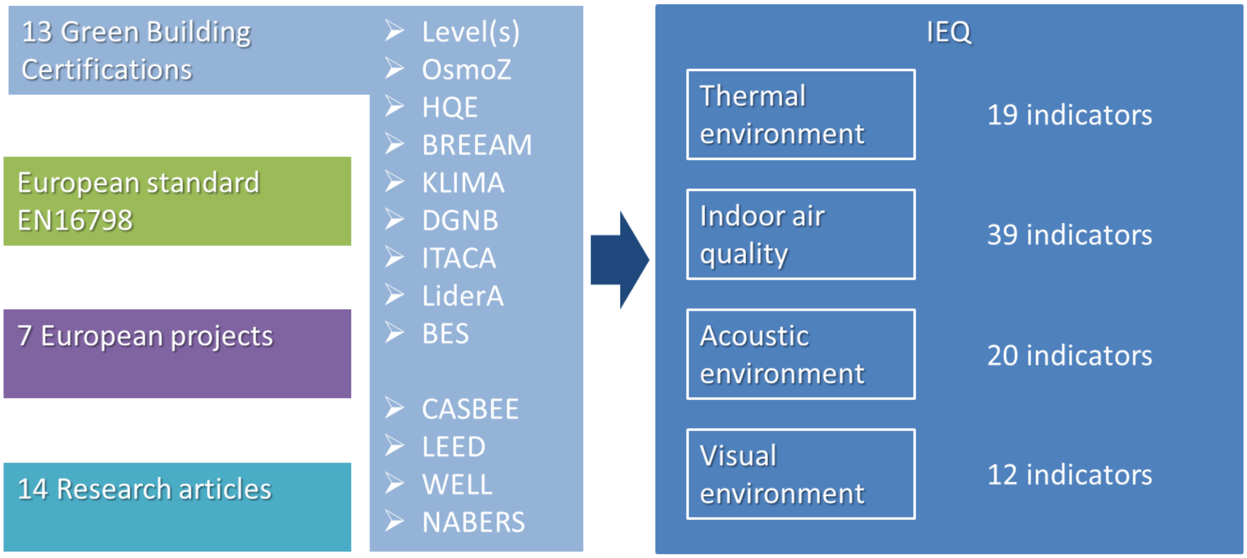

Figure 1. Overview of existing schemes and performance indicators. Wei et al. (2019), Energy and Buildings

These schemes co-exist with the mandatory Energy Performance Certificates (EPCs) required by the EPBD. EPCs relate mostly to designed or measured energy performance of the building. The main indicator of the EPC scheme is the EPC class, but generally other indicative values such as net and/or primary energy consumption, system-by-system energy breakdown, CO_2 emissions and delivered and exported energy values (share or renewable energy) are also shown as seen in Figure 2 below. Consequently, the energy performance is well-described in the EPCs, but sustainability and other performance indicators are not.

