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Energy performance of buildings — Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads —

Part 3: Calculation procedures regarding adaptive building envelope elements

Performance énergétique des bâtiments — Besoins d'énergie pour le chauffage et le refroidissement, les températures intérieures et les chaleurs sensible et latente —

Partie 3: Méthodes de calcul des éléments adaptables de l'enveloppe du bâtiment

Reference number
ISO 52016-3:2023(E)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by ISO Technical Committee ISO/TC 163, *Thermal performance and energy use in the built environment*, Subcommittee SC 2, *Calculation methods* in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 89, *Thermal performance of buildings and building components*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

A list of all the parts in the ISO 52016 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document, along with other international standards, assesses the overall energy performance of buildings (EPB). Throughout this document, this group of standards is referred to as the "set of EPB standards". A list of the standards in this set can be found on the EPB Center website.[1)]

All EPB standards follow specific rules to ensure overall consistency, unambiguity and transparency.

All EPB standards provide a certain flexibility with regard to the methods, the required input data and references to other EPB standards, by the introduction of a normative template in Annex A and Annex B with informative default choices.

The main target groups for this document are architects, engineers and regulators.

Further target groups are parties who want to motivate their assumptions by classifying the EPB for a dedicated building stock.

This document is also important for manufacturers and suppliers of adaptive building envelope elements.

Background information, including justification, explanation and demonstration of the calculation procedures in this document, is provided in ISO/TR 52016-4[2)].

The subset of EPB standards prepared under the responsibility of ISO/TC 163/SC 2 cover inter alia:

— calculation procedures on the overall energy use and EPB;

— calculation procedures on the internal temperature in buildings (e.g. in case of no space heating or cooling);

— indicators for partial EPB requirements related to thermal energy balance and fabric features;

— calculation methods covering the performance and thermal, hygrothermal, solar and visual characteristics of specific parts of the building and specific building elements and components, such as opaque envelope elements, ground floor, windows and facades.

ISO/TC 163/SC 2 cooperates with other Technical Committees for the details on, for example, appliances, technical building systems and indoor environment.

This document presents procedures for taking into account the effect of adaptive building envelope elements in the calculation of the energy needs for heating and cooling, internal temperatures and sensible and latent heat loads according to ISO 52016-1.

This document takes precedence if there is a conflict with any provision in ISO 52016-1.

NOTE 1 For instance some of the simplified calculation procedures in ISO 52016-1:2017, Annex G, *Dynamic transparent building elements*, are in conflict with the more refined procedures in this document.

Default references to EPB standards other than ISO 52000-1 are identified by the EPB module code number and given in Annex A (normative template in Table A.1) and Annex B (informative default choice in Table B.1).

EXAMPLE EPB module code number: M5–5, or M5–5.1 (if module M5–5 is subdivided), or M5–5/1 (if reference to a specific clause of the standard covering M5–5).

1) https://epb.center/support/documents.

2) Under preparation. Stage at the time of publication: ISO/WD TR 52016-4.

Table 1 shows the relative position of this document within the set of EPB standards in the context of the modular structure as set out in ISO 52000-1.

NOTE 2 In ISO/TR 52000-2[7] the same table can be found, with, for each module, the numbers of the relevant EPB standards and accompanying technical reports that are published or under preparation.

NOTE 3 The modules in Tables A.1 and B.1 represent EPB standards, although one EPB standard can cover more than one module and one module can be covered by more than one EPB standard, for instance a simplified and a detailed method respectively.

Table 1 — Position of this document (in casu M2-2 and M2-3), within the modular structure of the set of EPB standards

	Overarching		**Building (as such)**		**Technical building systems**									
Submodule	**Descriptions**		**Descriptions**		**Descriptions**	**Heating**	**Cooling**	**Ventilation**	**Humidification**	**Dehumidification**	**Domestic hot water**	**Lighting**	**Building automation and control**	**e.g. PV, wind**
sub1		**M1**		**M2**		**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**M10**	**M11**
1	General		General		General									
2	Common terms and definitions; symbols, units and subscripts		Building energy needs	ISO 52016-3 (this document)	Needs								a	
3	Applications		(Free) Indoor conditions without systems	ISO 52016-3 (this document)	Maximum load and power									
4	Ways to express energy performance		Ways to express energy performance		Ways to express energy performance									
5	Building categories and building boundaries		Heat transfer by transmission		Emission and control									
6	Building occupancy and operating conditions		Heat transfer by infiltration and ventilation		Distribution and control									

a The shaded modules are not applicable.

Table 1 *(continued)*

	Overarching		Building (as such)		Technical building systems									
Submodule	**Descriptions**		**Descriptions**		**Descriptions**	**Heating**	**Cooling**	**Ventilation**	**Humidification**	**Dehumidification**	**Domestic hot water**	**Lighting**	**Building automation and control**	**e.g. PV, wind**
sub1		**M1**		**M2**		**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**M10**	**M11**
7	Aggregation of energy services and energy carriers		Internal heat gains		Storage and control									
8	Building zoning		Solar heat gains		Generation and control									
9	Calculated energy performance		Building dynamics (thermal mass)		Load dispatching and operating conditions									
10	Measured energy performance		Measured energy performance		Measured energy performance									
11	Inspection		Inspection		Inspection									
12	Ways to express indoor comfort				BMS									
13	External environment conditions													
14	Economic calculation													

[a] The shaded modules are not applicable.

