TIMEPAC

Towards Innovative Methods for Energy Performance Assessment and Certification of Buildings

TIMEPAC GUIDELINE

Enhancing Energy Performance Certification:

Guidelines for data analysis

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TIMEPAC aims to modernize building certification practices according to the latest Energy Performance of Buildings Directive (EPBD) review. The guidelines series provides recommendations for stakeholders involved in building certification to improve their working procedures to meet the objectives of the Directive.

These guidelines are aimed to enhance EPCs by integrating operational data and develop new key performance indicators (KPIs) based on comprehensive analyses of selected buildings. These analyses include standard and tailored energy performance assessments, calibration against monitored data, economic evaluation of energy efficiency measures, indoor environmental quality evaluation, and the impact of building automation and control systems. Data may be sourced from actual measurements, conventional standards, or comparable buildings, depending on availability and analysis required.

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TIMEPAC “Guidelines for data analysis”

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The enhancement of the EPC schema through the integration of operational data is approached by proposing new Key Performance Indicators (KPIs). These KPIs were selected based on different analyses conducted during the TIMEPAC project, aiming to find a balance between ease of implementation and added informational value in the EPC. Specifically, the required analyses include:

1. Standard Energy Performance Assessment (SEPA),
2. Tailored Energy Performance Assessment (TEPA),
3. Calibration of TEPA against monitored data (CAL),
4. Economic evaluation of energy efficiency measures (ECM),
5. Indoor Environmental Quality evaluation (IEQ),
6. Building Automation and Control System impact assessment (BACS).

All the analyses to be performed require the creation of a building energy model (BEM).

2. Standard vs. tailored energy performance assessment

The standard and tailored energy performance (*EP*) assessment begins with creating an energy model of the building to be analysed. The input data required for this building energy model are listed and described in the "Guidelines for Data Collection" provided in the TIMEPAC Guidelines.

The distinction between standard and tailored energy performance assessments lies in defining user behaviour and climate conditions. These should follow the criteria presented in the following table.

Standard vs. tailored EP assessment		
EP assessment	User	Climate
Tailored	Real (actual)	Standard
Standard	Standard	Standard

3. Calibration against monitored data

Requirements for building energy model calibration:

1. Monitored data (monthly/seasonal energy consumptions, hourly indoor temperatures, or hourly energy consumptions)
2. Weather data (real data for the calibration period)

Building energy model calibration involves fine-tuning the simulation inputs so that observed energy consumptions (or environmental parameters) closely align with those predicted by the simulation program.

The proposed methodology is a manual calibration procedure, involving iterative adjustments to model parameters affected by uncertainties. These adjustments can be made individually or in combination. Figure 1 illustrates the general workflow for calibrating the building energy model.

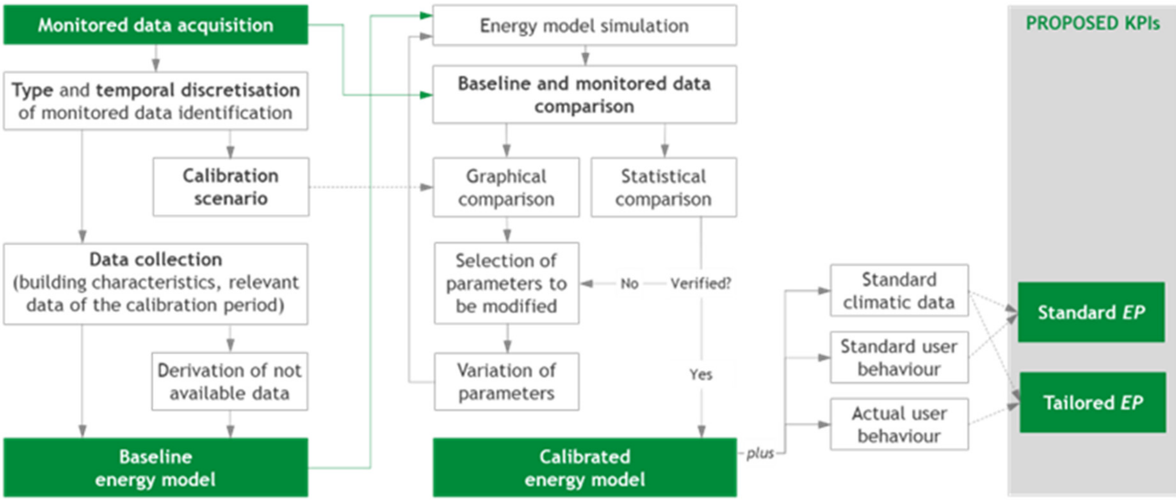

Figure 1. Building energy model calibration workflow.

In preparation for applying the manual calibration procedure, different preliminary phases are required. These steps include:

1. Analysis of the available monitored data.

   Begin by analysing the available monitored data to identify their type and temporal resolution. Common monitored data include indoor temperatures and energy consumptions (for different energy carriers), which may be recorded at daily, weekly, monthly, seasonal, or hourly intervals.

2. Identification of the calibration scenario.

   Based on the type and temporal resolution of the monitored data, three calibration scenarios can be identified:

   - Scenario 1: Applicable for daily, weekly, monthly, or seasonal monitored energy consumption data.
   - Scenario 2A, Applicable for hourly monitored temperatures.
   - Scenario 2B, Applicable for hourly monitored energy consumption data.

   The table below presents the applicability of each scenario. Detailed procedures for conducting building energy model calibration according to Scenario 1, 2A, and 2B are provided in Sections 3.1, 3.2, and 3.3, respectively.

Calibration scenarios		
Temporal discretisation	Energy consumptions	Hourly temperatures
Hourly	Scenario 2B	Scenario 2A
Daily	Scenario 1	-
Weekly	Scenario 1	-
Monthly	Scenario 1	-
Seasonal	Scenario 1	-

3. Selection of the calibration period.

   The calibration period is derived from an analysis of the monitored data. This step is essential to identify and determine specific input data for the building energy model, such as climatic data

4. Creation of the building energy model.

   The final preliminary step involves creating the base building energy model. For this, various real input data are required, including:

   - General information about the building,
   - Geographical and climatic data (climatic data should correspond to the calibration period, and align with the calculation timestep),
   - Geometrical characteristics, and
   - Monitored data.

If real data for the above input parameters are unavailable, model calibration cannot be performed.

However, in the absence of real data, the other necessary input data for creating the building energy model may be derived from similar buildings or standard values may be assumed. This applies to the following input data:

- Thermal properties of building components,
- Characteristics of technical building systems, and
- Operating conditions (e.g., user behaviour, set-point temperatures, etc.).

To achieve the most accurate results, using real data is strongly recommended.

3.1 Scenario 1: daily/weekly/monthly/seasonal energy consumptions

After the preliminary phases presented, the calibration scenario 1 (for daily, weekly, monthly, or seasonal energy consumptions) consists in the following steps:

1. Energy simulation for the base model and extraction of the outputs (energy consumptions for the available energy carriers),
2. Comparison between monitored and simulated outputs,
3. Verification of compliance with statistical indexes,
4. (If statistical indexes are not verified), modification of the base energy model and repetition of steps from 1 to 4, until statistical indexes are verified.

The energy simulation outputs required for the model calibration are the energy consumption values for the selected calibration period.

Step 1: Energy simulation for the base model and extraction of outputs

The base model must be simulated using actual external climatic data. Once the simulation is complete, the outputs, including energy consumption for scenario 1, should be extracted (or processed) with the same temporal resolution as the monitored data.

For example, if monitored energy consumption data are available in a specific format, as shown in Figure 2, the simulated energy consumption values must be aligned to the same temporal resolution. Therefore, when the monitored data have a variable temporal resolution, the base model should be simulated with an hourly (or, at a minimum, daily) calculation timestep. The hourly simulated energy consumption data should then be aggregated to match the specific time intervals of the monitored data.