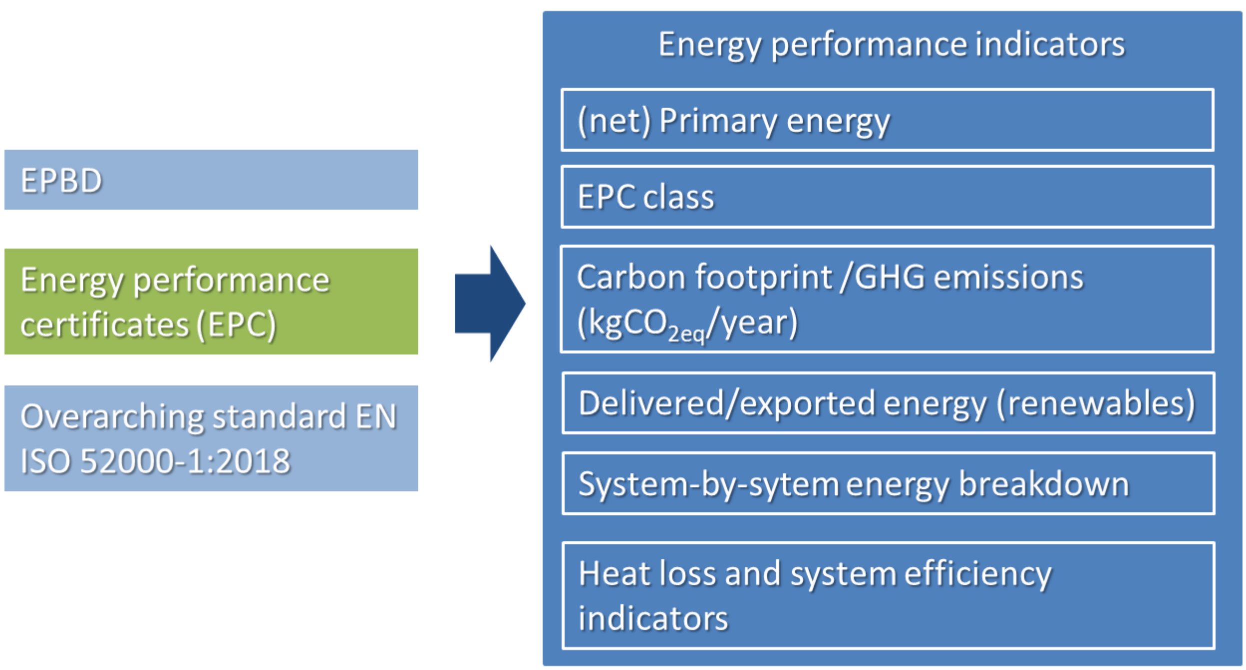

Figure 2. Overview of energy performance indicators

When considering indicators for the next generation of EPCs, it is evident that the main problem does not lie with the availability of indicators, but in the assessment effort and whether the EPC issuer is qualified for such an assessment. Most voluntary certification rating schemes are mainly targeted towards non-residential property investors and developers, e.g. larger industrial and commercial buildings. On the other hand, EPC scheme involves all buildings regardless of their type and size. There is a considerable difference in the assessment effort of these two types of schemes, and for bulk EPCs, the cost and the level of qualification needed for voluntary schemes cannot be matched. Consequently, only a selection of assessable parameters can be feasibly proposed as new performance indicators in the next generation of EPCs.

An important set of proposed parameters relate to the IEQ (indoor environment quality) of the building. These parameters are room temperature (which relates to the overall thermal comfort of the occupant), ventilation rates and CO_2 levels (relates to the indoor air quality (IAQ)), draught rates (relates to the local thermal discomfort) and HVAC system noise (relates to the acoustic comfort).

In Figure 3 below, the parameters of the TAIL indicator developed in ALliance for Deep RENovation (ALDREN) project is shown. The TAIL indicator is one example of a voluntary IEQ indicator, outlined are compatible parameters for inclusion as new indicators in EPCs.

	TAIL IEQ parameters	**EN16798**	**Level(s)**	**WELL**	**HQE**	**OsmoZ**	**BES**	**LEED**	**BREEAM**	**KLIMA**	**CASBEE**	**NABERS**	**DGNB**	**LiderA**	**ITACA**
T	Indoor temperature (°C)	x	x	x	x		x			x	x	x	x	x	
A	Noise level (dB(A))	x		x	x	x	x	x	x	x	x	x			
I	CO_2 (ppm)	x	x	x		x	x	x		x		x			
	Ventilation rate (L/s)	x	x	x	x	x	x	x	x		x	x	x		x
	Formaldehyde (µg/m^3)	x	x	x	x	x	x	x	x	x		x	x		
	Benzene (µg/m3)	x	x	x	x	x									
	$PM_{2.5}$ (µg/m3)	x	x	x	x	x		x							
	Radon (Bq/m3)	x	x	x	x		x								
	Indoor air relative humidity (%)	x	x	x						x					
	Visible mould (cm^2)		x	x											
L	Daylight factor (%)	x	x		x	x			x		x		x		x
	Illuminance (lux)	x	x	x			x	x	x		x			x	
	Number of parameters	*11*	*11*	*11*	*8*	*7*	*7*	*6*	*5*	*5*	*5*	*5*	*4*	*2*	*2*

Figure 3. TAIL indicators present in numerous voluntary schemes. Outlined parameters are suggested for implementation in next/generation EPCs. Wargocki (2019), REHVA Brussels Summit Conference.

Another example is the Estonian Green Label, which also assesses the IEQ from a similar list of parameters, along with the energy and location category indicators (Figure 4). These are both examples of very simple certificates, with only three or four levels of classification.

GREEN LABEL 2015

Building type:	non-residential building
Category:	12201 Office building
Street address:	Tänav 96
Building registry code:	111222333
Year built:	2014
Enclosed net floor area:	5000 m2
Client:	Name of contractor
Basis of classification for the Green label:	Principal building design
Green label category:	**C - Good**
Indoor climate category:	**C - Good**
Energy category:	**C - Good**
Location category class:	**B - Great**
Date of issue:	10.01.2015
Valid until:	9.01.2025
Label issuer	
Name:	Ettevõte OÜ
Registry code:	11122233
Liable specialist:	First name Last name
Green label 2015 classification criteria	
Indoor climate category.	
Main criterion. Ventilation air flow rate	B - Great
Main criterion. Room air temperature	B - Great
Auxiliary criterion. Air velocities	Did not apply
Auxiliary criterion. Room ventilation	Did not apply
Auxiliary criterion. Level of daylight	C - Good
Auxiliary criterion. Internal and External lighting	B - Great
Auxiliary criterion. Visual outdoor scenery	B - Great
Auxiliary criterion. Material emissions	C - Good
Auxiliary criterion. Noise	B - Great
Auxiliary criterion. User satisfaction	C - Good
Energy category.	
Main criterion. Energy efficiency	A- Excellent
Main criterion. Integration of building automation system	B - Great
Main criterion. Schooling of administration	C - Good
Auxiliary criterion. Energy efficiency of elevators	Did not apply
Auxiliary criterion. Efficient external lighting	B - Great
Auxiliary criterion. Control of electrical lighting	C - Good
Auxiliary criterion. Inspection of HVAC	B - Great
Location category.	
Main criterion. Public transport accessibility	B - Great
Main criterion. Accessibility to services	B - Great
Auxiliary criterion	Did not apply

Figure 4. Example of Estonian Green Label Class.

In the next section, a detailed description of IEQ parameters, categories, boundary values and their assessment within the context of EPCs is given.

Main indicators for indoor climate category assessment

The categories are related to the level of expectations by the occupants, see Table 1 below. A normal level is "Medium", while a higher level may be more appropriate for occupants with special needs, e.g. children, elderly and person with disabilities. A lower level does not pose a potential health risk but may decrease comfort.