Energy performance of buildings — Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads —

Part 3: Calculation procedures regarding adaptive building envelope elements

1 Scope

This document specifies procedures for the calculation of the energy needs for heating and cooling, internal temperatures and sensible and latent heat loads of a building according to the hourly calculation methodology in ISO 52016-1. Additions or modifications of the calculations are provided in this document if the building envelope contains one or more adaptive building envelope elements (building envelope elements with adaptive components that are either environmentally or actively controlled as a function of specific conditions). The adaptive building envelope element replaces the transparent building element in the calculation according to ISO 52016-1.

The three types of adaptive building envelope elements covered in this document are:

— building envelope elements with dynamic solar shading;

— building envelope elements with chromogenic glazing;

— building envelope elements with an actively ventilated cavity.

Environmentally activated control is described for building envelope elements with chromogenic glazing, but can also occur for other types of adaptive building envelope elements. In that case the same approach applies as for environmentally activated chromogenic glazing.

This document is applicable to the assessment of the energy performance of buildings (EPB) (energy performance labels and certificates), including comparison between buildings and checking conformity with minimum energy performance criteria.

It is also applicable to assess the contribution of the adaptive building envelope element to the smart readiness of a building.

In addition, this document provides indicators for the impact of the adaptive building envelope element on the performance of the building compared to a reference building envelope element. It is applicable to buildings at the design stage, to new buildings after construction and to existing buildings in the use phase.

This document is not applicable to geometrically complex adaptive building envelope elements that can only be modelled as multiple coupled thermal zones.

NOTE The background to the selection of adaptive building envelope elements is given in ISO/TR 52016-4.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 7345, *Thermal insulation — Physical quantities and definitions*

ISO 15099, *Thermal performance of windows, doors and shading devices — Detailed calculations*

ISO 52000-1, *Energy performance of buildings — Overarching EPB assessment — Part 1: General framework and procedures*

ISO 52016-1:2017, *Energy performance of buildings — Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads — Part 1: Calculation procedures*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 7345, ISO 9488, ISO 52000-1, ISO 52016-1, and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
adaptive building envelope element
building envelope or part of it with at least one layer having physical properties that can be adapted in a reversible way as a (passive, intrinsic) response to transient conditions or actively controlled to adjust to transient conditions or changing priorities

Note 1 to entry: A part of a building envelope can be a product or assembly consisting of single or multiple layers, usually with transparent components.

EXAMPLE 1 Examples of an adaptive building envelope element:

— a window or facade with *dynamic solar shading* (3.7) (blind or shutter);

— a window with *chromogenic glazing* (3.6);

— a window or façade with an *actively ventilated cavity* (3.8).

EXAMPLE 2 Examples of conditions:

— external, such as climate;

— internal, such as occupants' requirements;

— local, such as material temperature.

EXAMPLE 3 Example of physical properties:

— thermal;

— optical;

— structural.

EXAMPLE 4 Example of changing priorities:

— minimizing the building energy use;

— optimizing indoor environment conditions;

— minimizing glare;

— maximizing privacy.

3.2
actively controlled adaptive component
component with properties that vary as a function of specific situations or events, which can be the result of an active intervention

EXAMPLE Examples of such specific situations or events: set points (e.g. time, temperature, air flow, irradiance, illuminance), occupant intervention, complex algorithm.

3.3
environmentally activated adaptive component
component with properties that vary passively as a function of specific situations or events due to an intrinsic characteristic, without the possibility for an active intervention

EXAMPLE Examples of such specific situations or events: material temperature, irradiance or illuminance, solar position.

Note 1 to entry: Also known as passive or intrinsic control.

3.4
environmentally activated adaptive building envelope element
building envelope element with one or more environmentally activated adaptive components

3.5
actively controlled adaptive building envelope element
building envelope element with one or more actively controlled adaptive components

3.6
chromogenic glazing
glazing with optical and visual properties that can vary (passively or actively) as a function of a specific environmental condition

EXAMPLE

— thermochromic glazing (passive);

— thermotropic glazing (passive);

— photochromic glazing (passive);

— electrochromic glazing (active);

— liquid crystal glazing (active);

— suspended particle device (active).

3.7
dynamic solar shading
product installed to provide or modify characteristics (e.g. thermal, visual, security level) of a window, door, curtain walling or facade, to which it is applied

EXAMPLE

— internal blind (e.g. venetian blind, roller blind, vertical blind, pleated blind, honeycomb blind);

— external blind (e.g. vertical roller blind, external venetian blind);

— integrated blind (e.g. venetian blind, roller blind);

— blind in a closed cavity façade (e.g. unventilated);

— shutters (e.g. roller shutter, wing shutter, concertina shutter).

Note 1 to entry: Adapted from EN 12216:2018, 3.1.

3.8
actively ventilated cavity
cavity between two layers of glazings, or similar material, that is part of a building envelope element that can be intentionally ventilated with the purpose to exchange heat between the air and these layers or the internal environment

EXAMPLE Naturally, hybrid or mechanically ventilated cavity

— in a double envelope facade,

— in a window with integrated venetian or roller blinds, and

— with fixed or operated vent openings.

Note 1 to entry: A building envelope element with ventilation openings that can be operated to control ventilation of the building or building part, without thermal interaction within the building envelope element itself, is not considered as an *adaptive building envelope element* (3.1) with actively ventilated cavity. This also applies to ventilative cooling, which is a complementary potential technique to decrease the need for mechanical cooling and to increase thermal comfort.

