eXTENDing the energy performance assessment and certification schemes via a mOdular approach

Comfort Asset Rating Procedure (CARP)

User-guide

Version 1.0

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This document describes Comfort Asset Rating Procedure (CARP)

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This version is applicable to new and existing residential buildings, schools and offices that are unoccupied.

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INTRODUCTION

Considering that people spend approximately 90% of their time indoors (residences, schools, offices, etc.), the indoor environment has a significant effect on people's, health, comfort and wellbeing. Thermal comfort, indoor air quality (IAQ), visual and acoustic comfort are the main determinants of the indoor environmental quality (IEQ) and constitute a vital driver in ensuring the quality of life and overall wellbeing of building occupants.

Although ensuring adequate levels of indoor air quality, thermal comfort, lighting and acoustics within buildings are among the most essential drivers for renovation, these aspects are rarely covered in Energy Performance Certificates (EPCs). In order not to compromise health and wellbeing of building occupants, renovation recommendations should go hand by hand with IEQ aspects. Energy efficiency and IEQ improvements are inter-related and can be both simultaneously achieved. EPCs are an integral part of the EPBD and are among the most important sources of information of the energy performance of the EU's building stock and have a great potential to further keep track of the overall IEQ.

The X-tendo project is developing a framework of 10 'next-generation EPC features' that aim at improving the usability, reliability and compliance of EPCs. One of these features is the 'Comfort indicator' that would allow the assessment of building comfort levels in relation to indoor environmental quality, through reliable and evidence-based inputs. Evidence based IEQ inputs can originate from measurements, outcomes of occupant surveys, computer simulations and/or checklists. The development of the evaluation framework for the comfort indicator is based on four cross-cutting criteria: economic feasibility, compliance with international standards, quality and reliability and user-friendliness and is inspired by reliable frameworks and methods such as Level(s), Aldren project: TAIL index, etc.

The structure of this user-guide is comprised by five main chapters, the first one giving an overview of the Comfort Asset Rating Procedure (CARP) tool, and other four, one for each indicator: (i) thermal comfort, (ii) indoor air quality, (iii) visual comfort and (iv) acoustics. Each chapter starts by giving an overview and general description of the indicator. The evaluation criteria for that specific indicator are then presented. Each indicator consists of specific criteria describing a narrower area of evaluation of the indicator and within each criterion several parameters are found.

Scope of the user-guide

This user-guide describes the evaluation procedure covering Asset[1] rating of residential (single-family house, multi-family house, apartments) and non-residential buildings (offices and schools) and is complemented by CARP assessment tool (beta version) for each of the three building types which the assessor should fill in based on the guidelines listed in the presented in this user-guide.

[1] Assessment for new and unoccupied buildings

This user-guide is developed to assist assessors to determine the comfort rating of a specific building using a representative space. It provides a list of the necessary requirements that need to be assessed in order to come up with a score for the evaluation of the four indicators (thermal comfort, indoor air quality, visual comfort and acoustic comfort) of the building that is under assessment. The assessment is done through visual inspection and filling in of specific checklists and it requires the assessor to walk through the building.

Using the checklists given in this user-guide for the assessment of the indicators the CARP tool gives outputs to rate the level of comfort in a building.

GENERAL PRINCIPLES

Comfort Asset Rating Procedure (CARP)

The comfort asset rating procedure of buildings is meant for buildings that are newly constructed (not occupied yet), renovated (not occupied for more than a year) or existing that are not occupied. Asset rating for comfort may be granted for buildings for transactional or business purposes, however, not limited for other uses. But its validity must be limited until they are occupied as the rating may not represent actual impacts of building use and operation accurately. It is recommended to get operational rating after a year of occupancy.

Assessment approach for asset rating

Considering the fact that the building is unoccupied during the CARP, therefore not allowing for a building occupant survey or measurements, the required information for assessing and evaluating the indoor environment will be captured through checklists that will be filled in by the assessor (expert issuing the EPC) during an on-site visit for the building's inspection. The assessment protocol for each parameter is described within every criterion.

Building types and representative spaces

A representative space in a building refers to the zone where the CARP assessment would be conducted and is valid for the calculation of the rating. All the criteria and parameters are applicable to the representative space given here. The representative spaces are as follows:

- **Residences:** For the case of dwellings, that space is the living room.
- **Schools:** For schools, it should be a classroom (<=50sqm or 20-25 student stations) that is frequently occupied at full occupancy round the year
- **Offices**: The representative office should be a typical office (<15sqm occupied by 1-2 persons) of that building, which is also frequently occupied for a large period of time at full occupancy round the year.

These criteria must not be violated else the rating calculated would not represent realistic conditions.

Scoring and Weighting

Four main indicators will be assessed within the CARP: (i) thermal comfort, (ii) indoor air quality, (iii) visual comfort, and (iv) acoustic comfort. To identify the overall IEQ level, all four indicators will be assessed independently based on multiple criteria. Under each criterion, certain parameters will be assessed to achieve a required score (see Figure 1). A combined rating is possible to assess for all the indicators in the beta version and it is also possible to rate individual indicators as shown in Figure 1. By default, an equal weightage for all indicators is assumed.