Table 1 - Categories of indoor environmental quality according to EN 16798-1:2019

Category	Level of expectation	Explanation
IEQ_I	High	Should be selected for occupants with special needs (children, elderly, persons with disabilities).
IEQ_{II}	Medium	The normal level used for design and operation.
IEQ_{III}	Moderate	Will still provide an acceptable environment. Some risk of reduced performance of the occupants.
IEQ_{IV}	Low	Should only be used for a short time of the year or in spaces with very short time of occupancy.

Table 2. Description of IEQ categories, REHVA guidebook number 6

Indoor environment category	Room temperature (overall thermal comfort)	Ventilation supply air flow rate (air quality)	Draught (local thermal discomfort)
I – High (Best possible)	PPD[1] <6 %	PD[2] < 15 %	DR[3] <10 % Only occasional complaints of draught due to lower room temperatures in the wintertime
II – Medium (Default)	PPD <10 % Slightly reduced productivity	PD < 20 % Slight increase in number of symptoms relatable to SBS Slightly reduced productivity	DR <20 % Some complaints of draught due to lower room temperatures in the wintertime

III – Moderate Need for improved indoor environment in major renovations	PPD <15 % Significantly reduced productivity Increasing number of complaints of dry air and symptoms relatable to SBS Lower productivity in text editing due to numb fingers in winter	PD < 30 % Significant increase in number of symptoms relatable to SBS Reduced productivity High risk of moisture and and microbial growth in residential buildings	DR <30 % Frequent complaints of draught due to lower room temperatures in the wintertime Lower productivity in text editing due to numb fingers in winter
IV – Low (Inadequate) Not suitale for rooms with continuous occupancy, i.e. working, studying or living spaces	PPD < 25 % Significantly reduced productivity Frequent complaints of dry air and symptoms relatable to SBS Lower productivity in text editing due to numb fingers in winter	PD < 40 % Significant increase in number of symptoms relatable to SBS Significantly reduced productivity Increased number of sick-leave days in rooms with multiple workers High risk of moisture and and microbial growth in residential buildings	DR > 30 % General complaints of draught

In accordance with EN 16798-1:2019, the main indicators for the indoor climate assessment are room temperatures, air velocities, ventilation rates, CO_2 levels and building system noise levels. In the following tables, default values from the annex B of the same document are shown in the tables below.

Occupant comfort, health and performance are described by the room temperature and affect the office work productivity and learning performance of the occupant, while the ventilation rate and CO_2 levels affect the number of sick leave days.

Room/Operative temperature

Table 3. Minimum and maximum allowed operative temperatures according to EN 16798-1:2019.

Type of building/space	Category	Operative temperature °C	
		Minimum for heating (winter season), approximately 1.0 clo	Maximum for cooling (summer season), approximately 0.5 clo
Offices and spaces with similar activity (single offices, open plan offices, conference rooms, auditorium, cafeteria, restaurants, classrooms) Sedentary activity ~ 1,2 met	I	21,0	25,5
	II	20,0	26,0
	III	19,0	27,0
	IV	18,0	28,0
NOTE Assumed low air velocity < 0,1 m/s during heating period.			

Air velocity

Annex B default values are very strict, category I uses draught rate of 10% and summer values are not split for cooling situation (valve open) and situation without active cooling. For instance, in Estonia, DR of 15% and less strict velocity values are used for active cooling situations used in category I. Figures below

Table 4. Default draught criteria in EN 16798-1:2019 Annex B

	Draught		
Category	DR (draught rate)	Maximum air velocity in working and learning environment	
		Winter [m/s]	Summer [m/s]
Category I	10	0,10	0,12[c]
Category II	20	0,16	0,19[c]
Category III	30	0,21	0,24[c]
[c] When the air temperature is above 25 °C, higher maximum air speeds are allowed and often even preferred (draught becomes pleasurable breeze); but only under the condition that occupants have direct control over the air speed			

Table 5. Draught criteria in the Estonian national Annex of EN1679-1:2019

	Draught		
Category	DR (draught rate)	Maximum air velocity in working and learning environment	
		Winter [m/s]	Summer [m/s]
Category I	15	0,14	0,16[b]/0,19[c]
Category II	20	0,16	0,19[b]/0,25[c]
Category III	30		
[b] Maximum air velocity allowed in cooling season, in situation without cooling. [c] Maximum air velocity allowed in cooling season, in cooling situation.			

CO_2 levels

Table 6. Default design CO_2 concentrations above outdoor concentration, assuming a standard CO_2 emission of 20 l/(h/person), EN 16798-1:2019

Category	Corresponding CO_2 concentration above outdoors in ppm for non-adapted persons
I	550
II	800
III	1350
IV	1350

Ventilation rate

The total ventilation rate for the breathing zone is found by combining the ventilation for people and building calculated from Formula (1):

$$q_{tot} = n \cdot q_p + A_R \cdot q_B \quad (1)$$

where

q_{tot} = total ventilation rate for the breathing zone, l/s
n = design value for the number of persons in the room, -
q_p = ventilation rate for occupancy per person, l/(s·person)
A_R = floor area, m^2
q_b = ventilation rate for emissions from building, l/(s·m^2)

The perceived air quality levels are defined by default for non-adapted persons in non-residential building and adapted persons in residential buildings. In non-residential buildings, assuming adapted persons shall be justified.

Table 7. Design ventilation rates for non-adapted persons for diluting emissions (bio effluents) from people for different categories, EN 16798-1:2019.