3.9
simplified adaptive building envelope element
adaptive building envelope element (3.1) that is described with a model in which the thermal, daylight and solar properties, for a given state, can be pre-calculated

Note 1 to entry: The same (simplified) model as used to describe a transparent building element in ISO 52016-1:2017, 6.5.7.4.

3.10
detailed adaptive building envelope element
adaptive building envelope element (3.1) that is described with a more complex model than a *simplified adaptive building envelope element* (3.9)

Note 1 to entry: For a given state, the thermal, daylight and solar properties of the adaptive building envelope element depend on the conditions. These are calculated at each time interval on the basis of the model and the properties of the individual components.

3.11
illuminance
<at a point of a surface> quotient of the luminous flux incident on an element of the surface containing the point, divided by the area of that element

Note 1 to entry: This is expressed in lux, 1 lx = 1 lm·m^{-2}.

[SOURCE: ISO 16817:2017, 3.12, modified — Symbols were removed.]

3.12
daylight illuminance
E_v
illuminance produced by daylight

4 Symbols, subscripts and abbreviated terms

4.1 Symbols

For the purposes of this document, the symbols given in ISO 52000-1 and the following apply.

Table 2 — Symbols

Symbol	Name of quantity	Unit
A	area	m^2
a_{sol}	solar absorption coefficient	—
b	temperature reduction factor	—
E_v	daylight illuminance	lx
g	total solar energy transmittance	—
H	height	m
h	surface coefficient of heat transfer	$W/(m^2{\cdot}K)$
I_{sol}	solar irradiance	W/m^2
L	Length, width	m
N	number of items (integer only)	—
P	probability	—
Q	quantity of heat	kWh[a]
q	heat flow density	W/m^2
q_V	air (volume) flow rate	m^3/h
R	thermal resistance	$m^2{\cdot}K/W$
T	thermodynamic temperature	K
T	accumulated over- or under-temperature	K·h
t	time	s [a]
U	thermal transmittance	$W/(m^2{\cdot}K)$
θ	Celsius temperature	°C
Φ	heat flow rate, heat load, power	W

[a] Hours (h) are used as the unit of time instead of seconds when aggregating heat or energy flow (W) to quantity of heat or energy (kWh).

4.2 Subscripts

For the purposes of this document, the subscripts given in ISO 52000-1 apply.

In addition, subscripts from ISO 52016-1 that apply to this document are given in Table 3.

NOTE Relevant subscripts already given in ISO 52000-1 are included, if necessary, for the understanding of this document.

Table 3 — Subscripts from ISO 52016-1 that apply to this document

Subscript	Term	Subscript	Term	Subscript	Term
a	air	int	internal or indoor[c]	s	surface
an	annual	i	internal	se	surface external
C	cooling[a]	L	lighting[a]	r	radiation, radiative
c	structure, construction element	ld	load	re	radiative external (~r;e)
c	convection, convective	lim	limited	set	set-point

[a] Type of energy use (energy service).

[b] The subscript "e" is used for the term "external", in contrast with "internal", but if there is a risk of confusion between "external" to (for instance) a construction in general and "external", meaning outdoor environment, then the term "outdoor" is recommended for the latter.

[c] The subscript "int" is used for the term "internal", in contrast with "external", but if there is a risk of confusion between "internal" in a construction and "internal" in a building or thermal zone, then the term "indoor" is recommended for the latter.

Table 3 *(continued)*

Subscript	Term	Subscript	Term	Subscript	Term
calc	calculation	lr	long-wave radiation	sh	shading
ce	convective external (~c;e)	m	monthly	sht	shutter
ci	convective internal (~c;i)	mn	mean	sol	solar
day	daily	n	normal to surface	spec	specific
dayl	daylight	nd	need	st	state
e	external or outdoor[b]	noc	unoccupied period	sup	supply
eff	effective	oc	occupants	sys	system
el	element	occ	occupied period	tot	total
gl	glazing, glazed element	oel	opaque element	tr	transmission (heat transfer)
H	heating[a]	op	operative, opaque	V	visual
ht	heat transfer	p	projected	ve	ventilation (heat transfer)
i,j,k,z	indexes	ri	radiative internal (~r;i)	w	window
hyst	hysteresis			zt	thermal zone
				dglare	daylight glare

[a] Type of energy use (energy service).

[b] The subscript "e" is used for the term "external", in contrast with "internal", but if there is a risk of confusion between "external" to (for instance) a construction in general and "external", meaning outdoor environment, then the term "outdoor" is recommended for the latter.

[c] The subscript "int" is used for the term "internal", in contrast with "external", but if there is a risk of confusion between "internal" in a construction and "internal" in a building or thermal zone, then the term "indoor" is recommended for the latter.

NOTE In this document subscripts that are indexed (counting 1, 2, ...) can be found written in two ways:

— the comprehensive way: by adding an index (e.g. *i*) to the subscript, separated by a comma and written in italics, e.g. "w,*i*", for a variable related to a window, for window element *i*;

— the short way: as the subscript itself written in italics.

EXAMPLE "*m*" is the monthly value of a variable, for the month *m*;

— this is short for "m,*i*": the monthly value of a variable, for the month *i*.

Similarly, if there is no risk of confusion, it is also possible to write: "*wi*" instead of "w,*i*".

Addition subscripts given in Table 4 apply.