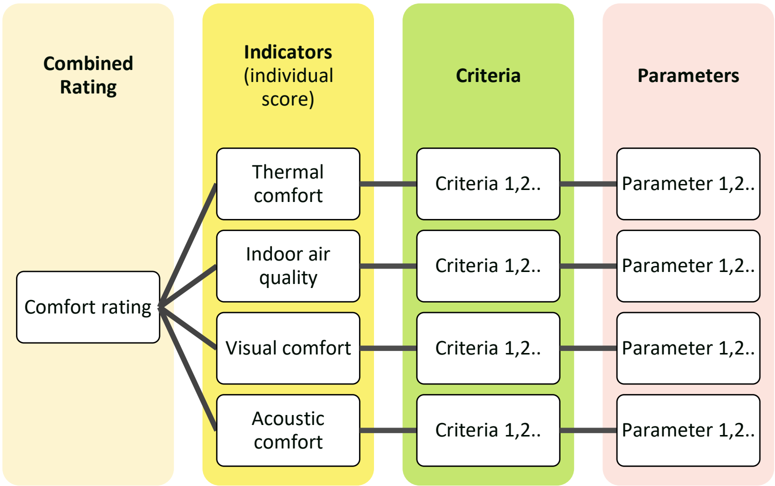

Figure 1: Structure of criteria and parameters for each indicator

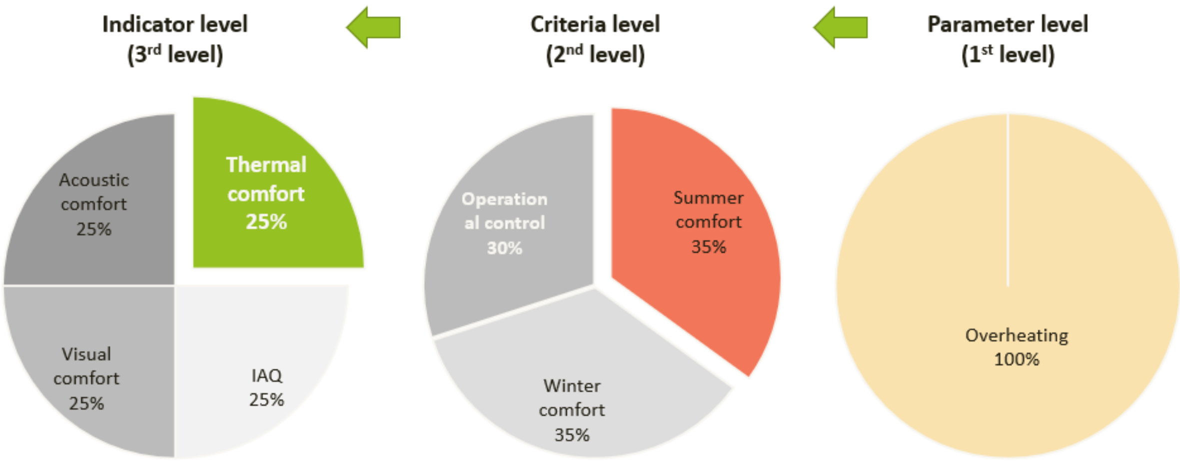

Figure 2: An example of two levels of weightage for the thermal comfort indicator

A description of the terms used and their explanation for the comfort feature assessment is given below (refer to Figure 1 and Figure 2):

a) **Indicators:** This refers to the four main components of the comfort feature. These components may be assigned equal or different relative weightage depending on the different aspects, e.g. region, type of buildings etc. Each indicator will be assessed based on several criteria.

b) **Criteria:** The criteria are the aspects that are assessed under each indicator. The list of criteria is prepared based on existing literature. Criteria are assigned different or similar relative weightages based on expert inputs in the tool.

c) **Parameters:** Certain parameters are used to assess each criterion based on the impact on comfort and health and well-being of the occupants. Relative weightage is assigned to each parameter based on expert inputs. Each parameter can obtain a score of 0 (worst) to 10 (best) which is assessed using a checklist. Individual scales for each parameter are developed for their scoring.

1 OVERVIEW OF THE COMFORT ASSET RATING PROCEDURE (CARP) TOOL

This guideline is accompanied by CARP beta versions for residential, office and school assessment. All the tabs in the CARP tool are highlighted in the guide in blue colour for quick referencing.

Information tab [INFO]

Legend for sheets

Comfort rating display

Individual Indicator Rating Display

Input data tabs

The 'INFO' tab includes a disclaimer of Comfort Asset Rating Procedure (CARP) and it briefly describes the legends of cells and tabs. In dark blue and yellow are the tabs in which results are displayed (no inputs data are required) whereas grey tabs are input data tabs, that the user needs to complete.

Legend for cells

0	*User-input cells*
0%	*Weights*
Cell	*Linked cells to calculation tabs*
0	*Calculated outputs*

Regarding the legends for cells, in light yellow are input cells that are found in the grey tabs which are required to be filled in by the assessor.

Turquoise cells are found in the comfort rating display that represent the individual indicator weights that should be filled in by the assessor (default weights are assumed to be 25% for all indicators). However, the sum of weights of all selected indicators must be always 100%.

The orange underlined text found in cells of the yellow tabs, link the parameters to the respective assessment tabs, whereas the orange cells found in the yellow tabs represent the calculated outputs and scores of each parameter, based on the data inserted in the grey tabs.

Comfort rating display tab [Comfort Rating]

This tab gives the overall rating of comfort in the assessed zone. After assigning weights in each of the indicators (thermal comfort, indoor air quality, visual comfort and acoustic comfort), based on the inputs provided in each of the corresponding tabs, this tab visualises the achieved rating of comfort (Figure 3).

Figure 3: Visualized combined single comfort rating

Yellow tabs

There are four yellow tabs, one for each indicator: thermal comfort, indoor air quality, visual comfort, acoustic comfort. Each of these tabs presents an overview of the individual rating per indicator (see Figure 4).

Score	3.3	Rating	Bad

Figure 4: Example individual score and rating of the indicator in yellow tabs

Also, a breakdown of the individual scores of the specific parameters is given within each criterion. These are mainly output tabs, however, they give the option to the user to define weights for each of the criteria if necessary.