Category	Expected Percentage dissatisfied, %	Airflow per non-adapted person l/(s · person)
I	15	10
II	20	7
III	30	4
IV	40	2,5

Table 8. Design ventilation rates for diluting emissions from buildings, EN 16798-1:2019.

Category	Very low polluting building (LPB1) l/(s m²)	Low polluting building (LPB2) l/(s m²)	Non low-polluting building (LPB3) l/(s m²)
I	0,50	1,0	2,0
II	0,35	0,7	1,4
III	0,20	0,4	0,8
IV	0,15	0,3	0,6

Building service systems noise

Table 9. Design equivalent continuous sound level, $L_{Aeq,nT}$ [dB(A)] for continuous sources, EN 16798-1:2019

Building	Type of space	Equivalent continuous sound level $L_{Aeq,nT}$ [dB(A)]		
		Cat. I	Cat. II	Cat. III
Offices	Small offices	≤30	≤35	≤40
	Landscaped offices	≤35	≤40	≤45
	Conference rooms	≤30	≤35	≤40
Schools	Classrooms	≤30	≤34	≤38

Indoor climate category assessment in new buildings

Design documentation of the building must state the design criteria of the indoor environment parameters. These parameters must include ventilation rates, heating and cooling set-point temperatures, maximum air velocities and HVAC noise in major space categories. Furthermore, calculation or simulation reports that prove that the design criteria are met must also be appended to the documentation where applicable. If this data is present, then there are no further actions needed to assess the indoor climate category. If this data is not present or is partially missing, then the relevant calculations or simulations must be conducted and submitted for the indoor climate category assessment.

Indoor climate category assessment in existing buildings

Generally, assessment of the building indoor climate category begins with checking compliance with indoor category III, then compliance with category II and finally with category I. If the building does not comply with category III, then it will belong to indoor climate category IV. Assessment of these categories requires different levels of knowledge and expertise from the assessor. For categories III and IV, on-site inspection and brief overview of design documents should provide enough information to make the assessment. This level of assessment could be done by people who have some knowledge of indoor climate and HVAC systems, for example construction engineers, building designers and heads of maintenance and administration. For correct assessment of categories I and II, expert knowledge of

HVAC systems, indoor climate, building physics and measurement technology is required. The assessment process involves thorough on-site inspections, detailed review of design documentation, on-site measurements, simulations of indoor climate, and for category I, indoor climate questionnaires for occupants. Therefore, this level of assessment can be done only by qualified assessors.

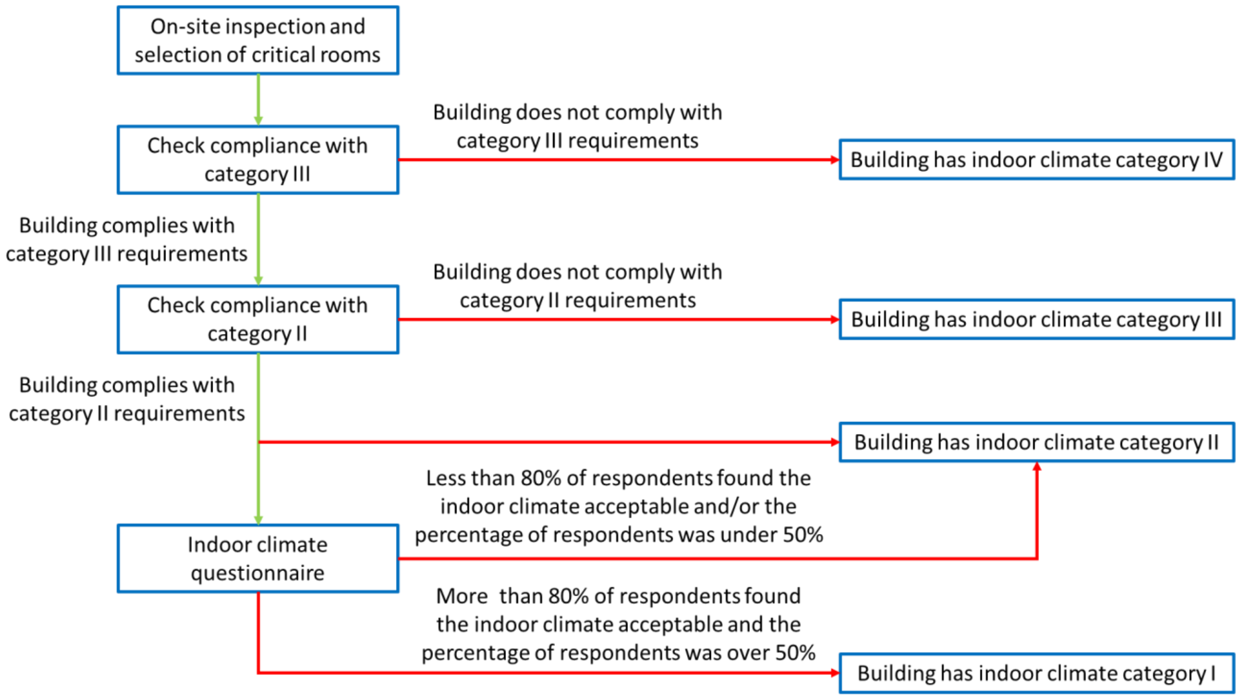

Figure 5. Process of indoor climate category assessment.