From	To	Number of days [d]	Monitored energy consumption [kWh]
10/14/2019	10/21/2019	7	399
10/21/2019	10/30/2019	9	807
10/30/2019	11/11/2019	12	2199
11/11/2019	11/18/2019	7	2184
11/18/2019	11/25/2019	7	1917
11/25/2019	12/2/2019	7	1855
12/2/2019	12/9/2019	7	2439
12/9/2019	12/16/2019	7	2565
12/16/2019	12/23/2019	7	2025
12/23/2019	1/7/2020	15	5681
1/7/2020	1/13/2020	6	2280
1/13/2020	1/27/2020	14	5551
1/27/2020	2/3/2020	7	2254
2/3/2020	2/17/2020	14	4426
2/17/2020	3/2/2020	14	4013
3/2/2020	3/9/2020	7	2175
3/9/2020	3/30/2020	21	4905
3/30/2020	4/6/2020	7	1696
4/6/2020	4/14/2020	8	973
4/14/2020	4/20/2020	6	640
4/20/2020	4/27/2020	7	804
4/27/2020	5/4/2020	7	712
5/4/2020	5/12/2020	8	303

Figure 2. Example of output extraction.

Step 2: Comparison between monitored and simulated outputs

The comparison between monitored and simulated outputs can be done by means of either statistical or graphical comparisons. It is suggested to perform both comparisons. Figure 3 presents an example of this procedure applied using by an Excel file. The inputs required in this example are:

- Beginning and end of the temporal intervals of the monitored data,
- Daily average outdoor air temperature for the temporal intervals of the monitored data,
- Measured energy consumption values,
- Simulated energy uses.

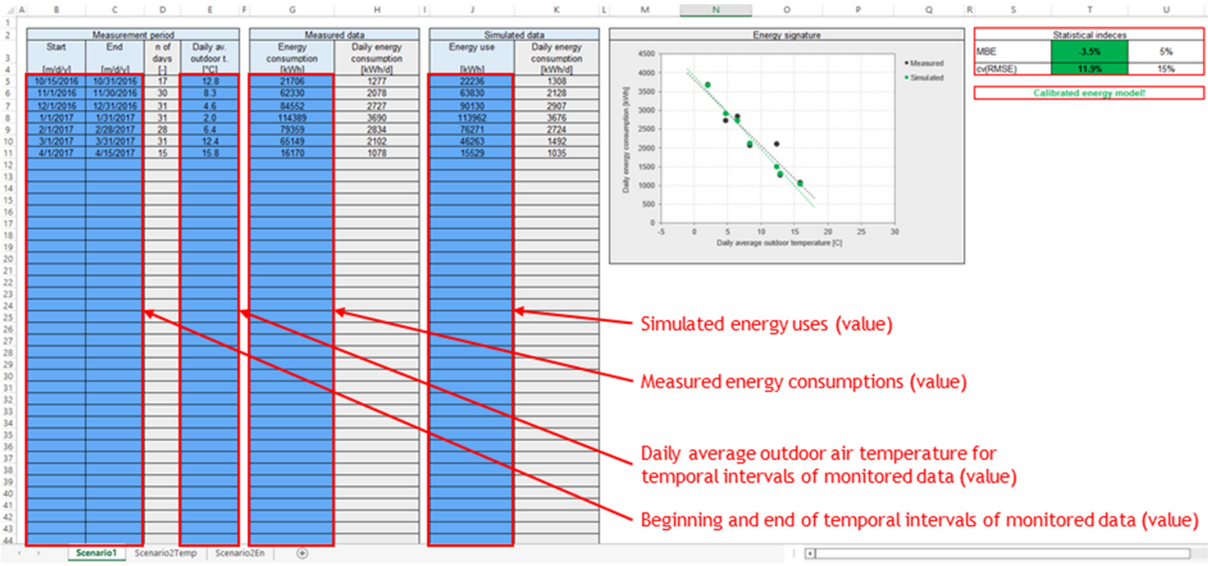

Figure 3. Inputs for statistical and graphical comparison for calibration scenario 1.

As for the beginning and end of the temporal intervals of the monitored data, these must be inserted in a month/day/year or day/month/year format in order to derive the number of days of each temporal interval. The daily average outdoor temperature is mandatory for the graphical comparison. This should be calculated for each specific temporal intervals of the monitored data. The simulated energy consumption must respect the temporal discretisation and temporal intervals of the monitored data, as specified above.

Step 3: Verification of compliance with statistical indexes

The verification of statistical indexes can be automatically calculated using MS Excel files, as presented in Figure 4. Two statistical indexes were considered for calibration scenario 1, namely:

- Mean Bias Error (*MBE*), for which the limit value is assumed equal to ±5%, and,
- Coefficient of variation of the root-mean-square error [*cv(RMSE)*], for which the limit value is set at 15%.

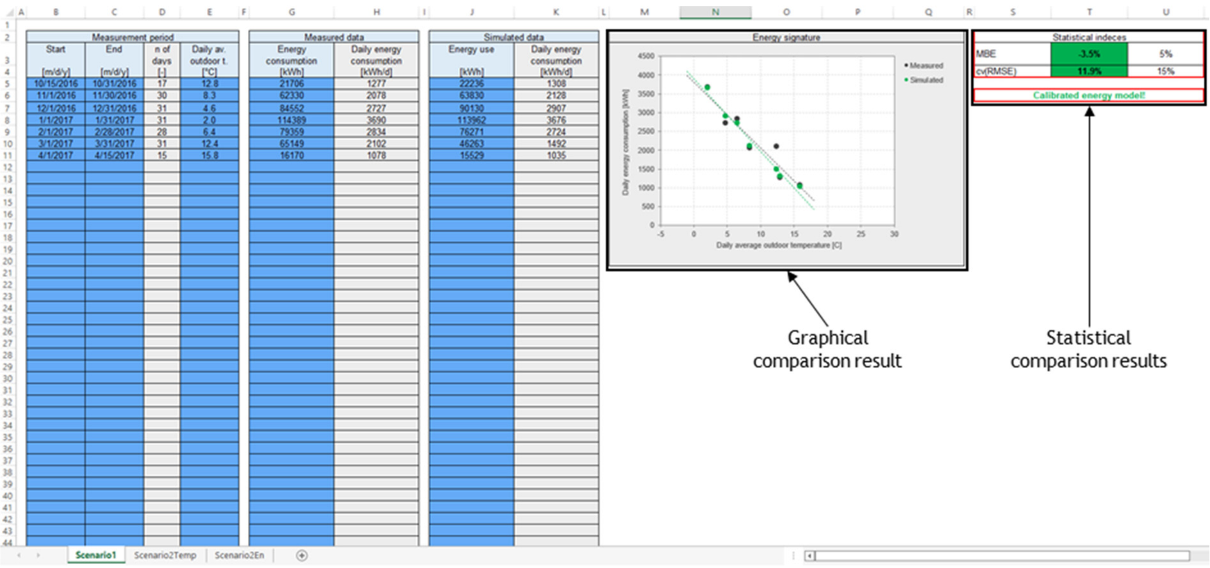

Figure 4. Outputs for statistical and graphical comparison for calibration scenario 1.

<u>If both the *MBE* and the *cv(RMSE)* are within the limit values, the building energy model can be considered as calibrated.</u> In this case, the proposed procedure ends. Otherwise, it continues to the next step (step 4).

Step 4: Modification of base model

When the statistical indexes are not verified, the base energy model must be modified. The choice of the parameters to be modified in the model should be guided by the graphical comparison (Figure 4). Specifically, it consists in the comparison between the trend lines representative of both the monitored and simulated data. The following situations may occur:

1. <u>Differences in the trend line slopes.</u>

   In this case, the parameters to be modified are the ones influenced by the temperature difference between the indoor and outdoor environments. These includes:

   - Thermal properties of building components,
   - Thermal bridges linear thermal transmittance,
   - Ventilation/Infiltration rates.

2. <u>Shift between trend lines.</u>

   In this case, the parameters to be modified are the ones not influenced by the difference between indoor and outdoor temperature. These includes:

   - Internal heat gain load and/or profiles,
   - Heating/cooling set-points,
   - HVAC technical specifications, and
   - HVAC operation profile.

Following these indications, the choice of the parameters to be modified should firstly focus on those input data for which high uncertainties were identified in the creation of the building energy model (e.g., standard or reference data).

Once the base model is modified, the procedure should continue again from step 1 to step 4, until the statistical indexes are verified.