The user can select the parameter (underlined in orange) that needs to be evaluated by clicking on it, and it will automatically guide him/her to the relevant tab that needs to be completed.

Grey tabs

The inputs required for the calculation of scoring of each individual indicator should be filled in the grey tabs. The table below indicates the grey input tabs that correspond to each of the yellow indicator tabs:

Thermal_Comfort (TC)	TC_Winter_comfort TC_Summer_comfort TC_Operational_control
Indoor_Air_Quality (IAQ)	IAQ_Contaminants IAQ_Ventilation IAQ_NatVentilation_tool
Visual_Comfort (VC)	VC_Illuminance VC_Operational control
Acoustic_Comfort (AC)	AC_Noise levels & Control

2 THERMAL COMFORT INDICATOR [Thermal_comfort (TC)]

Based on the definition of EN ISO 7730, 'thermal comfort is that condition of mind which expresses satisfaction with the thermal environment' [2]. The thermal environment is defined by several environmental parameters such as temperature (air, radiant), relative humidity, personal parameters such as clothing, level of activity, gender and age (parameters that affect metabolic rate) [3].

Criteria, parameter definitions and checklists

The methods to evaluate the thermal comfort indicator are defined under 3 main criteria (C1, C2, C3) and 7 indicators (P1.1, P2.1, P3.1, P3.2, P3.3, P3.4 and P3.5) as shown in Figure 5.

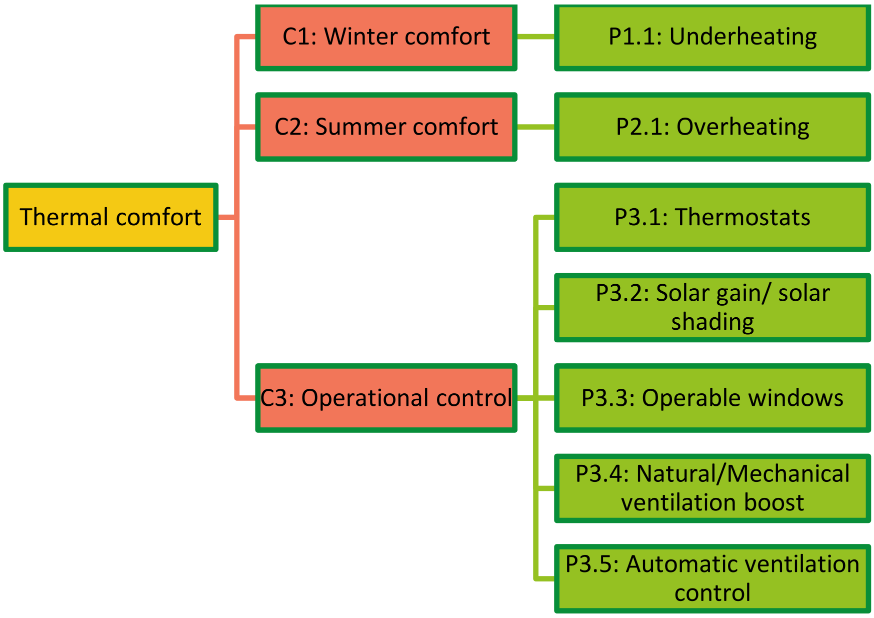

Figure 5: Criteria and parameters for thermal comfort indicator

CRITERION 1: Winter comfort [TC_Winter_comfort]

In CARP, winter comfort is assessed through the probability to insufficiently heat the space, it assesses the 'underheating' risk of buildings. The development of this methodology is based on the 'Overheating in new homes' tool of the Good Homes Alliance[2]. All answers are predefined and are given as a drop-down menu (light yellow cell) for each section.

Parameter 1.1 Underheating

There are several factors increasing the likelihood of underheating. These are listed below:

Geography:

Geographical location influences external temperature and solar radiation. For this reason, based on the national climatic conditions, the division of each country in climatic zones is taken into account. Schemes in the North are typically more at risk of under-heating. The user specifies the country and the climatic zone of the location of the building.

Site characteristics:

Neighbouring buildings and trees can reduce solar gains from exposed facades such as windows during winter. The assessor should choose 'yes' if at least half of the exposed facades are shaded.

[2] Home - Good Homes Alliance

Building/ system characteristics:

The building type ('Type of building'' cell) can affect the underheating risk as the more exposed facades (e.g. detached house) to the external environment can lead to a higher risk of heat loss.

The assessor should further specify if the walls, roof and floor are insulated as lack of insulation can cause unintended heat losses (Insulation -wall/roof/floor- cell). Considering that windows are primary components of heat loss of the building's fabric the assessor should further specify if the windows installed are single, double or triple ('Windows' cell).

Age of construction:

The age of the building is further required as it is a determinant of the degradation of the building envelope and its capacity to provide air-tightness ('Age of the building' cell).

Factors that reduce underheating probability are listed below:

Location:

The assessor should further specify the location of the building as outdoor temperatures are generally higher in urban areas (e.g. see urban heat island effect) than in rural areas.

Site characteristics:

Barriers to wind such as neighbouring trees and buildings are effective in reducing the overall heat loss of the buildings against the prominent wind direction.

Building/ system Characteristics:

Building characteristics related to the thermal mass of the building's construction can also affect the risk of underheating. Thermal mass stores heat during the day and release it at night. The assessor must specify if the building concerns a light, medium or heavy construction and should also answer on whether a central heating system is used.

Heat gain:

The orientation of windows can further affect the risk of underheating as windows with South, West and East orientations can increase the useful solar gains at different times within the day.