Process of indoor climate category assessment in existing buildings

Prior to the on-site inspection, it is recommended to contact the building owner, administrator or the person responsible for maintenance to gather additional or missing information for the assessment process. In particular, the measurement protocol of the ventilation system is needed to cross-check design air flow rates and noise (sound pressure) levels. Additionally, as-built drawings of HVAC systems are needed to verify the integrity of the on-site systems. If the ventilation documentation is not provided, then air flow measurements must be carried out on-site.

It is also necessary to determine characteristic and critical rooms of the building where measurements will be carried out if necessary.

Characteristic rooms – most typical rooms within the building with constant occupancy, such as office, class or living rooms or individual workspaces in an open office setting. Generally, 3-10 rooms are required for a representative sample. It is necessary to consider the following:

- intended use of the rooms, e.g. office space, classroom, living room etc.
- orientation of the rooms with respect to the cardinal directions
- presence of HVAC systems, e.g. rooms with and without air conditioning devices

Critical rooms – rooms where thermal comfort problems are most likely to occur, such as rooms with large glazed surfaces or high internal heat gains. Generally, 3-10 rooms are required for a representative sample. Examples of critical rooms include but are not limited to rooms where:

- air conditioning devices are missing, or selected devices are improper for the room type and load
- glazed surfaces constitute a considerable area of the building envelope
- windows are oriented to the southern and western facades (risk of overheating)
- windows are in different facades (corner rooms)
- glazed surfaces are not shaded
- internal gains are higher than typical
- air flow rates are lower than typical and where supply air is not cooled
- opening of windows is not possible or is limited

Indoor climate category III and IV assessment

Category III is achieved when the following criteria are fulfilled:

- Heating system is present and the heat output in rooms with regular occupancy can be controlled on a room or zone basis
- Mechanical ventilation is present in rooms with regular occupancy. Air flow rates or CO_2 levels must be in accordance with EN 16798-1.
- Rooms with regular occupancy where glazed surfaces are on the east, south-east, south, south-west or west facades have mechanical cooling and the indoor temperature can be controlled on a room or zone basis. Alternatively, the absence of cooling devices can be justified with a simulation calculation in critical rooms.

If a measurement protocol of the ventilation system is not provided, then the air flow rates in characteristic rooms must be measured and checked against reference values in EN16798-1. Alternatively, CO_2 levels can be measured and compared to EN16798-1 during at least 4 hours of occupancy instead.

The measurement periods in a non-residential building must be at least four hours in typical use conditions. Air flow rates may alternatively be assessed by measuring each air handling unit’s total air flow rate vs design conditions in served spaces, given that the device is working at the intended capacity and its air filters are clean.

Indoor climate category I and II assessment

Assessment of compliance to these levels requires simulation or measurement of indoor climate along with a thorough review and analysis of design and as-built documentation of HVAC systems. Both calculated and measurement-based assessments are allowed, as well as a combined approach for different technical systems

On-site inspections and review of documentation shall verify that:

- chosen technical solutions can maintain required levels of indoor climate parameters in all rooms with regular occupancy
- HVAC systems are in working condition and match with as-built drawings and documentation

- normative air flow rates and sound pressure levels have been considered in the system design and are demonstrated in measurement protocols.

For calculation-based approach, the following calculations or simulations are required:

- cooling load calculations for characteristic and critical rooms
- terminal and room unit air flow jet analysis in manufacturer or validated third party software for characteristic and critical rooms

For measurement-based approach, the following measurements are required:

- air temperature measurements during the heating and cooling season in characteristic and critical rooms. Minimum length of measurements shall be at least one month and must include periods with typical heating and cooling loads.
- air velocity measurements during the cooling season with the cooling device operating and during the cooling season without cooling load
- air flow rate and sound pressure level measurements if measurement protocols are not available.

For category I assessment, indoor climate survey must be done among the occupants in addition to the previously described step. The questionnaire must cover the following aspects:

- room air temperature (hot, warm, slightly warm, neutral, slightly cool, cool, cold)
- air quality (according to EN16798-2)

Examples of questionnaires from EN 16798-2:2019 are shown in Figure 6 below.

How do you rate your thermal sensation?	How do you perceive the temperature?
Hot	Clearly acceptable
Warm	
Slightly warm	Just acceptable
Neutral	Just unacceptable
Slightly cool	
Cool	Clearly unacceptable
Cold	

Do you want the room temperature?
a) Higher
b) No change
c) Lower

How do you perceive the air quality?	How do you perceive the odour intensity?
Clearly acceptable	No odour
	Weak odour
Just acceptable	Moderate odour
Just unacceptable	Strong odour
	Very strong odour
Clearly unacceptable	Overpowering odour

Figure 6. Examples of questionnaires for subjective evaluations, EN 16798-2:2019.

Short deviations from the category boundary values are allowed on a weekly, monthly or hourly basis, see

Table 10 below. This allows for short time deviations e.g. when opening windows, where short time increased air velocity and noise will be accepted. By using more than one criterion (e.g. both annually and weekly), it is possible to e.g. set an indirect criterion for how long consecutive periods of increased or reduced temperatures can be accepted.

Table 10. Default allowed length of deviation from the category boundary values corresponding to a certain % of occupied hours, EN16798-2:2019

x% / y% of period	**Weekly hours**		**Monthly hours**		**Yearly hours**	
	20 %	50 %	12 %	25 %	3 %	6 %
Working time	8	20	21	44	63	126
Total hours	40		175		2 100	
Total time	33	58	86	180	259	518
Total hours	166		720		8 640	

An example of visualization of the indoor environment qualification is shown in Figure 7. This type of visualization has the advantage of better describing the annual environment with the duration of different category levels being indicated.