3.2 Scenario 2A: hourly temperatures

After the preliminary phases presented, the calibration scenario 2A (for indoor temperatures) consists in the following steps:

1. Energy simulation for the base model and extraction of the outputs (hourly indoor air temperatures),
2. Comparison between monitored and simulated outputs,
3. Verification of compliance with statistical indexes,
4. (If statistical indexes are not verified), modification of the base energy model and repetition of steps from 1 to 4, until statistical indexes are verified.

<u>The energy simulation outputs required for the model calibration are the hourly values of indoor temperature for the selected calibration period.</u>

Step 1: Energy simulation for the base model and extraction of outputs

The base model must be simulated considering the real external climatic data. Once simulated, it is required that the outputs, which are hourly values of indoor air temperature for scenario 2A, are extracted with the same temporal discretisation as the monitored data (hourly).

Step 2: Comparison between monitored and simulated outputs

The comparison between monitored and simulated outputs can be done by means of either statistical or graphical comparisons. It is suggested to perform both comparisons Figure 5 presents an example of this procedure applied using an Excel file. The inputs required in this example are:

- Date and time of the monitored data (not mandatory),
- Hourly outdoor air temperature for each measurement timestep,
- Measured hourly indoor air temperature (for each measurement timestep),
- Simulated hourly indoor air temperature (for each measurement timestep).

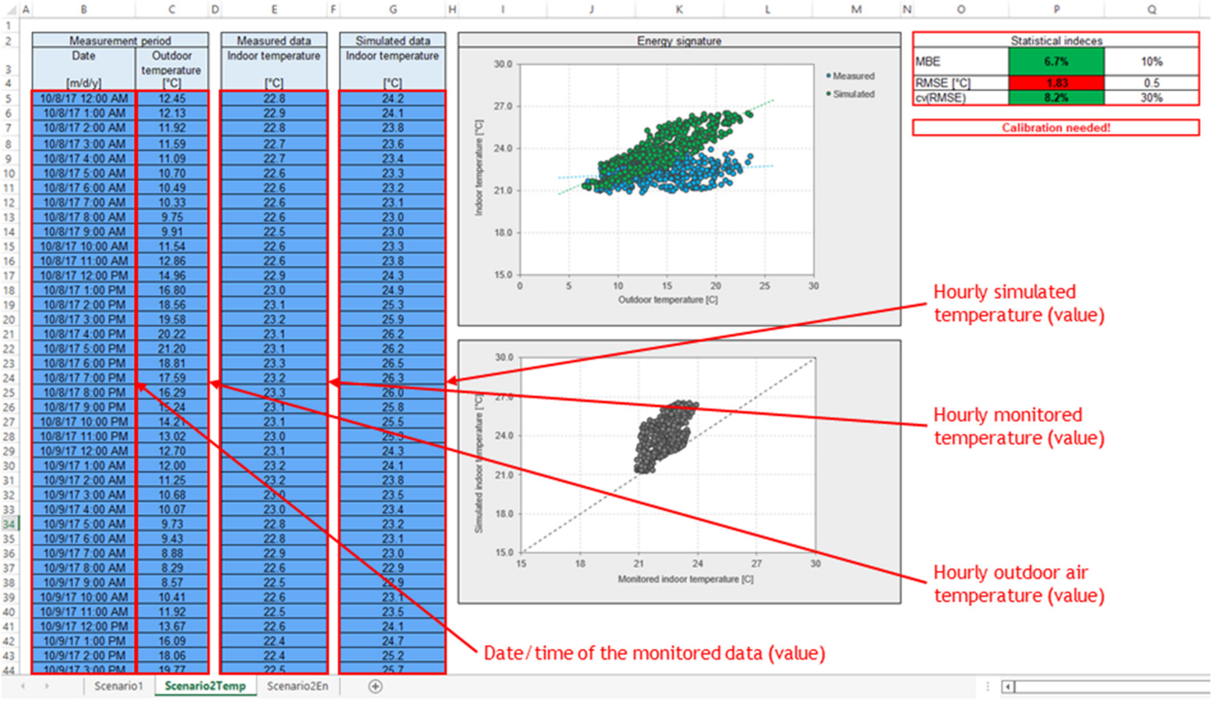

Figure 5. Inputs for statistical and graphical comparison for calibration scenario 2A.

The hourly outdoor temperature is mandatory for the graphical comparison. The simulated hourly indoor temperatures must respect the temporal discretisation of the monitored data, as specified above.

Step 3: Verification of compliance of statistical indexes

The verification of statistical indexes can be automatically calculated using MS Excel files, as presented in Figure 6. Two statistical indexes were considered for calibration scenario 1, namely:

- Mean Bias Error (MBE), for which the limit value is assumed equal to ±10%,
- Root-Mean-Square error (RMSE), for which the limit value is assumed equal to 0,5 °C, and
- Coefficient of variation of the root-mean-square error [cv(RMSE)], for which the limit value is assumed equal to 30%.

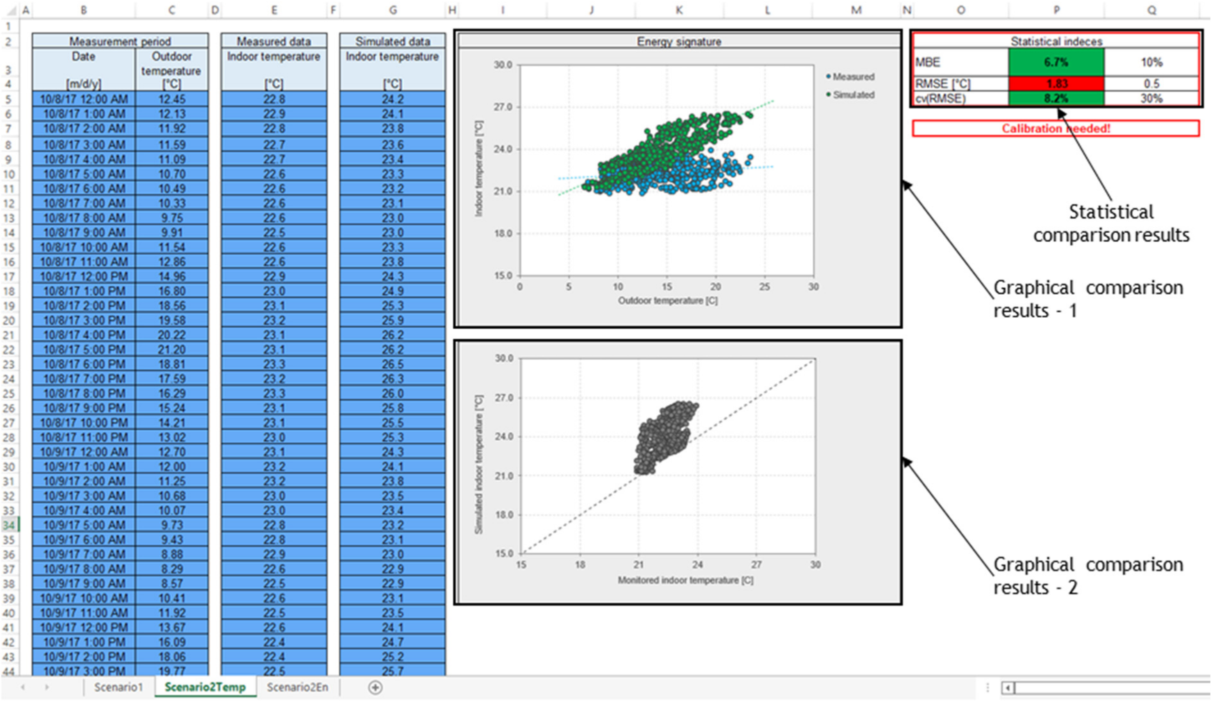

Figure 6. Outputs for statistical and graphical comparison for calibration scenario 2A.

<u>When both the *MBE*, the *RMSE*, and the *cv(RMSE)* are within the limit values, the building energy model can be considered as calibrated.</u> In this case, the proposed procedure ends. Otherwise, it continues to the next step (step 4).