Based on the selections of the assessor for factors responsible and that reduce underheating, the scores are calculated and an indication of 'underheating probability' is given in cell C23.

CRITERION 2: Summer comfort [TC_summer_comfort]

In CARP, summer comfort is assessed through the probability overheating in buildings. As in the case of winter comfort all answers are predefined and are given in a drop-down menu (light yellow cell) for each section.

Parameter 2.1 Overheating

There are several factors that increase the likelihood of overheating. These are listed below:

Geography:

Geographical location influences external temperature and solar radiation. For this reason, based on the national climatic conditions, the division of each country in climatic zones is taken into account. Schemes in the South are typically more at risk of overheating. The input to these is automatically taken from [TC_winter_comfort] tab.

Site characteristics:

The way building users open, and close windows is affected by either internal (indoor or outdoor odours, high temperatures etc.) or external factors. In this section, based on the building site's characteristics e.g. outdoor air pollution, noise, security or privacy issues, the assessor should specify whether he/she anticipates that the building users will keep their windows closed during the day and night due to outdoor factors.

Building/ system characteristics:

The building type ('Type of building'' cell) can affect the overheating risk as the more enclosed buildings (e.g. mid- terrace house) can lead to a higher risk of overheating.

Solar heat gain and ventilation:

In the 'Estimated average glazing ratio' option the assessor should calculate the window to wall ratio of windows in the East, West and South facades, and select from predefined percentages.

Ventilation aspect:

Based on the location of windows within the building, the assessor should be able to identify the ventilation strategy that will potentially take place (single-sided, cross and stack ventilation).

Factors that minimise the risk of underheating. These are listed below:

Geography/ location:

Water bodies such as sea, rivers, lakes, ponds or large fountains can cause cooling through evaporation (evaporative cooling). The assessor should specify with a 'yes' or 'no', the building's proximity to green spaces and water bodies. At least 50% area in the surroundings within a 100m radius would be effective in reducing overheating.

Site characteristics:

Horizontal and vertical surfaces that are either covered with cool materials (paints, pavements etc.) or tinted with lighted colors and are in the proximity of the building, will have a strong effect in the building's microclimate. The assessor should characterize the majority of the surrounding surfaces ('Immediate surroundings surfaces' cell) and should further choose whether shading from neighboring trees and buildings can reduce the solar gains of exposed building's surfaces in East, West and South orientations.

Building characteristics:

The assessor should characterize the thermal mass of the building (light, medium, heavy) as a high thermal mass during summer months work as cooler by absorbing heat during the day and releasing it slowly during the night ('Exposed thermal mass category' cell).

Air conditioners, ceiling or portable fans, are effective ways to cool down the building and reduce discomfort during summer ('Cooling devices (AC, fans etc.)' cell).

Solar heat gain and ventilation:

Shading of exposed facades such as external louvers, awnings etc. can offer an effective mean of reducing solar gains ('External shading' cell). The assessor should specify if the exposed areas (windows) are fully or partially shaded.

Considering that windows with larger opening and effective opening areas can help in heat dissipation. The assessor should select the percentage of opening area for the 'Ventilation aspect' defined in the previous section.

CRITERION 3: Operational control [TC_Operational_control]

A criterion for occupant control is also included in the thermal comfort assessment. It covers the essential aspect of operational control of the buildings in the assessment that has been found to be effective in maintaining the satisfactory level of indoor comfort. Occupant behaviour is challenging to measure and predict. Evaluation of operational control would be done based on certain parameters assessed via checklists.

Parameter 3.1: Thermostats

Thermostat exists in different forms across different building spaces. Therefore, the developed checklist in Table 1 is based on the flexibility and convenience of adjusting the thermostats. This parameter can be used for residential, office and school buildings.

Table 1: Checklist for thermostats

Thermostats	No thermostat	Central thermostat (non-programmable)	Individual room control (non-programmable)	Central thermostat (programmable)	Individual room control (programmable)	Wi-Fi thermostat	Smart thermostat (self-learning)

Parameter 3.2: Solar shading

There are multiple types of shading or solar control devices in the building spaces. The checklist provided in Table 2 is based on the effectiveness in solar control devices in controlling the solar gain inside the space. This parameter can be used for residential, office and school buildings.

Table 2: Checklist for solar gain

Solar shading	No shading/No direct solar gain	Curtains (manual)	Curtains (automatic)	Internal blinds (manual)	Internal blinds (automatic)	External blinds (manual)/ fixed external shading	External blinds (automatic)

Parameter 3.3 Operable windows

One of the major aspects of thermal regulation of building aspect is the occupant control and adjustment availability of windows in the building spaces. In Table 3, the checklist is prepared based on the effective open area that windows offer to the occupant for ventilation. This parameter can be used for residential, office and school buildings.

Table 3: Checklist of operable control of windows

Operable windows	No windows	Fixed windows	Top hung/ Double hung windows	Sliding windows	Pivoted windows	Casement/tilt and turn windows

Parameter 3.4: Natural/Mechanical ventilation boost

Especially during summers, the thermal comfort conditions are driven by natural ventilation possibilities inside the buildings. Therefore, in Table 4, a checklist is provided in the order to assess the effectiveness to boost the natural ventilation in the building spaces. This parameter can be used for residential, office and school buildings.

Table 4: Checklist for natural ventilation boost

Natural ventilation boost	No natural ventilation	Trickle ventilation	One sided window ventilation	Cross-ventilation (windows on opposite sides)	Passive stack ventilation (ventilation from roof and windows)

Buildings with mechanical ventilation are more comfortable if they have options to regulate the mechanical ventilation in conditions when the occupancy is high or there is too much damp air inside. Table 5 provides a checklist for the assessment of the options available to boost the mechanical ventilation. This parameter can be used for residential, office and school buildings.