Table 4 — Additional subscripts

Subscript	Term	Subscript	Term	Subscript	Term
adapt	adaptive	limHE	operative temperature limit between heating and neutral mode	stA, stB, ...	states of a specific dimension of variation (A, B are placeholders for more specific subscripts
chro	chromogenic	limRL	upper limit for low radiation mode	vest	ventilation related state
close	closed	limRH	lower limit for high radiation mode		

Table 4 *(continued)*

Subscript	Term	Subscript	Term	Subscript	Term
limCO	operative temperature limit between neutral and cooling mode	limTH	limit between high and very high operative temperature		
limGY	lower limit for glare mode	limTN	limit between fine and high operative temperature		
limLL	limit between normal and low daylight mode	st	state; in case of variations in more than one dimension: a unique combination of states in each dimension		

4.3 Abbreviated terms

For the purposes of this document, the abbreviated terms given in ISO 52000-1:2017, Clause 4 and Table 5 below apply.

Table 5 — Abbreviated terms

Abbreviated term	Term
AVF	active ventilated façade
CCD	charge-coupled device
DGP	daylight glare probability
HVAC	heating, ventilation and air conditioning
n.a.	not applicable
PIR	passive infrared
ZT	thermal zone

5 Description of the method

5.1 Output of the method

The output of the calculation is the output of the hourly calculation methodology of ISO 52016-1:2017, 6.1.

Additional output consists of key performance indicators to show the difference between the performance of the thermal zone with the adaptive building envelope element against reference or other building envelope elements.

5.2 General description of the method

The calculation procedure consists of the following steps:

Step 1:

Identify the type of adaptive building envelope element (6.4).

Step 2:

— If the adaptive building envelope element is “simplified”: gather the input data of the adaptive building envelope element (see 6.4.3).

— If the adaptive building envelope element is “detailed”: determine the details of the model the adaptive building envelope element and gather the input data of its components (see 6.4.4).

Step 3:

Connect the model of the adaptive building envelope element to the model of the thermal zone in ISO 52016-1 (see 6.5).

Step 4:

Select the control scenario

Select the control type (see 6.6)

EXAMPLE 1 Environmentally activated or actively controlled (manual, motorized, automated)

For an environmentally activated adaptive building envelope element (see 6.7)

For an actively controlled adaptive building envelope element (6.8), with the following sub-steps:

a) Select the applicable conditions and events for the control and select which methods apply to identify the conditions and events (6.8.2).

b) Select the applicable sensors to detect the conditions or events and gather the associated extra input data (6.8.3).

   EXAMPLE 2 Solar irradiance or illuminance meter; clock + location + algorithm to identify sun position.

c) Selection of methods to identify the conditions or events (6.8.4)

   EXAMPLE 3 For daytime versus night time: measured solar irradiance, calculated sun path or pre-calculated table with sunrise and sunset.

d) Apply the reference control scenario (6.8.7), based on a number of assumptions and rules (6.8.5 and 6.8.6).

   EXAMPLE 4 Roller blinds fully extended when high solar irradiance.

e) Specify the criteria (values) for the conditions and events as a function of control type, space category and other factors (6.8.7).

Step 5:

Perform the hourly calculation according to ISO 52016-1 with the additions and adaptations from Step 1 through Step 4 (see 6.9).

Step 6:

Post-processing of the output of the calculation (6.10).

NOTE 1 Worked examples are provided in ISO 52016-4.

The overviews of all output data with indication of the possible destination (6.1) and all input data with indication of the source (6.3) enable to check the overall consistency between related EPB standards, where the output of one EPB standard is needed as input for the other.

NOTE 2 This conforms to the common template for each of the EPB standards.

The first steps of the calculation procedure are more generic than needed for the specific reference control scenarios. In this way the calculation procedures are ready to cover other, e.g. more novel and complex technologies, in a later update.

6 Calculation method

6.1 Output data

Subclause 6.1 provides the overview of all output data. When and how these output data are produced is specified in 6.4 to 6.10.

NOTE This subclause conforms to the common template for each of the EPB standards. It enables to check input-output relations between the EPB standards and availability of output data.

The output of the calculation is given in ISO 52016-1:2017, Tables 2 to 10. Additional output is given in Table 6, which lists the key performance indicators for the difference between the performance of the thermal zone with the adaptive building envelope element against reference or other building envelope elements.

Table 6 — Output data — Key performance indicators of the adaptive building envelope element against a reference element

Description	Symbol	Unit	Validity interval[a]	Intended destination module[b]	Varying[c]
Absolute difference in annual (a) heating, (b) cooling and (c) heating plus cooling needs per m^2 useful floor area of the thermal zone, zt	$\Delta Q_{\text{H/C/HC;nd;zt}}$	$kWh/(m^2.a)$	- ∞ to ∞	M2-4	N
Relative difference in annual (a) heating, (b) cooling and (c) heating plus cooling needs per m^2 useful floor area of the thermal zone, zt	$dQ_{\text{H/C/HC;nd;zt}}$	%	- ∞ to ∞	M2-4	N
Absolute difference in annual (a) low resp. (b) high temperatures: accumulated hours of indoor operative temperature of the thermal zone zt, during occupancy below 20 °C resp. above 25 °C [d]	$\Delta T_{\text{low/high;zt;an}}$	K·h	- ∞ to ∞	M2-4	N
Relative difference in annual (a) low resp. (b) high temperatures: accumulated hours of indoor operative temperature of the thermal zone, zt ,during occupancy below 20 °C resp. above 25 °C [d]	$dT_{\text{low/high;zt;an}}$	%	- ∞ to ∞	M2-4	N

[a] Practical range, informative.