Step 4: Modification of base model

When the statistical indexes are not verified, the base energy model must be modified. The choice of the parameters to be modified in the model should be guided by the graphical comparison (Figure 6). Specifically, the first graphical comparison (energy signature) consists in the comparison between the trend lines representative of both the monitored and simulated data. The following situations may occur:

1. <u>Differences in the trend line slopes.</u> In this case, the parameters to be modified are the ones influenced by the temperature difference between the indoor and outdoor environments. These includes:
   - Thermal properties of building components,
   - Thermal bridges linear thermal transmittance,
   - Ventilation/Infiltration rates.
2. <u>Shift between trend lines.</u> In this case, the parameters to be modified are the ones not influenced by the difference between indoor and outdoor temperature. These includes:
   - Internal heat gain load and/or profiles,
   - Heating/cooling set-points,
   - HVAC technical specifications, and
   - HVAC operation profile.

The second graphical comparison, instead, shows the direct comparison between the monitored and the simulated hourly temperatures. The line in the graph represents the perfect equality between the simulated and monitored. When the points in the graph are above the dashed line, this means that simulation is overestimating the indoor temperatures, and vice versa.

Following these indications, the choice of the parameters to be modified should firstly focus on those input data for which high uncertainties were identified in the creation of the building energy model (e.g., standard or reference data).

Once the base model is modified, the procedure should continue again from step 1 to step 4, until the statistical indexes are verified.

3.3 Scenario 2B: hourly energy consumption

After the preliminary phases presented, the calibration scenario 2B (for hourly energy consumption) consists in the following steps:

1. Energy simulation for the base model and extraction of the outputs (hourly energy consumption for the available energy carriers),
2. Comparison between monitored and simulated outputs,
3. Verification of compliance with statistical indexes,
4. (If statistical indexes are not verified), modification of the base energy model and repetition of steps from 1 to 4, until statistical indexes are verified.

The energy simulation outputs required for the model calibration are the hourly energy consumption values for identified calibration period.

Step 1: Energy simulation for the base model and extraction of outputs

The base model must be simulated considering the real external climatic data. Once simulated, it is required that the outputs, which are energy consumption values for scenario 2B, are extracted with the same temporal discretisation as the monitored data.

Step 2: Comparison between monitored and simulated outputs

The comparison between monitored and simulated outputs can be done by means of either statistical or graphical comparisons. It is suggested to perform both comparisons. Figure 7 presents an example of this procedure applied using an Excel file. The inputs required in this example are:

- Date and time of the monitored data (not mandatory),
- Hourly energy consumption values for each measurement timestep,
- Measured energy consumption values (for each measurement timestep),
- Simulated energy uses (for each measurement timestep).

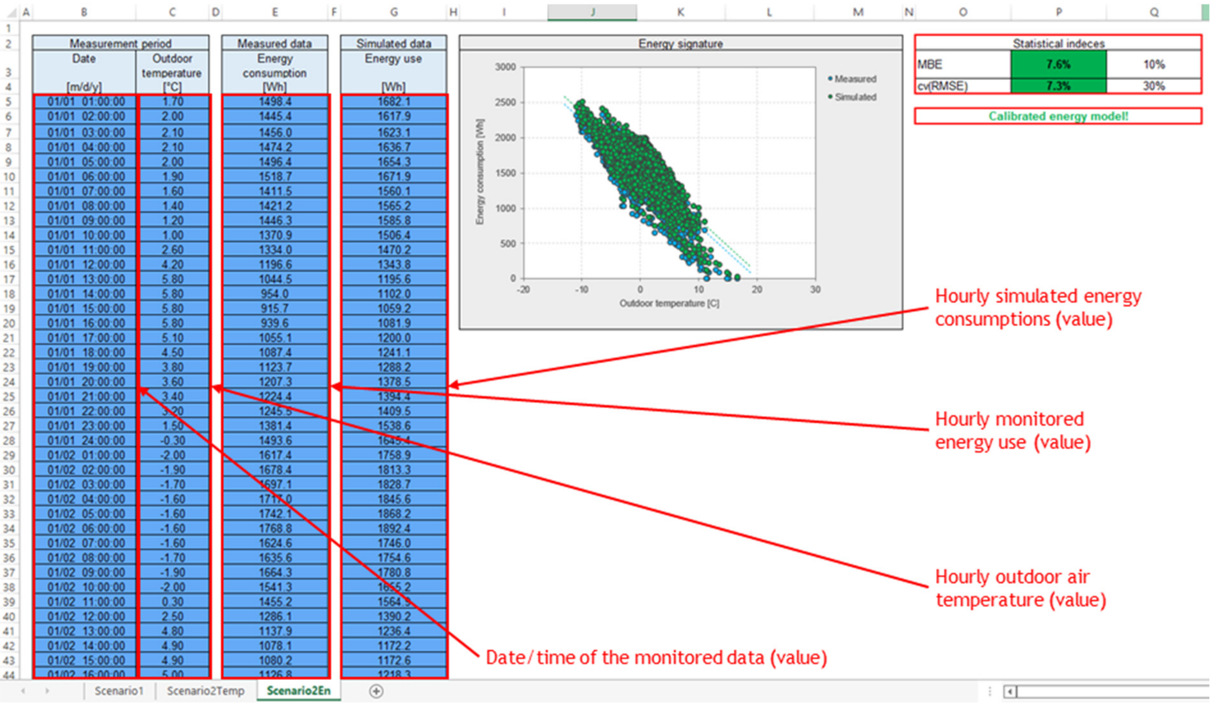

Figure 7. Inputs for statistical and graphical comparison for calibration scenario 2B.

The hourly outdoor temperature is mandatory for the graphical comparison. The simulated energy consumption must respect the temporal discretisation of the monitored data, as specified above.

Step 3: Verification of compliance with statistical indexes

The verification of statistical indexes can be automatically calculated using MS Excel files, as shown in Figure 8. Two statistical indexes were considered for calibration scenario 1, namely:

- Mean Bias Error (*MBE*), for which the limit value is assumed equal to ±10%, and,
- Coefficient of variation of the root-mean-square error [*cv(RMSE)*], for which the limit value is assumed equal to 30%.

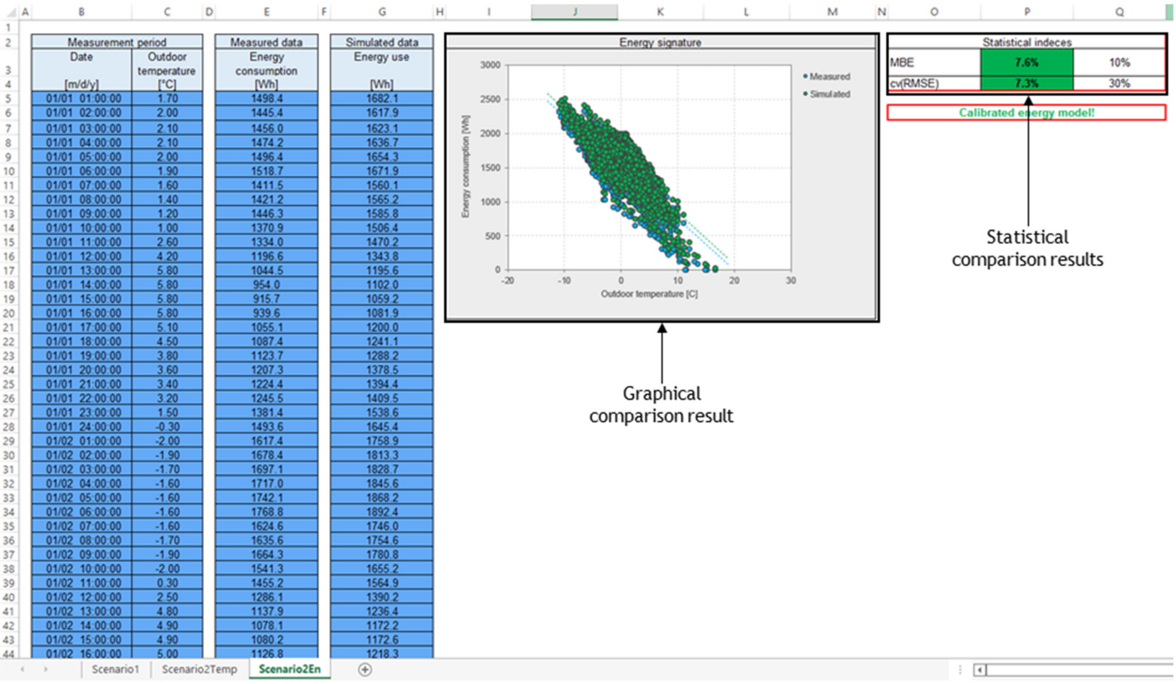

Figure 8. Outputs for statistical and graphical comparison for calibration scenario 2B.