Table 5: Checklist of mechanical ventilation boost

Mechanical ventilation boost	Mechanical ventilation without boost	Ceiling/portable fans	High occupancy fresh air boost	Warm air/damp air boost present	Occupancy and warm/damp air boost present

Parameter 3.5: Automatic ventilation control

Buildings that have automatic ventilation control automatically adjust to the needs of occupants and have found to be effective in maintaining indoor thermal conditions inside the space. Table 6, provides a checklist assessing the presence of automatic ventilation systems. This parameter can be used for residential, office and school buildings.

Table 6: Checklist for automatic ventilation control

Automatic ventilation control	No	Yes	
Automatic windows and ventilators	Operator controlled	programmable	Sensor controlled
Automatic ventilation control	without demand control	with demand control	

3 INDOOR AIR QUALITY INDICATOR [Indoor_Air_Quality (IAQ)]

Acceptable indoor air quality refers to the indoor air that hasn't got harmful concentrations of contaminants with which most of the exposed building occupants are satisfied [13][3]. Source of contaminants in residential buildings are building occupants (CO_2 concentrations released from human respiration) activities such as cooking or smoking, indoor combustion sources, emissions from furnishings, cleaning products, construction materials [14]. The most common contaminants are carbon dioxide, carbon monoxide, particulate matter and volatile organic compounds (VOCs). Ventilation plays a critical role in removing contaminants from buildings and is crucial to ensure thermal comfort and good indoor air quality. However, introduction adequate levels of ventilation without addressing or removing indoor sources of air pollution (e.g. wood stoves, fireplaces etc.) may lead to a limited improvement in indoor air quality.

Criteria, parameter definitions and checklists

There are many criteria that are measured to assess the indoor air quality of buildings. European countries have addressed the importance of indoor air quality by including legislation on indoor air contaminants [15]. The indoor air quality is assessed through a combination of 4 criteria (C1, C2 and C3) and 6 parameters (P1.1, P1.2, P2.1, P2.2, P3.1 and P3.2) shown in Figure 6.

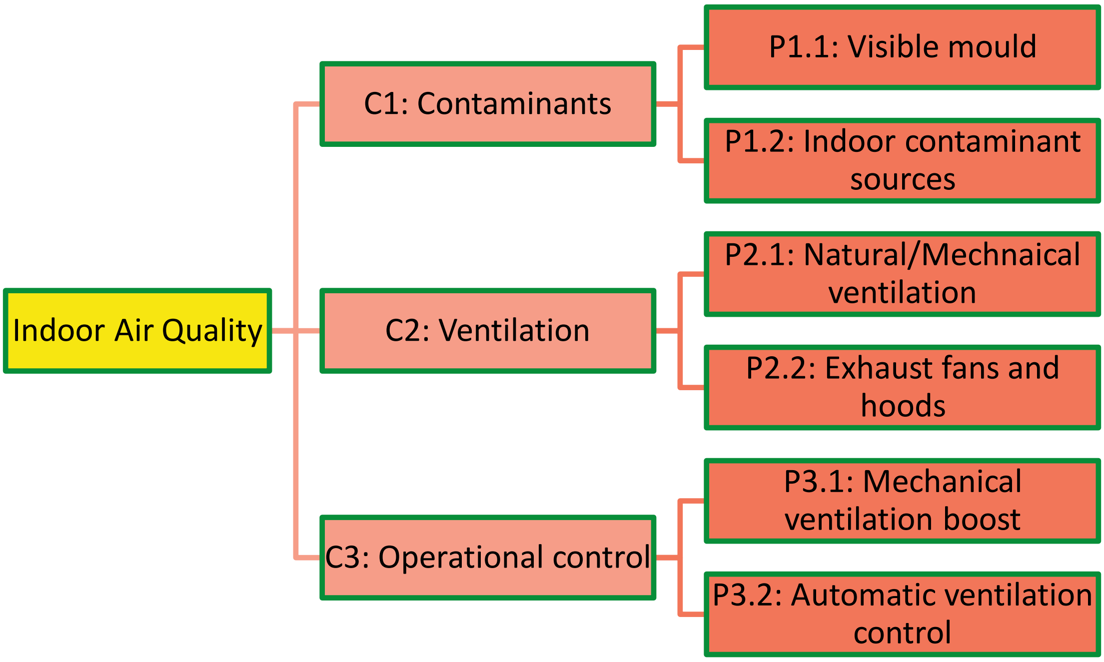

Figure 6: Criteria and parameters for Indoor Air Quality indicator

CRITERION 1: Contaminants [IAQ_Contaminants]

Parameter 1.1: Visible Mould

High humidity or moisture content in the indoor air is a primary cause for the growth of mould inside the buildings. It gives rise to microbial pollution that involves hundreds of species of bacteria and fungi including mould that grow indoors when sufficient moisture is available [21]. Indoor moisture is more likely to occur in houses that are overcrowded, lack appropriate heating, poor ventilation, and lack of insulation. Exposure to microbial contaminants is clinically associated with respiratory symptoms, allergies, asthma and immunological reactions [22]. Mould have been found more common in less-affluent homes living under fuel poverty. Mould also occur in school buildings, day-care centres, offices and other buildings [21]. The areas affected inside a building could be easily detected by observing the patches on walls, floor or ceilings having visible mould growth.

Based on Level(s) framework [23] in Table 7, the checklist for mould visible mould assessment is provided for residential, office and school buildings.