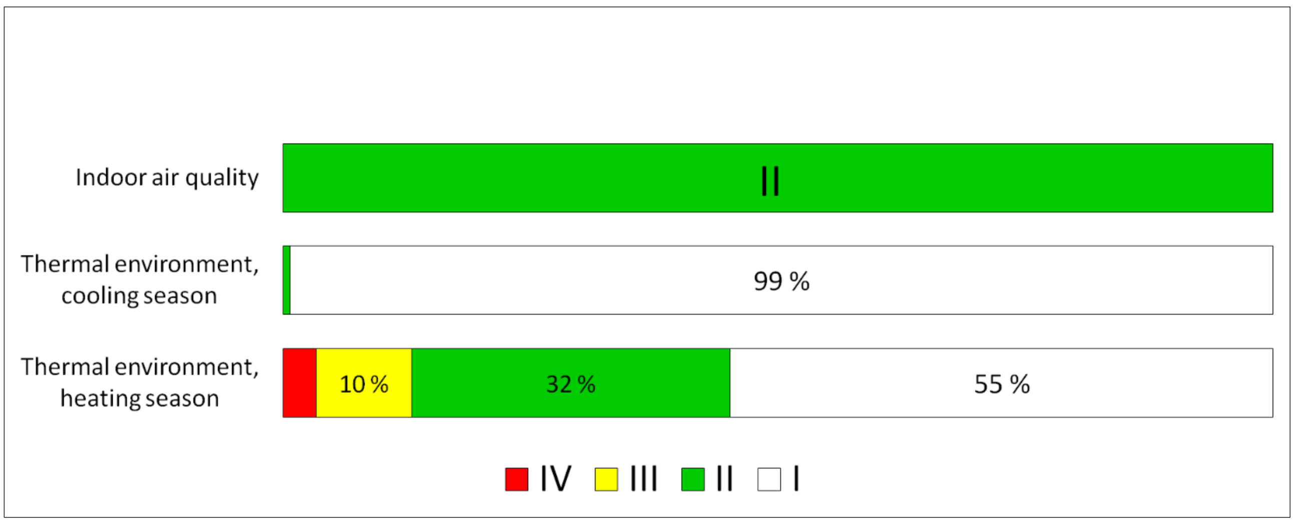

Figure 7. Example of indoor environment classification by footprint diagram.

Consortium-wide data collection – Case Study EPCs

The aim for collecting the existing EPCs for all U-CERT case studies was to see which data, input data relevant for heating/cooling/ventilation/indoor climate/etc., but also energy data and output data (including indicators), is available in the current generation of EPCs. All 11 stakeholders submitted a translated version of their EPCs, which were then analysed in eight categories.

Envelope data

Table 11. Envelope data of Case Study EPCs. Legend: x- fully present, o – partially present, blank – missing.

Case study	Element-by-element breakdown	Thermal transmittance	Element surface areas	Orientation of façade elements	SHGC	Total heat loss coefficient	Thermal bridges	Infiltration	Closure type	Total
9										0%
6						x				11%
5	x	x	x							33%
2	x	x							x	33%
1	x	x	x		x					44%
8	x	x		x	x					44%
4	x	x	x	x	x					56%
3	x	x	x	x		x	x		x	78%
7	x	x	x	x		x	x	x		78%
11	x	x	x		x	x	x	x		78%
10	x	x	x	x	x		x	x	x	89%
Total	82%	82%	64%	45%	45%	36%	36%	27%	27%	

Envelope data is generally well described, typically a break-down of thermal properties of all or typical envelope elements is given (walls, floor, roof, windows, doors and other openings). For glazed surfaces, generally the SHGC or another equivalent parameter was given. In a smaller portion of buildings, infiltration (airtightness) and thermal bridge data was also given.

Relevant data that was occasionally present:

- Building thermal capacity (kJ/K)
- Hygro(thermal) properties of individual material layers

Ventilation system data

Table 12. Ventilation data of Case Study EPCs

Case study	Mechanical/natural	Annual electricity	Air flow	SFP	HX efficiency	Total
1						0%
2	x					20%
3	x					20%
4	x	x				40%
5	x	x	o	o	o	40%
6	x	x				40%
7	x	x	x	x		80%
8	x	x	x		x	80%
9	x	x	x	x		80%
10	x	x	x		x	80%
11	x	x	x	x	x	100%
Total	91%	73%	45%	27%	27%	

In almost all cases, the ventilation system was described in at least some detail. Surprisingly, only 45% of the EPCs listed the rated air flows, with even smaller portion describing the fan performance or heat exchanger efficiencies.

Relevant data that was occasionally present:

- Zone supply temperature set-points
- Frost protection temperature of the heat exchanger
- Breakdown of CAV/VAV systems
- Description of the control strategy (user profiles, extract temperature, CO_2 level, free cooling)

Heating system data

Table 13. Heating System data of Case Study EPCs

Case study	Yes/no	Annual energy	Generation type	Installed power	Generation efficiency	Emitter type	Total
6	x	x					33%
2	x	x	x			x	67%
3	x	x	x		o	x	67%
1	x	x	x	x	x		83%
4	x	x	x	x	x		83%
5	x	x	x	x		x	83%
7	x	x	x		x	x	83%
9	x	x	x	x	x		83%
10	x	x	x	x	x		83%
11	x	x	x	x	x		83%
8	x	x	x	x	x	x	100%
Total	100%	100%	91%	64%	64%	45%	

The heating system is well-described in all submitted EPCs. Most EPCs showed the installed power, heat generation type and efficiency. Emitter types were described in just over half the EPCs.