[b] Informative.

[c] "Varying": value can vary over time: different values per time interval, for instance: hourly values or monthly values (not constant values over the year).

[d] In the context of the improvement of the set of EPB standards, specifications for a winter and summer thermal comfort score is under preparation, based on EN 16798-1, to replace this performance indicator in the future.

[e] with subscript gl instead of w for the optical properties, because the daylight and solar properties are per m^2 of projected transparent area.

Table 6 *(continued)*

Description	Symbol	Unit	Validity interval[a]	Intended destination module[b]	Varying[c]
Monthly or annual mean thermal transmittance or *U*-value of the adaptive building envelope element w, weighted by indoor-outdoor temperature difference	$U_{w;mn;m/an}$	$W/(m^2K)$	0 to 5	M2-4	Y (M)
Monthly or annual mean solar transmittance or *g*-value of the transparent part of the adaptive building envelope element w, weighted by incident irradiance [e]	$g_{gl;mn;m/an}$	-	0 to 1	M2-4	Y (M)
Monthly or annual mean daylight transmittance, τ_V of the transparent part of the adaptive building envelope element w, weighted by incident illuminance [e]	$\tau_{V;gl;mn;m/an}$	-	0 to 1	M2-4	Y (M)

[a] Practical range, informative.

[b] Informative.

[c] “Varying”: value can vary over time: different values per time interval, for instance: hourly values or monthly values (not constant values over the year).

[d] In the context of the improvement of the set of EPB standards, specifications for a winter and summer thermal comfort score is under preparation, based on EN 16798-1, to replace this performance indicator in the future.

[e] with subscript gl instead of w for the optical properties, because the daylight and solar properties are per m^2 of projected transparent area.

6.2 Calculation time intervals

The calculation time intervals shall be hourly.

If daily, monthly or yearly data are needed, they may be aggregated from hourly data by taking the monthly mean or monthly total values and adding the subscript corresponding with the period (d, m, an). The number of hours per month can be aggregated in the same way.

NOTE 1 The hourly time interval corresponds to the time intervals needed for energy calculations and the availability of hourly integrated solar irradiance data. If data on shorter time intervals is available, the method can be applied to shorter time intervals.

NOTE 2 For glare prevention, the hourly time interval can be too large, possibly leading to an unrealistically optimistic scenario. As mitigation, a conservative criterion for glare risk is applied.

A simplified monthly calculation can be developed at national level on the basis of statistical evaluation of a range of test cases calculated with the hourly method. The principles of a simplified method are provided in ISO 52016-1:2017, Annex G.

6.3 Input data

6.3.1 General

Subclause 6.3 provides the overview of all input data. When and how these input data are needed is specified in 6.4 to 6.10.

NOTE This subclause conforms to the common template for each of the EPB standards. It enables to check input-output relations between the EPB standards and availability of input data from other sources.

Input data for calculation according to ISO 52016-1:2017, 6.3 shall be used with additions as shown in 6.3.2, 6.3.4 and 6.3.5.

6.3.2 Input data of a simplified adaptive building envelope element

The list of input data of the adaptive building envelope element as given in ISO 52016-1:2017, Table 14 for transparent building elements (including windows or curtain walls), for the hourly calculation procedures, applies with the following differences:

Table 7 applies for the thermal, daylight and solar properties for each state, *st*, as specified in 6.6.

Table 7 — Input data for the thermal, daylight and solar properties of a simplified adaptive building envelope element

Name	Symbol	Unit	Validity interval[a]	Origin[b]	Varying[c]
Thermal transmittance of the adaptive building envelope element, for each state *st*	$U_{w;st}$	W/(m²·K)	0 to 10	M2-5	Yes
Total solar energy transmittance of the transparent part of the adaptive building envelope element, for each state *st*	$g_{gl;st}$ [d]	-	0 to 1	M2-8	Yes
Daylight transmittance of the transparent part of the adaptive building envelope element, for each state *st*	$\tau_{V;gl;st}$ [d]	-	0 to 1	M2-8	Yes

[a] Practical range, informative.

[b] For example: EPB module or (e.g. product) standard or "local" (type, geometry).

[c] "Varying": value can vary over time: different values per time interval, for example: hourly values or monthly values (not constant values over the year).

[d] with subscript gl instead of w for the optical properties, because the daylight and solar properties are per m² of projected transparent area.

NOTE An adaptive building envelope element with actively ventilated cavity is, as a rule, considered as a detailed adaptive building envelope element using a complex model, but a simplified approach, as described in 6.4.3.3 is possible. In that case, no extra input data are needed: the impact of heat exchange related to air circulation in and through the adaptive building envelope element is implicitly taken into account in the thermal and solar properties as listed in Table 7.

6.3.3 Input data of a detailed adaptive building envelope element

The list of input data of the adaptive building envelope element as given in ISO 52016-1:2017, Table 14 for transparent building elements (including windows or curtain walls) for the hourly calculation procedures, applies with the following differences:

In case of a detailed adaptive building envelope element, Table 8 applies for the thermo-optical properties of the components of the transparent building element.