Table 7: Checklist for mould inspection

Mould	Larger areas with visible mould (>=2500cm^2)	Damage with moderate area visible mould (<2500cm^2)	Moderate area visible mould (<2500cm^2)	Damage with minor area visible mould (<400cm^2)	Minor area visible mould (<400cm^2)	No visible mould

Parameter 1.2: Indoor contaminant sources

In residential buildings, some indoor sources that increase the contaminant levels are cooktops, fireplaces, portable heater etc. A checklist is provided in Table 8, to assess the presence of these sources and include in evaluation of the criterion.

Table 8: Checklist for indoor contaminant sources (residential)

Cooking stove	Solid fuel	Gas	Modular cook top (gas and electric)	Electrical coil cool top	Electric smooth cook top	Induction
Heating stove	Solid fuel	Gas	Electric			
Unvented stove	Yes	No				
Fireplace (operational)	Yes	No				
Portable heater	Yes	No				

Refer Annex I for checklists for office and school buildings.

CRITERION 2: Ventilation [IAQ_Ventilation]

Table 9 from EN 16798-1 provides a direct corelation of required air flow rates with measured CO_2 concentration in building spaces. The level of CO_2 concentration is used as an indicator of measuring the ventilation rate for occupants [16]. Therefore, based on the assessment conducted in Criterion 1: Contaminants (Parameter 1.1) the reference in Table 9 is used for corresponding airflow rate for evaluation of Parameter 2.1 and 2.2. Due to health reasons the total minimum airflow rate during occupancy expressed as l/s per person should never be below 4 l/s per person (WHO).

Table 9: Corresponding air flow rates to CO_2 concentration

Category *(Residential/School/Office)*	**Corresponding CO_2 concentration above outdoors in PPM for non-adapted persons***	**Corresponding air flow rate# (l/s per person) - A_f**	**Corresponding ventilation rate (ach)**
I	≤550	≥10	$$V_r = \frac{A_f \times N \times 3.6}{V}$$
II	≤800	≥7	
III	≤1350	≥4	
IV	≥1350	≤4	
NOTE: #when major contribution to emissions is by people			*V*= Volume of the room A_f= Air flow rate *N*= No. of persons

Parameter 2.1: Natural/Mechanical ventilation

Natural ventilation

To calculate the rate of natural ventilation link provided for tab [IAQ_NatVentilation_tool] should be used. Natural ventilation rates will be estimated in this tab after specifying inputs related to climate conditions, general building characteristics and the number, dimensions and type of windows, based on a tool available from the Passive House Institute[3]. Specifically, the indoor to outdoor temperature difference and the wind speed are required. The assessor should also define the room volume (living room for residential) and the average number of people that would occupy the room at any given time.

Window group 1 and Window group 2 should be used if there is cross-ventilation on opposite sides.

The number of windows, clear width, height as well as the tilt and its opening should be specified.

The assessor should only fill in the cells in light yellow, the rest of the cells are results of calculations that are automatically filled in.

Mechanical ventilation

For mechanically ventilated residences, the room volume, the average number of people typically occupying the room and the average mechanical ventilation rate of the room should be specified.

[3] Passivhaus Institut

Parameter 2.2: Forced ventilation

This parameter is assessed only for residential buildings. Residential ventilation needs differ for different rooms. Kitchen/ bathrooms must be equipped with ventilation boost to reduce the levels of indoor air pollution created due to sources such as cooking, bathing products etc. The minimum exhaust air flow for toilets, bathrooms and kitchens should be 35, 50 and 70 m^3/h, according to category II of EN16798-1. However, for assessment of this parameter only the presence of exhaust is taken into account based on the checklist given in Table 10.

Table 10: Checklist for exhausts (only residential)

Kitchen hood/exhaust	No	Yes	Manual switch	Automatic with manual override
Bathroom exhaust	No	Yes	Manual switch	Automatic with manual override
Toilet exhaust	No	Yes		
Utility exhaust	No	Yes		

CRITERION 3: Operational control

No inputs are required for this criterion. Inputs are automatically drawn from the themal comfort indicator.

4 VISUAL COMFORT INDICATOR [Visual_Comfort (VC)]

Adequate lighting in buildings should create a pleasant appearance of the space, allow building occupants move safely and conduct their visual tasks effectively and accurately [29][30]. Excessive brightness or glare from either solar or electric sources can be disruptive; therefore, appropriate lighting levels can be ensured by natural or/and artificial lighting.

Recent studies have shown that lighting affects mood and circadian rhythms (sleep-wake cycle) and can improve our performance and wellbeing. Natural light significantly influences the visual comfort, while well-being and motivation of people can be affected without sufficient exposure to natural lighting. Daylight exposure through windows has a significant positive effect on sleep quality as well. However, increased use of glazing can increase the heat losses of a building, therefore, a correct balance between thermal losses and daylight levels is needed.

Criteria, parameter definitions and checklists

Three main criteria of visual comfort have been identified (i) Illuminance levels, and (ii) operational control (see Figure 7). Each of the criteria includes parameters that can be assessed through checklists.