Relevant data that was occasionally present:

- Control strategy (thermostatic valves, room sensors)
- Distribution losses
- Circulation pump and insulation data

Cooling system data

Table 14. Cooling system data of Case Study EPCs

Case study	Yes/no	Annual energy	Generation type	Generation efficiency	Installed power	Distribution type	Total
6	x	x					33%
5	x	x	o	o	o	o	33%
2	x	o	x			x	50%
3	x	x	x			x	67%
7	x	x	x	x			67%
11	x	x	x	x			67%
1	x	x	x	x	x		83%
4	x	x	x	x	x		83%
9	x	x	x	x	x		83%
10	x	x	x	x	x		83%
8	x	x	x	x	x	x	100%
Total	100%	91%	82%	64%	45%	27%	

The cooling system is also well-described in all studied buildings similarly to the heating system.

Relevant data that was occasionally present:

- Control strategy – free cooling (GSHP, night-time ventilation)
- Distribution losses

Domestic hot water system data

Table 15. Domestic hot water system data of Case Study EPCs

Case study	Yes/no	Annual energy	Generation type	Generation efficiency	Tank capacity	Total
6	x	x				40%
5	x	x	x			60%
2	x	x	x		x	80%
3	x	x	x		x	80%
7	x	x	x	x		80%
11	x	x	x	x		80%
1	x	x	x	x		80%
4	x	x	x	x		80%
9	x	x	x	x		80%
10	x	x	x	x	x	100%
8	x	x	x	x	x	100%
Total	100%	100%	91%	64%	36%	

Relevant data that was occasionally present:

- Number of taps, shower, toilets etc
- Distribution losses
- Data about circulation pumps, pipe insulation
- Greywater heat recovery

Lighting data

Table 16. Lighting data of Case Study EPCs

Case study	Yes/no	Annual energy	Installed power	Total
6	x	x		67%
3	x	x		67%
7	x	x		67%
1	x	x		67%
5	x	x	x	100%
2	x	x	x	100%
11	x	x	x	100%
4	x	x	x	100%
9	x	x	x	100%
10	x	x	x	100%
8	x	x	x	100%
Total	100%	100%	64%	

Relevant data that was occasionally present:

- Illuminance (lx), efficiency ($W/(m^2lx)$)
- Breakdown of lamp types (LEDs, CFLs, incandescent)
- Control strategy (motion sensors, daylight sensors)

Renewables data

Table 17. Renewables data of Case Study EPCs

Case study	Yes/no	Annual energy production	Generation type	Installed power	Generation efficiency	Total
1		o	o	o	o	0%
4		o	o	o	o	0%
8	o	o	o	o	o	0%
6	x	x				40%
3	x	x	o	o	o	40%
5	x	x	o	o	o	40%
7	x	x	x			60%
10	x	x	x	o	o	60%
2	x	x	x	x		80%
11	x	x	x	x		80%
9	x	x	x	x	x	100%
Total	73%	73%	45%	27%	9%	

Energy performance data

Table 18. Energy performance data of Case Study EPCs

Case study	EPC Class	Energy breakdown by systems	Net energy demand	Primary energy demand	GHG emission, eq. CO_2	Energy breakdown by carrier	Partial Indicators	Total
2	x	x	x					43%
10	x	x		x	x			57%
8	x	x	x	x		x		71%
5	x	x	x		x		x	71%
11	x	x	x	x		x		71%
1	x	x	x	x	x		x	86%
4	x	x	x	x	x		x	86%
3	x	x	x	x	x	x		86%
7	x	x	x	x	x	x		86%
6	x	x	x	x	x	x	x	100%
9	x	x	x	x	x	x	x	100%
Total	100%	100%	91%	82%	73%	55%	45%	

Presented energy data is almost perfect – along with the mandatory EPC class, also the energy breakdown by systems and net energy demand of the building is present in all but one of the case studies. In two cases, the primary energy indicators have not been established.

More significantly, there are no power indicators present in the current implementation of EPCs.

Proposal for next generation EPC indicators

The review of existing performance indicators shows that in the context of EPC development, the main problem is not the availability of indicators, but rather the **required assessment effort and qualification of the EPC issuer.** A plethora of voluntary schemes provide IEQ, energy performance, power and many other indicators, but generally the amount of necessary input data, time and competence of the assessor exceed the levels established under the current implementation of EPCs especially for existing buildings.

New buildings and major renovations

For the inclusion of new generation performance indicators, EPC-s should be based on dynamic simulations or hourly calculations for energy and room temperatures, otherwise the IEQ performance and power assessment would not be possible to conduct or additional simulations, basically with the extent of another EPC would be needed. However, in many countries EPC-s for new buildings are already simulated with commercial dynamic simulation tools or with simplified hourly tools, in which cases an involvement of new performance indicators could be seen as natural development step.