Table 8 — Input data for the thermo-optical properties of the components of a detailed adaptive building envelope element

Name	Symbol	Unit	Validity interval[a]	Origin[b]	Varying[c]
For the adaptive building envelope element w [d]:					
The number of nodes of the model	$N_{w;pt}$	-	2 to 10	M2-8	No
Convective heat transfer coefficient internal surface	$h_{w;ci}$	W/(m²·K)	0 to 50	M2-5	Yes
Long-wave radiative heat transfer coefficient internal surface	$h_{w;ri}$	W/(m²·K)	0 to 50	M2-5	Yes
Thermal conductance between two nodes *pli* and *plj*	$h_{w;pli;plj}$	W/(m²·K)	0 to 1 000	M2-8	Yes
Convective heat transfer coefficient external surface	$h_{w;ce;st}$	W/(m²·K)	0 to 50	M2-5	Yes
Long-wave radiative heat transfer coefficient external surface	$h_{w;re;st}$	W/(m²·K)	0 to 50	M2-5	Yes
Effective solar absorptance of each node	$a_{sol;gl;eff;st}$	-	0 to 1	M2-8	Yes
Direct solar transmittance, for each state *st*	$\tau_{sol;gl;st}$	-	0 to 1	M2-8	Yes
Daylight transmittance, for each state *st*	$\tau_{V;gl;st}$	-	0 to 1	M2-8	Yes
[e]					

[a] Practical range, informative.

[b] For example: EPB module or (e.g. product) standard or "local" (type, geometry).

[c] "Varying": value can vary over time: different values per time interval, for instance: hourly values or monthly values (not constant values over the year).

[d] with subscript gl instead of w for the optical properties, because the optical properties are per m² of projected transparent area.

[e] In exceptional cases more input data can be required, depending on the details of the adaptive building envelope element, such as thermal capacity per node and transmittance for long-wave radiation per node.

For adaptive building envelope elements with actively ventilated cavity, Table 9 applies for the air flow related input data, Table 10 for the modes of ventilation and Table 11 for the types of ventilation.

Table 9 — Input data for the air flow related properties of an adaptive building envelope elements with actively ventilated cavity

Name	Symbol	Unit	Validity interval[a]	Origin[b]	Varying[c]
If naturally ventilated: the location and size of the vent openings as required in M2-8, per ventilation state, *vest*	See M2-8	See M2-8	See M2-8	M2-8	Yes
If mechanically ventilated: the air flow rate between specific nodes or internal or external environment, per ventilation state, *vest*	$q_{V;i;j}$	m³/s	0 to ∞	M2-8	Yes

[a] Practical range, informative.

[b] For example: EPB module or (e.g. product) standard or "local" (type, geometry).

[c] "Varying": value can vary over time: different values per time interval, for instance: hourly values or monthly values (not constant values over the year).

Table 10 — Ventilation modes for adaptive building envelope elements with actively ventilated cavity

Name	Description	Identifier
Applied ventilation mode, per state *vest*	[a]	AVF-mode_xxxx [a]
...		

[a] Choice between options given in 6.4.3.3.

Table 11 — Ventilation type for adaptive building envelope elements with actively ventilated cavity

Name	Description	Identifier
Applied ventilation type	[a]	AVF-type_xxxx [a]

[a] xxxx is the placeholder for the options given in 6.4.3.3.

6.3.4 Control related input data

Table 12 applies for the control type and Table 13 for the number and description of states.

Table 12 — Control type

Name	Description	Identifier
Applied control type	[a]	CNTRL_xxxx [a]

[a] xxxx is the placeholder for the options given in 6.6.

Table 13 — List of states

State number [a]	Description of state	Optionally: Numbering and description per dimension of states (see 6.4.3) [ab]			
		Substate A number	Description substate A	Substate B number	Description substate B
1					
2					
...					
...					
...					
...					

[a] The table may be extended with extra rows and columns if needed.

[b] More than one dimension is, e.g. a venetian blind (a) retracted or extended with (b) slats open or closed, or a combination of internal and external blind.

For actively controlled adaptive building envelope elements, Table 14 applies, for the sensors for the control, selected from the options given in 6.8.3.

Table 14 — List of sensors applied for the control

Variable	Symbol	Unit

For actively controlled adaptive building envelope elements, Table 15 applies, for the methods to identify the conditions or events, selected from the options given in 6.8.4.

Table 15 — Applied methods to identify the conditions or events

Mode	As assumed (in practice) [a]	As modelled in the calculation [b]	Comment [c]
DAY-MODE *Daytime or night time*			
HC-MODE *Heating, neutral or cooling mode of the thermal zone*			
TINT MODE *Operating temperature*			
RAD-MODE *Level of solar irradiance or illuminance*			
OCC-MODE *Occupancy*			
GLARE-MODE *Glare occurrence*			
DAYL-MODE *Low daylight*			
HFLW-MODE *Heat flow direction*			

[a] Select from the options given in 6.8.4 identified as MC1, MC2, ..., resp. AC1, AC2, ...

[b] Select from the options given in 6.8.4 identified as MM1, MM2, ..., resp. AM1, AM2, ...

[c] Optional, informative.

Table 16 applies for additional input data for the control, depending on the type and further specifications of the control, as specified in 6.6 for environmentally activated adaptive building envelope elements and in 6.8 for actively controlled adaptive building envelope elements.

Table 16 — Control related additional input data

Name	Symbol	Unit	Validity interval [a]	Origin [b]	Varying [c]
Internal operative temperature	$\theta_{int;op}$	°C	0 to 50	ISO 52016-1	Yes
For environmentally activated building envelope elements: the environmental condition [d], for each state *st*	X_{st} [d]	[...] [d]	... [d]	Product	Yes
For environmentally activated building envelope elements: half of the hysteresis	$\Delta X_{st;hyst}$ [d]	[...] [d]	... [d]	Product	No
Position (height, width and distance) of occupant relative to the adaptive building element [e]	H_{occ}, L_{occ}, D_{occ}	m	0 to 10	Local	No

[a] Practical range, informative.