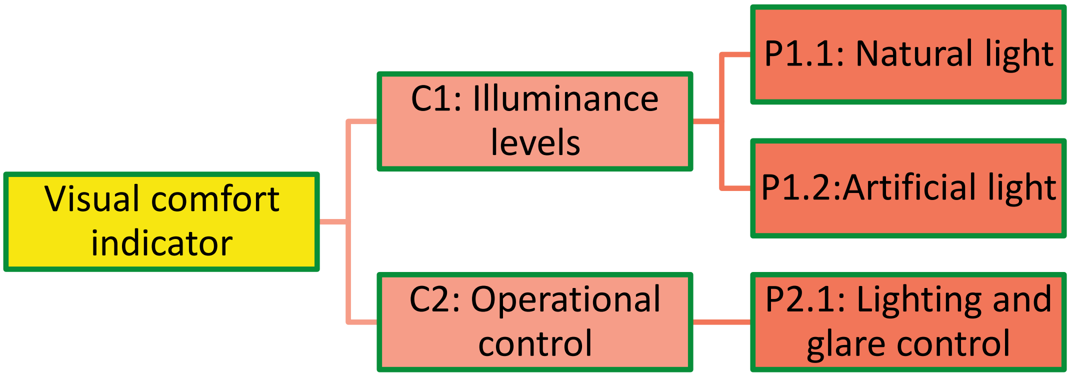

Figure 7:Structure of criteria and parameters within the visual comfort indicator

CRITERION 1: Illuminance levels [VC_Illuminance]

Illuminance is one of the main parameters that determine the luminous environment and represents the total amount of light delivered on a surface by either natural daylight or electrical fitting. Daylighting and artificial lighting must operate interactively. Exposure to adequate levels of natural light strengthens the alignment of our circadian rhythms and reduces dependence on electricity for artificial lighting [39].

Parameter 1.1: Natural light

To evaluate the levels of natural light for CARP, the areas of windows per orientation within the representative space (e.g. living room for residences, single office or classroom) should be measured and filled in the Table 11 for parameter 1.1 given in tab: [VC_Illuminance]. The effective floor area[4] of the room should be also inserted at the top of the same tab. The window to floor area ratio (WFR) is then estimated (in cell K18) and based on the categorization given in Table 12 'Category for residential buildings/offices/schools', a score for natural light is then estimated (cell L18).

[4] Effective floor area is measured by removing the area of an irregular part from the total area of the room

Table 11: Table to enter window areas per orientation

ID	**East (m^2)**	**West (m^2)**	**North (m^2)**	**South (m^2)**
Window 1				
Window 2				
Window 3				
Window 4				
Window 5				
Window 6				
Window 7				
Window 8				
Window 9				
Window 10				
Total area				

Table 12: Window to floor area ratio (WFR) classification for South, West and East facing facades (for all building types) [42]

Categories	**Window to Floor Area Ratio (WFR)** ***Residential***	**Window to Floor Area Ratio (WFR)** ***Office and School***
I	>20 and ≤30%*	>35 and ≤50%*
II	>10 and ≤20%	>20 and ≤35%
III	≥5 and ≤10%	≥10 and ≤20%
IV	<5%	<10%
Note: To avoid over lit spaces in buildings a maximum value is defined.		

Parameter 1.2: Artificial light

Electric lighting should provide appropriate lighting level for all tasks performed in a space without causing glare or resulting to large variation between different surfaces of the space[43]. The artificial light parameter refers to the evaluation of the levels of artificial lighting within the space. Based on the classification given in Table 13 the scoring for artificial lighting levels will be conducted.

Table 13: Illuminance classification (adapted from [36])

Category	**Residences** (Lux)	**Schools** (Lux)	**Offices** (Lux)
I	250 ≤ Illuminance < 500	500 ≤ Illuminance < 750	750 ≤ Illuminance < 1000
II	150 ≤ Illuminance <250	300 ≤ Illuminance < 500	500 ≤ Illuminance < 750
III	50 ≤ Illuminance < 150	no criteria	300 ≤ Illuminance < 500
IV	Illuminance < 50	Illuminance<300	Illuminance < 300

The availability of artificial lighting will be assessed based on the installed electric lighting systems. In case that information is not part of the EPC databases, the assessor should log the number of installed incandescent light bulbs and fluorescent/LED lamps (cells in light yellow under table in parameter 1.2 of tab [VC_Illuminance]) and calculate the total lumens installed per room based on given Wattage (Table 14). Illuminance is given by the total lumens per unit area.

Table 14: Checklist for the assessment of artificial lighting illuminance (to be completed by assessor) [44]

Incandescent light bulbs installed		**Fluorescent/LED lamps**		**Lumens (lm)**	**Total Lumens (lm)**
Count	**Watt**	**Count**	**Watt**		
	25		6.23	375	
	40		10	600	
	60		15	900	
	75		18.75	1125	
	100		25	1500	
	150		37.5	2250	
	200		50	3000	

CRITERION 2: Operational control [VC_Operational_control]

Parameter 2.1: Lighting and glare control

Lighting control refers to the control of brightness and lighting positions in a room through light adjustment or switching on/off.

Information on lighting and glare control can be collected via checklists for residential/office and school buildings where the assessor should choose of the following selections.

Table 15: Checklist for shading (for all building types)

Availability of shading for lighting or glare control (for south facing windows)

	None	Adjustable work or activity area	interior window shading e.g. shades, curtains, internal blinds)	Tinted/reflective/fritted glazing	external shading systems (e.g. external blinds, awning)	Variable opacity glazing e.g. electrochromic glass etc.
Availability of devices to control artificial lighting and glare						
	None		Adjustable work or activity area	Task lighting	Adjustable lighting controls	Filter and diffusers

5 ACOUSTIC COMFORT INDICATOR [Acoustic_Comfort (AC)]

Acoustic comfort comprises the ability to protect building occupants from noise and provide a suitable acoustic environment to fulfil the purposes that the building is designed for [45]. Noise can cause annoyance, hearing damage or interference to speech intelligibility depending on its levels [31]. The acoustic quality of the built environment can be affected by different factors such as the buildings' location, the city design, the building design the construction type and the material of construction elements. Road traffic, aircrafts, construction sites can generate increased levels of external noise, while background noise from HVAC systems or even noise from the neighbours can be disruptive [46]. The acoustic environment must be designed to avoid these harmful effects and the criteria used to specify an acceptable acoustic environment are expressed in sound levels decibels (dB), noise rating (NR) or noise criteria (NC) [47]. The World Health Organization (WHO) recommends a background noise level lower than 45 dB(A).