<u>When both the *MBE* and the *cv(RMSE)* are within the limit values, the building energy model can be considered as calibrated.</u> In this case, the proposed procedure ends. Otherwise, it continues to the next step (step 4).

Step 4: Modification of base model

When statistical indexes are not met, adjustments to the base energy model are necessary. The selection of parameters to modify should be informed by the results of a graphical comparison (Figure 8)., which involves examining trend lines representing both monitored and simulated data. The following situations may arise:

1. <u>Differences in the trend line slopes.</u>

   In this case, the parameters to be modified are the ones influenced by the temperature difference between the indoor and outdoor environments. These includes:

   - Thermal properties of building components,
   - Thermal bridges linear thermal transmittance,
   - Ventilation/Infiltration rates.

2. <u>Shift between trend lines.</u>

   In this case, the parameters to be modified are the ones not influenced by the difference between indoor and outdoor temperature. These includes:

   - Internal heat gain load and/or profiles,
   - Heating/cooling set-points,
   - HVAC technical specifications, and
   - HVAC operation profile.

Following these guidelines, the selection of parameters to modify should initially focus on input data with high uncertainties identified during the creation of the building energy model (e.g., those using standard or reference data).

Once the base model is modified, the procedure should continue again from step 1 to step 4, until the statistical indexes are verified.

4. Economic evaluation of energy efficiency measures

The economic evaluation of the energy efficiency measures (EEMs) is conducted by analysing the building in its original state (referred as the "baseline") and comparing it with various scenarios that implement energy efficiency measures (EEMs) (referred as "scenario"). This evaluation follows the steps outlined in Figure 9:

1. Determination of the general parameters,
2. Determination of the specific case parameters,
3. Calculation of economic cost analysis indicators.

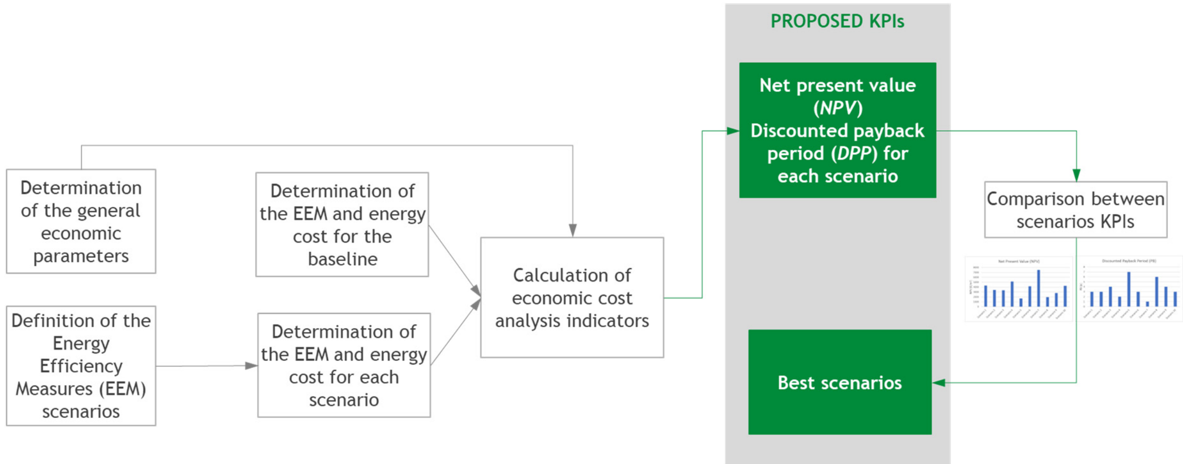

Figure 9. Economic evaluation of energy efficiency measures workflow.

4.1 Determination of the general parameters

Two main activities must be performed before the economic assessment of each individual case.

1. Determination of the economic general parameters

   This includes defining parameters such as the interest rate and the yearly increment cost of each energy carrier, as shown in Figure 10. The interest rate is a constant value, while the yearly increment cost of the energy carrier must be specified for each energy carrier used in the baseline or scenarios, for each year of the calculation period. Additionally, the conditioned net floor area should be determined to allow normalization of the results.

2. Defining the number of scenarios for the application of EEMs

   This activity involves determining the number of scenarios for the application of energy efficiency measures (EEMs), as presented in Figure 10. It also requires specifying the EEMs applied in each scenario.

	Default value (Italy)	Used value
Interest rate [%]	4%	4%
Calculation period [a]	30	30
Conditioned floor area [m^2]	-	100
Number of considered scenarios	-	5

Year	Electricity yearly increment cost			Natural gas yearly increment cost		
	Default value (Italy)	Used value	Cost evolution	Default value (Italy)	Used value	Cost evolution
2023	0,0%	0,0%	1,0000	0,0%	0,0%	1,0000
2024	3,4%	3,4%	1,0338	3,2%	3,2%	1,0323
...	...	...	...	...	...	...
2053	3,4%	3,4%	2,7069	1,2%	1,2%	1,4892

Figure 10. Main general data.

4.2 Determination of the specific case parameters

Both for the baseline and each scenario, the relevant information regarding time and costs must be determined, as shown in Figure 11 and Figure 12.

For each Energy Efficiency Measure (EEM) and the associated technology, characteristic years are predefined. These represent the number of years a technology, whether existing or subjected to an EEM, is expected to last before it needs replacement. These values are predetermined for each specific technology, with differentiation made, where necessary, for the main technical building sub-system affected by the measure.

			Energy efficiency measures																			
			EEM 1	EEM 2	EEM 3	EEM 4	EEM 5	EEM 6	EEM 6	EEM 7	EEM 7	EEM 8	EEM 9	EEM 9	EEM 10	EEM 10	EEM 11	EEM 12	EEM 13	EEM 14	EEM 15	TOTAL
Investment cost [€]			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0
Annual maintenance cost [€]			1920,00	138,60	0,00	0,00	0,00	1920,00	0,00	58,30	244,55	138,60	0,00	0,00	0,00	0,00	0,00	0,00	244,55	0,00	0,00	2361
Repl./Disposal costs [€]			24000,00	0,00	0,00	0,00	0,00	24000,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	24000
New technology life [a]			30	30	30	30	30	15	15	20	15	20	20	15	15	15	20	20	20	20	15	TOTAL
isting tech. year of replacement			0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	
2023	0	1,000	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0
2024	1	0,962	1846,15	133,27	0,00	0,00	0,00	1846,15	0,00	56,06	235,15	133,27	0,00	0,00	0,00	0,00	0,00	0,00	235,15	0,00	0,00	4485
2025	2	0,925	1775,15	128,14	0,00	0,00	0,00	1775,15	0,00	53,90	226,10	128,14	0,00	0,00	0,00	0,00	0,00	0,00	226,10	0,00	0,00	4313
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
2053	30	0,308	7991,62	42,73	0,00	0,00	0,00	591,97	0,00	17,98	75,40	42,73	0,00	0,00	0,00	0,00	0,00	0,00	75,40	0,00	0,00	8838
TOTAL			**40600**	**2397**	**0**	**0**	**0**	**46527**	**0**	**1008**	**4229**	**2397**	**0**	**0**	**0**	**0**	**0**	**0**	**4229**	**0**	**0**	**101387**

Figure 11. Main data for baseline or scenario (EEM).