IEQ performance indicators:

- IEQ indicators are generally divided into 3-4 categories, such as thermal comfort, air quality, acoustics, visual comfort etc.
- These indicators are mainly applicable for new buildings – design documentation should include the IEQ criteria to which the building was designed along with relevant calculation or simulation results and measurements where necessary.
- Some of the data required for IEQ assessment is already present in EPCs of selected countries. Such data are ventilation rates, heating and cooling setpoints and cooling system data. Based on this existing data, general thermal comfort, air quality and noise categories can be easily determined while local thermal discomfort assessment would be typically needed to determine the category of the thermal comfort in the comprehensive and reliable fashion.
- Complete IEQ assessment requires typically some additional design tasks and competence of the designer/assessor. These additional design tasks should collect information about air distribution to assess air velocities, i.e. to conduct supply air devices jet calculation with relevant software in representative rooms that is very important for occupant comfort and wellbeing because draught complaints are one of the most common complaints in modern offices. In some cases, an additional room temperature and cooling load simulations may also be required, but in many cases, these are already included in the design of HVAC & energy.

Power indicators:

- Current EPCs consider only the energy expenditure of the building, while the power needs are completely neglected.
- Existing energy performance minimum requirements may lead to situation where buildings with similar energy expenditures, but different power profiles may cause highly different load for the corresponding distribution grids (electricity, district heating, district cooling) in a contrasting manner.
- Energy flexibility is an issue raised by Smart Readiness Indicator, but is currently not addressed in any EPC:

  - Responding to the grid demand and supply allows for (peak) power shifting, as well as using alternative means of energy production or storage, e.g. renewables if available on-site.
  - It is expected that some flexibility indicators could be developed under the Smart Readiness Indicator assessment, where grid flexibility and demand-response are evaluated parameters
- Starting point for flexibility indicators can be simple delivered and exported energy duration curves with hourly data by energy carrier which help to describe the effect of the building on distribution grids:
  - More flexibility indicators may be developed within the SRI framework
  - Simple and robust power indicator is to consider the ($5^{th}/95^{th}$ percentile of hourly peak power loads W/m2) of delivered and exported energy.

Ventilation system	Air flow rate supply/extract m³/s	System SFP kW/(m³/s)	Heat recovery type	Heat recovery temperature -	Exhaust air min. temp.[1] °C	Supply air temperature[2] °C
CAV-1	6.40/6.40	1.84*	Wheel	0.85*	-5	variable
CAV-2	0.80/0.80	1.47	Plate	0.74	2	variable

[1] heat recovery frost protection
[2] to be reported for systems with constant supply air temperature
* weighted average values for the all thermal wheels

Indoor Air Quality (IAQ) Category II

Energy use of technical systems	Electricity kWh/a	Heat kWh/a	Electricity kWh/(a m²)	Heat kWh/(a m²)
Heating system	-	-	-	-
Space heating	14318	-	4.0	-
Supply air heating	4942	-	1.4	-
DHW heating	8011	-	2.2	-
Auxiliary electricity	-	-	-	-
Ventilation system[1]	41460	-	11.5	-
Cooling system	4623	-	1.3	-
Auxiliary electricity	832	-	0.2	-
Lighting	48334	-	13.4	-
Appliances	68237	-	18.9	-
Sum (total energy use of technical systems)	190757	-	52.9	-

[1] supply air heating is accounted as a part of heating system

+ setpoint 25°C, Summer thermal comfort Category I

Cooling system	Cooling period average EER -	Fraction of total cooling energy[6], -	Auxiliary electricity kWh/(m² a)	Cooling curve[5] °C / °C	Cooling losses factor β_{je}, β_{jek}, β_{rs},-
Central cooling	3.6	1.00	0.2	15/18	0.0, 0.0, 0.0

[5] at design outdoor temperature, to be reported for hydronic systems
[6] 1.0 if no free cooling

Figure 8. An example of already available data in existing Estonian EPC which allows to conduct partial IEQ assessment of a new building – showing IAQ Category II and summer general thermal comfort Category I.

Existing buildings

Often very limited data is used (and in many cases available) when EPC-s for existing buildings are prepared. This can lead to a very crude estimation of the energy performance of the building, with the focus on keeping the issuing cost of the EPC low rather than providing an accurate actual energy use or energy performance. As rather a common practice, default values are often assumed, and available design documentation is not inspected and used in its full detail, and in some cases EPC-s may not be based or include measured energy data.

Detailed inspection and measurements to conduct more comprehensive assessment of energy and IEQ can be seen completely unrealistic in current schemes and practices for existing buildings, because:

- These procedures are usually very time-consuming, including data collection and measurements which are typically not available when compared to current implementation of measured energy used based EPCs in existing buildings. This increase in workhours more by factor 10 of the assessor will raises the cost of the EPC above feasible levels.

- EPC assessors do not necessarily possess the correct skillset or competence to accurately conduct such inspections and measurements.
- To be meaningful and accurate, one needs to conduct indoor climate surveys along with measurements – such a service is targeted to interested clients/owners, but not suitable for bulk EPCs.

While IEQ assessment in existing buildings is complicated, power indicators can be easily implemented in existing buildings as well, under the assumption that hourly metering data is available, or such smart meters would be installed.

Measured energy usage and energy cost data could be included to **increase the credibility** of EPC-s for end customers. Running energy expenditure and costs in Euros are a lot more tangible to the end user than tier/category-based indicators, which are generally perceived as relative performance indicators (e.g. category A is better than category B, but by how much is often misunderstood or disregarded). Total energy expenditure (electricity/heat/other) of the building is generally metered and available even if sub-metering data by systems is not.

U-CERT

User-Centred Energy Performance Assessment and Certification

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