Criteria and parameter definitions and checklists

To evaluate the acoustic environment, we have identified 2 main criteria, those of acoustic levels and operational control. Within acoustic levels there are the two parameters of indoor and outdoor noise and within operational control there is the parameter of window adjustment and sound absorbing materials.

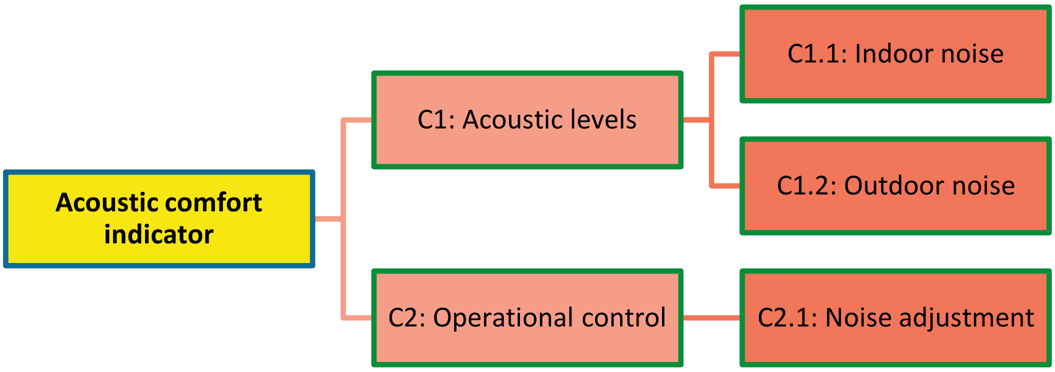

Figure 8: Criteria and parameters for acoustic comfort indicator

CRITERION 1: Noise levels [AC_Noise levels & Control]

Parameter 1.1: Indoor noise

The main sources of indoor noise are home appliances, ventilation systems and technical installations and neighbours. Noise levels should be further examined based on additional information related e.g. to sound absorbing materials, collected through checklists shown in Table 17 ([AC_Noise levels & control] tab, table linked to Parameter 1.1). Examples of sound absorbing materials are summarised in Table 16.

Table 16: Examples of sound absorbing materials for walls, floors and ceiling [36]

Walls	Rock-wool and Glass-wool- type sound absorbing materials etc.
Floors	Carpet, tatami matting etc.
Ceiling:	Rockwool glass-wool, gypsum board type sound absorbent ceiling material etc.

Table 17: Indoor noise checklist (for all building types)

Sound absorbing materials used in walls, floor, roof			
Not used	Used in 1 of the areas	Used in 2 of the areas	Used in all areas
Noise producing appliances in the room (e.g. refrigerator, freezer etc.)			
No	Yes		

Is the room completely separated by doors, partitions etc. from other spaces?	
No	Yes
Access to HVAC systems to adjust airflows	
No	Yes
Does the HVAC system have an adequate silencing system installed against noise from fans, ducts, machine vibrations etc.?	
No	Yes

Parameter 1.2: Outdoor noise

Loud or repetitive outdoor noise can be risk factor for health outcomes, especially in urban areas. Individuals exposed to traffic noise have higher risk for diabetes, heart attack, and people exposed to aircraft and road traffic higher risk for hypertension. Comfort and well-being can be significantly improved when preventing excessive exterior noise [41]. Main sources of outdoor noise include road, rail, air traffic industries and construction work [49].

The noise sources that are in vicinity to the building should be identified and the building construction's characteristics will facilitate the evaluation of the outdoor noise. That information will be collected through checklists filled in by the assessor.

Table 18: Checklist for outdoor noise levels (for all building types)

Please describe the noise sources that are in vicinity					
Airport	Railway/ construction-demolition works/industrial activity	Heavy traffic (main streets, highways)	Urban area (low traffic)	Quiet rural area	
Please describe the building's construction (in relation to noise)					
Single glazing, no thermal insulation	Single glazing, thermal insulation	Single glazing, thermal insulation, sound-proofing insulation	Double glazing, no thermal insulation	Double glazing, thermal insulation	Double glazing, thermal and sound proofing insulation

CRITERION 2: Operational control [AC_Noise levels & Control]

Parameter 2.1: Noise adjustment

Occupant control of noise is of the main ways of defence against excessive noise exposure. This criterion assesses the extent to which building occupants are given this opportunity through either access to openable windows towards a silent side or flexibility to close internal doors. The options for selection are given in Table 19.

Table 19: Checklist for noise adjustment (all building types)

Openable windows towards silent side	
Yes	No
Flexibility to close internal doors	
Yes	No

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ANNEX I

Indoor Air Quality [Indoor_Air_Quality (IAQ)]

CRITERION 1: Contaminants [IAQ_Contaminants]

Parameter 1.2: [IAQ_Contaminants]

Table 20: Checklist for indoor contaminant sources (office)

Kitchenette in office	**Yes**	**No**
Low VOC paint used	**Yes**	**No**
Printer/copying machine	**Yes**	**No**
New carpets/ upholstery/ furniture	**Yes**	**No**
Cleaning products used	**Yes**	**No**

Table 21: Checklist for indoor contaminant sources (school)

Kitchenette in classroom	**Yes**	**No**
Low VOC paint used	**Yes**	**No**
Printer/copying machine	**Yes**	**No**
Low VOC carpet/ furniture/ upholstery	**Yes**	**No**
Cleaning products used	**Yes**	**No**