		Energy carriers				
		Electric	Natural gas	District heating	Other	**TOTAL**
Annual cost [€/a]		1101	10276	0	0	**11377**
Year						
2023	0	1101	10276	0	0	**11377**
2024	1	1138	10607	0	0	**11746**
2025	2	1177	10934	0	0	**12110**
2026	3	1217	11065	0	0	**12281**
2027	4	1258	11198	0	0	**12455**
2028	5	1300	11332	0	0	**12632**
2029	6	1344	11459	0	0	**12803**
2030	7	1389	11588	0	0	**12978**
2031	8	1436	11745	0	0	**13181**
2032	9	1485	11895	0	0	**13379**
2033	10	1535	12046	0	0	**13581**
2034	11	1586	12200	0	0	**13786**
2035	12	1640	12346	0	0	**13986**

Figure 12. Main data for baseline or scenario (energy carriers).

As shown in Figure 11, the investment cost, annual maintenance cost, and replacement, or disposal cost must be determined for all cases and for each EEM or the technology associated.

In the case of the baseline (the existing building), the investment cost should be set to zero, as the building is already in use. However, the other cost sections (annual maintenance and replacement/disposal) must be filled with the correct values.

For all cases, the annual costs for all the energy carriers used in the analysed building must be determined, as shown in Figure 12. These costs result from the combination of the energy needs derived from the energy calculation procedure, multiplied by the energy carrier cost, which varies from country to country.

4.3 Calculation of economic cost analysis indicators

The main calculation procedures are performed for the baseline and for each scenario. For each Energy Efficiency Measure (EEM) or associated technology, and for each energy carrier, the annual actualised costs are calculated for the reference period, as shown in Figure 13.

For each scenario, the following calculations are made:

1. The annual cash flow derived from the comparison with the baseline.
2. The sum of cash flows over the analysis period.
3. The actualized Net Present Value (NPV).
4. The Discounted Payback Period (DPP).

In the results, for the whole set of scenarios, the net present value (NPV) should be normalized by the conditioned floor area. Similarly, the payback period should also be calculated. Both parameters should be presented in a table and a graph.

Year [a]		Cash Flow [€]	Sum of cash flows [€]
2023	0	11622,80	11622,80
2024	1	12000,48	23623,28
2025	2	12375,39	35998,67
...	...	...	...
2053	30	19620,90	477850,10

NPV	[€]	**477850,1**
	[€/m^2]	**4778,5**
DPP	[a]	**1**

Figure 13. Scenario results and calculations.

5. Indoor environmental quality evaluation

Two distinct domains are considered for the indoor environmental quality (IEQ) assessment, which will follow the procedures outlined in EN ISO 16798-1 and CEN/TR 16798-2. The IEQ assessment will focus on:

1. Thermal comfort
2. Indoor air quality (IAQ).

Some preliminary phases are required for assessing both IEQ domains:

1. <u>Selection of representative spaces within the building</u>

   For simplicity, IEQ evaluations will be conducted in representative spaces, which may include individual rooms or thermal zones. The selection of these spaces should consider the following criteria

   - Varied intended uses,
   - Different occupancy densities,
   - Varied sizes and orientation, and
   - Different floors of the building.

2. <u>Identification of the IEQ comfort category</u>.

   Each chosen representative space should be assigned an IEQ comfort category based on its intended use. The comfort categories specified in EN ISO 16798-1 are presented in the following table. These categories reflect the expected comfort level for occupants. The "medium" level (Category II) is typically standard, while a higher category may be chosen for spaces serving occupants with specific needs (e.g., children, elderly individuals, or those with disabilities). Lower categories reduce comfort but do not present any risk.

Categories of indoor environmental quality (EN ISO 16798-1)	
Category	Level of expectation
IEQ I	High
IEQ II	Medium
IEQ III	Moderate
IEQ IV	Low

Most intended uses, such as offices and residential buildings, are typically associated with Category II. However, the choice of comfort category should be tailored to address the specific needs of the building under consideration.

5.1 Thermal comfort evaluation

Requirements for thermal comfort evaluation:

1. Hourly energy model (either calibrated or not)
2. Hourly occupancy profiles (either actual or standard)
3. Climatic hourly data (standard)

Thermal comfort evaluation will follow the adaptive comfort theory, which is applicable only to buildings without mechanical cooling. The assessment will be based on either a standard model (standard weather data and user profiles) or a tailored model (standard weather data and actual user profiles). Both standard and tailored models can be developed from the calibrated energy model, if available.

Following the preliminary phases, the thermal comfort assessment using the adaptive theory includes the following steps (Figure 14):

1. Selection of the evaluation period,
2. Calculation of the running mean outdoor temperature,
3. Definition of the operative temperature comfort range,
4. Calculation of the thermal comfort index,
5. Definition of the thermal comfort quality index (proposed KPI).

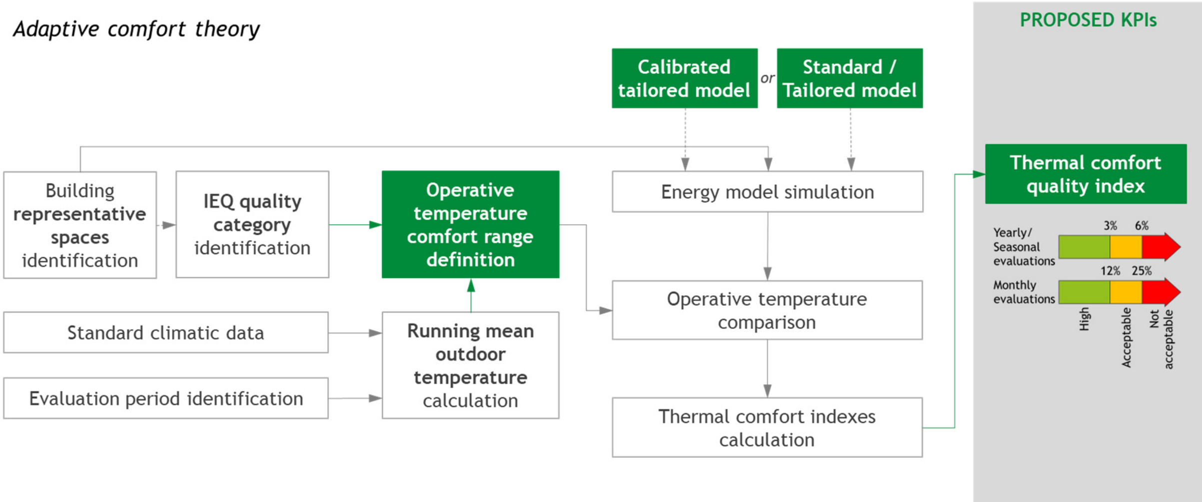

Figure 14. Thermal comfort assessment procedure.

For each representative space, the inputs required (Figure 15) are as follows:

- Comfort category (as defined above),
- Hourly external air temperature (from standard weather data),
- Hourly occupancy profile (using either standard or actual user data),
- Hourly indoor operative temperature,
- Beginning and end of the evaluation period.

<u>The only energy simulation outputs required for the thermal comfort assessment is the hourly indoor operative temperature for the identified representative spaces.</u>

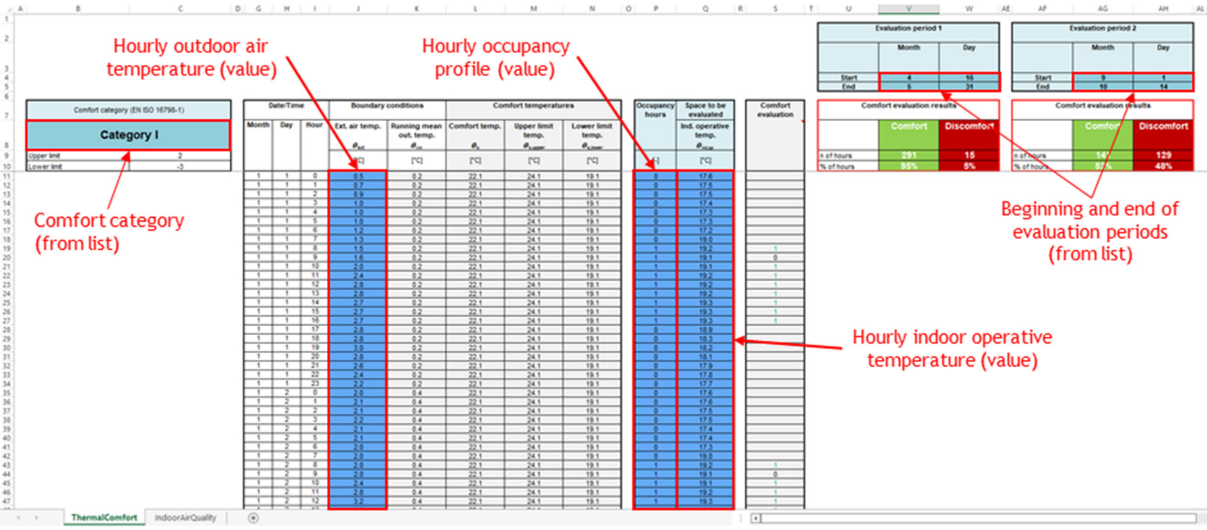

Figure 15. Input data for the thermal comfort assessment.