[b] For example: EPB module or (e.g. product) standard or "local" (type, geometry).

[c] "Varying": value can vary over time: different values per time interval, for instance: hourly values or monthly values (not constant values over the year).

[d] Placeholder for the environmental conditions (e.g. the glazing temperature).

[e] Position of head, in case of estimation of glare risk if using geometrical position of occupant versus sun.

6.3.5 Climatic input data

Depending on the type and further specifications of the control, as specified in 6.8 for actively controlled adaptive building envelope elements, the climatic input data listed in Table 17 apply, in addition to the input data already needed for ISO 52016-1.

Table 17 — Additional climatic input data

Name	Symbol	Unit	Validity interval [a]	Origin [b,d]	Varying [c]
Wind velocity	$v_{w;a;t}$	m/s	0 to +50	M1-13	Yes
Wind direction	$z_{w;e;t}$	degrees	0 to 360	M1-13	Yes
Cloudiness of the sky	-	okta	0 to 1	M1-13	Yes

[a] Practical range, informative.

[b] For example: EPB module or (e.g. product) standard or "local" (type, geometry).

[c] "Varying": value can vary over time: different values per time interval, for instance: hourly values or monthly values (not constant values over the year).

[d] Some of the conditions of use can be adapted by system specific input.

6.3.6 Constants and physical data

All relevant constants and physical data given in ISO 52016-1:2017, 6.3 apply.

6.3.7 Input data from Annex A and Annex B

Annex A contains the normative template for choices in references, methods and input data. Informative default choices in references, methods and input data are given in Annex B, respecting the template of Annex A.

All these choices and input data are indispensable for the application of this document.

6.4 Properties of the adaptive building envelope element

6.4.1 General

A distinction is made between a simplified (model of the) adaptive building envelope element and a detailed (model of the) adaptive building envelope element, as explained in 6.4.2.

NOTE For readability it is called simplified or detailed adaptive building envelope element, although it actually concerns the model of the adaptive building envelope element that is simplified or detailed. There is a relation between the complexity of the element and the complexity of the model, but different levels of model simplifications are possible.

If the adaptive building envelope element consists of sections that have the same properties, but which can be individually controlled, then each section shall be modelled as a separate adaptive building envelope element, because at a given time interval each section can be in a different state.

More specific details are given per category of technology in 6.4.3 for a simplified adaptive building envelope element and in 6.4.4 for a detailed adaptive building envelope element.

6.4.2 Simplified or detailed adaptive building envelope element

6.4.2.1 Simplified adaptive building envelope element

A simplified adaptive building envelope element is defined in 3.9. It is described with a model in which the thermal, daylight and solar properties, for a given state, can be pre-calculated. This model is based on the following assumptions:

a) The thermal, daylight and solar properties (for each state) are considered to be independent of the environmental conditions, by defining fixed boundary conditions for conditions such as temperature, sun position, cloudiness and solar irradiance level.

b) The thermal mass is neglected.

c) The secondary solar energy transmission is approximated as a contribution to the direct solar energy transmission to the internal environment (thermal zone).

NOTE 1 See ISO 52022-3 or ISO 15099. More explanation can be found in ISO/TR 52016-4.

NOTE 2 The reason for simplification c) is to avoid that for the hourly calculation method more input data are needed than for the monthly calculation method. Without this simplification the threshold to use the hourly calculation method would be higher, which would have an adverse impact on the road towards more realistic calculations.

Because of these assumptions, the number of nodes in the model is limited to 2 (internal and external surface).

Because of assumption a) the thermal, daylight and solar properties of the adaptive building envelope element can be pre-calculated and provided as input values.

6.4.2.2 Detailed adaptive building envelope element

A detailed adaptive building envelope element is defined in 3.10. It is described with a more complex model than the model for a simplified adaptive building envelope element. This is the case if one of the following assumptions applies:

a) The thermal or solar properties (for a given state) are a function of the environmental conditions, such as indoor or outdoor temperature, sun position, cloudiness or the solar irradiance.

b) The number of layers is higher than 2 (internal and external surface) and cannot be mathematically reduced to 2, because either:

   1) the temperature of one of the additional layers is needed as input;

   2) the thermal, daylight or solar properties of the adaptive building envelope elements at a given hour depend on the temperature of one or more of the additional layers; such layer can include the air layer in a cavity;

c) The thermal mass cannot be neglected, because the element contains a layer with significantly higher mass than a glazing or blind.

EXAMPLE

ad a):

(1) this actually applies already for an adaptive building envelope element with venetian blinds (sun position), or internal blinds (temperature dependent air circulation behind the blind), but typically this is approximated by calculating the value for a standard situation;

(2) an adaptive building envelope element with a wide closed cavity: the thermal resistance is significantly temperature dependent due to local air circulation;

ad b1): an adaptive building envelope element with thermochromic glazing;

ad b2): an adaptive building envelope element with a naturally ventilated cavity in which the air flow is a function of the air and adjacent surface temperatures (buoyancy);

ad c): an adaptive building envelope element with a massive opaque panel on part of the area.