Step 1: Selection of the evaluation period

As mentioned, the adaptive comfort theory applies to buildings without mechanical cooling. Therefore, this theory can be applied during the non-conditioned months, specifically in the shoulder seasons (spring and autumn), and summer—provided the space is not served by a cooling system.

For buildings without mechanical cooling, one evaluation period should be selected. This period starts at the end of the heating season and ends at the beginning of the following heating season. For example, for a building in Northern Italy (where the heating season runs from October 15th to April 15th), the evaluation period should start on April 16th and end on October 14th.

For buildings with mechanical cooling, two evaluation periods should be considered. The first period starts at the end of the heating season and ends at the beginning of the cooling season. The second period starts at the end of the cooling season and ends at the beginning of the following heating season.

Step 2: Calculation of the running mean outdoor temperature

According to EN 16798-1, the running mean outdoor temperature is calculated using only the hourly outdoor air temperatures as input data (see Figure 15):

$$\Theta_{\mathrm{rm}} = \frac{\Theta_{\mathrm{ed}-1} + 0,8\ \Theta_{\mathrm{ed}-2} + 0,6\ \Theta_{\mathrm{ed}-3} + 0,5\ \Theta_{\mathrm{ed}-4} + 0,4\ \Theta_{\mathrm{ed}-5} + 0,3\ \Theta_{\mathrm{ed}-6} + 0,2\ \Theta_{\mathrm{ed}-7}}{3.8}$$

where $\Theta_{\mathrm{ed}\text{-}i}$ is the daily mean outdoor air temperature for the *i*-th previous day.

Step 3: Definition of the operative temperature comfort range

According to EN 16798-1, the operative temperature comfort ranges are determined according to the selected thermal comfort category (see Figure 15) and the running mean outdoor temperature. This range represents the interval in which a variation of the indoor operative temperature is allowable.

For category 2:

- Upper limit: 0,33 Θ_{rm} + 21,8 [°C]
- Lower limit: 0,33 Θ_{rm} + 14,8 [°C]

Step 4: Calculation of the thermal comfort index

The thermal comfort index is calculated for the identified evaluation periods. For this calculation, the hourly occupancy profile and the simulated hourly indoor operative temperatures are required (Figure 15). Specifically, the occupancy profile should be filled out with the following criteria:

- A value of 0 means the representative space is unoccupied, and
- A value of 1 means the representative space is occupied (with at least one person).

The comfort index is calculated only the occupied hours. Two comfort indexes are considered (Figure 16):

- Percentage of comfort hours (*PCH*), calculated as the percentage of occupied hours in which the indoor operative temperature is within the thermal comfort range,
- Percentage of discomfort hours (*PDH*), calculated as the percentage of occupied hours in which the indoor operative temperature exceeds the thermal comfort range.

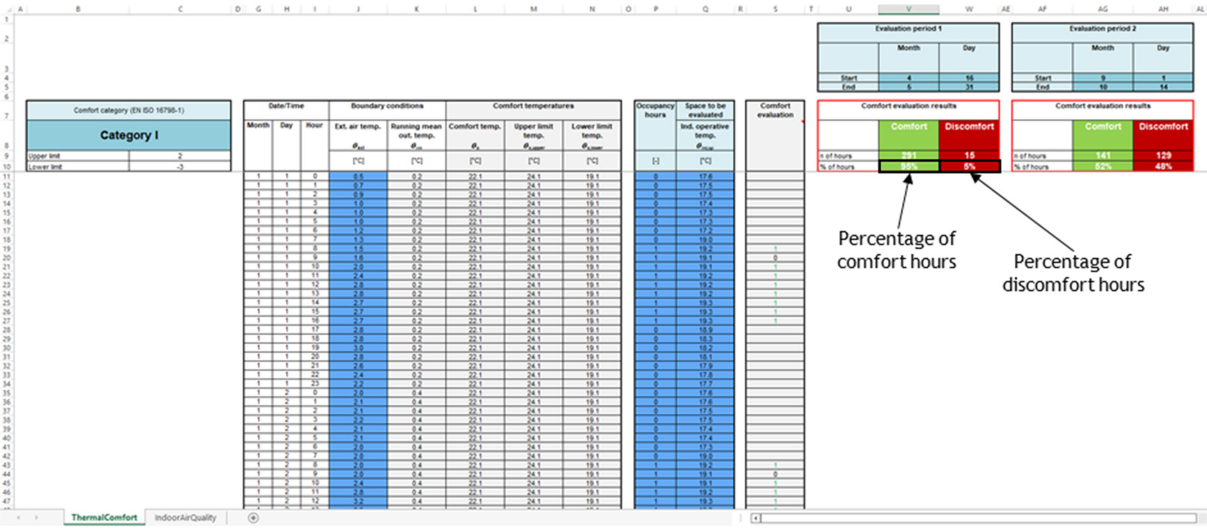

Figure 16. Outputs for the thermal comfort assessment.

Step 5: Definition of the thermal comfort quality index (proposed KPI)

The proposed KPI is a qualitative index that indicates the level of thermal comfort expected in the analysed representative spaces. It is defined by the percentage of discomfort hours, as follows (CEN/TR 16798-2):

- If *PDH* ≤ 3%, a high thermal comfort level is expected,
- If 3% <*PDH* ≤ 6%, an acceptable thermal comfort level is expected, and
- If *PDH* > 6%, then a not acceptable thermal comfort level is expected.

5.2 Indoor air quality assessment

Requirements for indoor air quality evaluation:

1. External air flow rate

   This can be either a measured or design value, derived from natural or mechanical ventilation.

The indoor air quality (IAQ) evaluation will be carried out by comparing the actual external air flow rate (either measured or design value) with the minimum required to guarantee indoor air quality. This comparison will follow the specifications of EN ISO 16798-1 (method A).

For each representative space, the inputs (see Figure 17) required for this evaluation are:

- Comfort category (as defined above),
- Intended use of the space,
- Building polluting level,
- Conditioned net floor area,
- Conditioned net volume,
- Number of occupants,
- Measured or design external air flow rate.

No energy simulation outputs are required for the indoor air quality assessment.

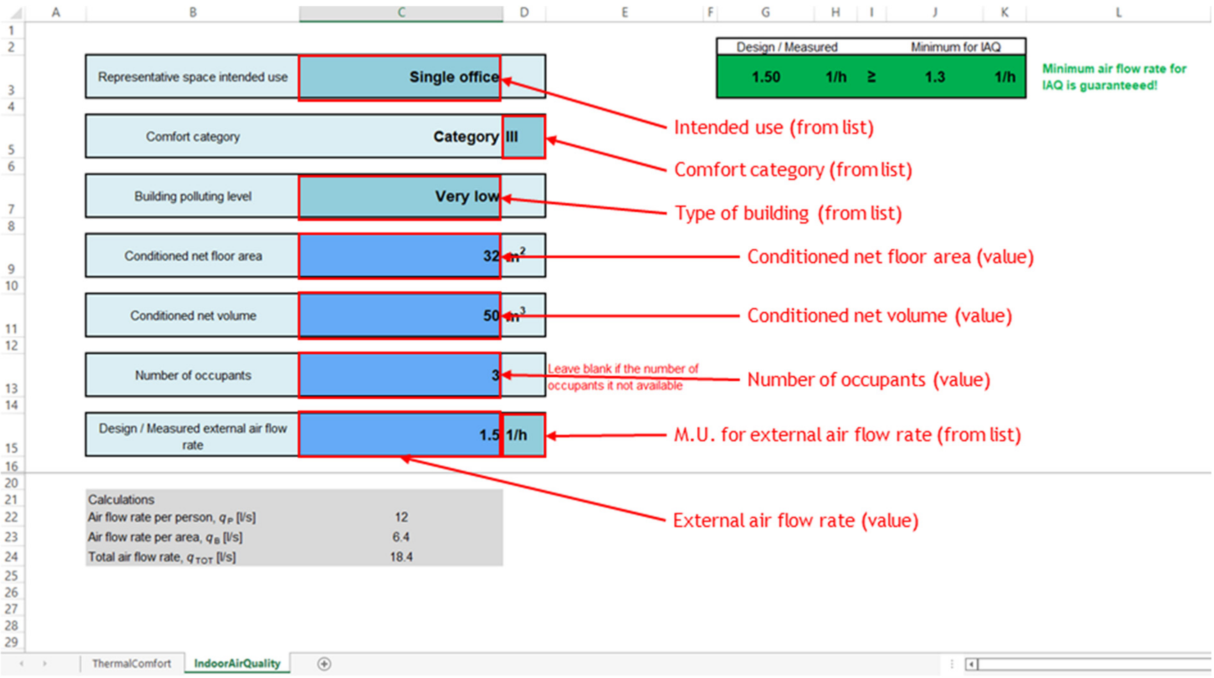

Figure 17. Inputs data for the indoor air quality assessment.

It is possible to choose between the representative space intended uses specified by the EN ISO 16798-1 technical standard: These include: single office, landscaped office, conference room, auditorium, restaurant, class-room, kindergarten, department store, conference room, auditorium, and classroom.

Regarding the building polluting level, according to EN ISO 16798-1 the building may be classified as:

- Very low-polluting building: "A building where predominantly very low-emitting materials and furniture are used, activities with emission of pollutants are prohibited, and no previous emitting sources (like tobacco smoke, cleaning materials) were present",
- Low-polluting building: "A building where predominantly low emitting materials are used and materials and activities with emission of pollutants are limited",
- Not low-polluting building: "A building where no effort has been done to select low-emitting materials and where activities with emission of pollutants are not limited or prohibited".

The number of occupants in the representative space is not a mandatory data point. If not available, it can be left blank, and the calculations will use a standard occupancy density based on the building's intended use. However, if this data is available, it is preferable to use the actual number of occupants for more accurate results.

Finally, the measured or the design value for the external air flow rate ($q_{m/d}$) is a mandatory data point, as the analysis depends on the comparison between this value and the minimum required airflow for indoor air quality. In addition to providing the value, it is also needed to specify the measurement unit (MU). Available inits include l/s, l/h, m^3/s, m^3/h, and h^{-1} (ACH). In case the air flow rate is provided in h^{-1}, the conditioned volume must also be specified.

The proposed KPI is a qualitative index that identifies if the minimum air flow rate requirement for indoor air quality (q_{IAQ}) is met (see Figure 18). It is defined as follows:

- If $q_{m/d} < q_{IAQ}$, the minimum air flow rate for IAQ is not guaranteed, and
- If $q_{m/d} \geq q_{IAQ}$, the minimum air flow rate for IAQ is guaranteed.

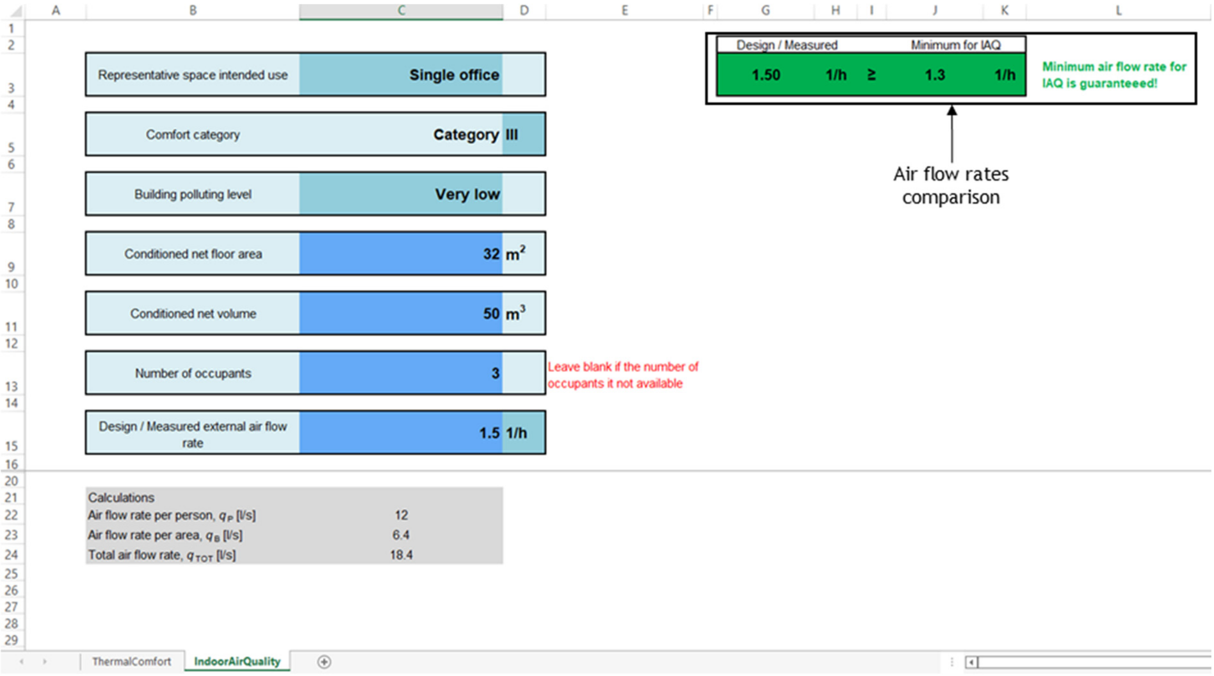

Figure 18. Outputs data for the indoor air quality assessment.

6. Building Automation and Control System impact assessment

To determine the impact of the Building Automation and Control Systems (BACS), the proposed procedure focuses on specific functions identified using the following steps, as outlined in Figure 19.

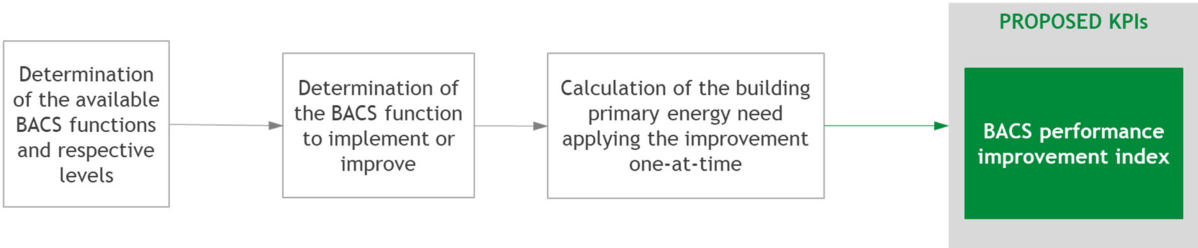

Figure 19. Building Automation and Control System impact assessment workflow.

Initially, for each function listed in EN ISO 52120-1, the user should determine whether the function is installed at any level or if it cannot be implemented in the specific building. For each available function, the actual BACS level should be identified.

The second step is to define the functions relevant to the procedure. The user should exclude any functions that cannot be installed in the building (e.g., heating emission control for Thermally Activated Building Structures, or TABS, if the building lacks TABS) and functions already operating at the maximum level.

Each selected function should be analysed individually, incrementally improving its BACS level by one. This improvement should then be applied to the energy calculation procedure, with the effect on the primary energy requirement assessed.

A simple “BACS performance improvement” index can then be calculated as follows:

$$E_{\mathrm{BACS},\,i} = \frac{EP_0 - EP_i}{EP_0}$$

Where:

- EP_0 is the primary energy need for the building in the original state,
- EP_i is the primary energy need for the building with the function improvement i applied.

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