6.4.3 Properties of a simplified adaptive building envelope element

6.4.3.1 Adaptive building envelope element with dynamic solar shading

6.4.3.1.1 General

If an adaptive building envelope element can be adapted in two or more dimensions, states within one dimension can be specified by introducing a separate subscript, for example:

N_{stA} is the number of primary states of the adaptive building envelope element;

N_{stB} is the number of secondary states of the adaptive building envelope element;

N_{stC} is the number of tertiary states of the adaptive building envelope element.

stA, stB, stC, .. are the placeholders for more specific subscripts.

In any case, the subscript *st* shall be used for each unique combination of states.

EXAMPLE Venetian blinds down (e.g. Bst =2) combined with horizontal slats (e.g. slatst = 1) is, e.g. combined state *st* = 3.

Commonly available dimensions of states for an adaptive building envelope element with dynamic solar shading, depending on the product or assembly, can be used, as listed in Table 18.

Table 18 — Commonly available dimensions of states for an adaptive building envelope element with dynamic solar shading

Dimension of states	Description	Examples
Primary	Covering the transparent area or not	— Retracted, partially extended or fully extended venetian or roller blind — Retracted, partially extended or fully extended curtain — Retracted, partially extended or fully extended shutter
Secondary, option 1	Change of properties	— lat position of venetian blinds (open, partially closed, closed) — Shift in position of duo blind (from a specific maximum to a specific minimum transparency) — Second blind with different properties
Secondary, option 2	A secondary solar shading component, covering the transparent area or not	As primary
Tertiary	A combination of primary, secondary option 2 and secondary option 1	A combination of the examples above

If there are more than two states per dimension, the intermediate states can be used in the control scenario to find a balance for conflicting desired properties.

NOTE In the control scenarios (6.8) the fine-tuning is used (a) to find a balance between thermal aspects (energy and thermal comfort) and lighting aspects (daylight access and view out) and (b) to avoid glare while maintaining daylight access and view out.

6.4.3.1.2 Venetian blind

In case of venetian blind, intermediate states can apply to the tilt angle of the slats (if movable), between the two extremes: open or closed.

The number of intermediate states and corresponding position of the slats may be chosen freely, within the technological possibilities of the product, taking into account the following considerations:

— The optimum slat position to maximize daylight and view out while optimizing solar control and minimizing glare risk, can be specified at each hour. It is a function of the position of the sun in relation to the assumed position of the occupants and the position and optical properties of the adaptive building envelope element.

— Alternatively, a fixed slat position can be assumed that is conservative with respect to minimization of glare risk and with respect to solar heat gain (during heating mode), because the solar and daylight transmittance is not very sensitive for the precise slat angle if in partly closed position.

In a simplified approach, it can be assumed that the slats are fixed in such a position that direct solar (beam) transmittance is blocked.

EXAMPLE In case of vertical adaptive building envelope elements, a slat angle of 45° works well in hot seasons for most climates.

NOTE 1 See ISO/TR 52016-4, including reference to the results of Swiss research on the optimization of slat position.

NOTE 2 In the case of venetian blinds with the slats in such a position that direct solar radiation is fully blocked, the solar energy transmission by diffuse radiation and by ground-reflected radiation can be significantly more than the total solar energy transmittance at normal incidence, $g_{gl;n}$ would suggest.

6.4.3.1.3 Roller blind

In case of a roller blind, intermediate states can apply to adjusting the portion of the area that is covered by the blind.

The number of intermediate states and corresponding position of the blind may be chosen freely, within the technological possibilities of the product, taking into account the following considerations:

— The optimum position to maximize daylight and view out while optimizing solar control and minimizing glare risk can be specified at each hour. It is a function of the position of the sun in relation to the assumed position of the occupants and the position and properties of the adaptive building envelope element.

— Alternatively, a fixed position can be assumed that is conservative with respect to minimization of glare risk and with respect to solar heat gain (during heating mode).

— To find a balance between thermal aspects (energy and thermal comfort) and lighting aspects (daylight access and view out) the position of the blind can be arbitrary.

NOTE See further explanation in ISO/TR 52016-4.

6.4.3.1.4 Input data

The properties required as extra input for the calculation involving an adaptive building envelope element with dynamic solar shading, are:

$U_{w;st}$ is the thermal transmittance of the adaptive building envelope element in state *st*, which shall be determined according to ISO 52016-1:2017, 6.5.8.3, for each state of variation, *st*, in W/(m²·K);

$g_{gl;st}$ is the total solar energy transmittance of the transparent part of the adaptive building envelope element in state *st*, which shall be determined according to ISO 52016-1:2017, 6.5.13.2, for each state of variation, *st*;

$\tau_{V;gl;st}$ is the daylight transmittance of the transparent part of the adaptive building envelope element in state *st*, which shall be determined according to the same procedure as used for the determination of $g_{gl;st}$;

N_{st} is the number of states covering the range of variations in properties;

Minimum value: $N_{st} = 2$

Maximum value: the number of states shall not exceed the technical possibility to operate at intermediate states.

Alternatively, if technically possible and if the properties are known as a continuous function of the variation, the calculation can be performed with a continuous variation: $N_{st} = \infty$.

NOTE For actively controlled adaptive building envelope elements, a hysteresis is not an input data as for the environmentally activated adaptive building envelope elements. For actively controlled adaptive building envelope elements, hysteresis is specified in the control scenario.

6.4.3.2 Adaptive building envelope elements with chromogenic glazing

6.4.3.2.1 Environmentally activated chromogenic glazing

Environmentally activated control applies to certain types of chromogenic glazings, in which the optical properties vary with the material state.

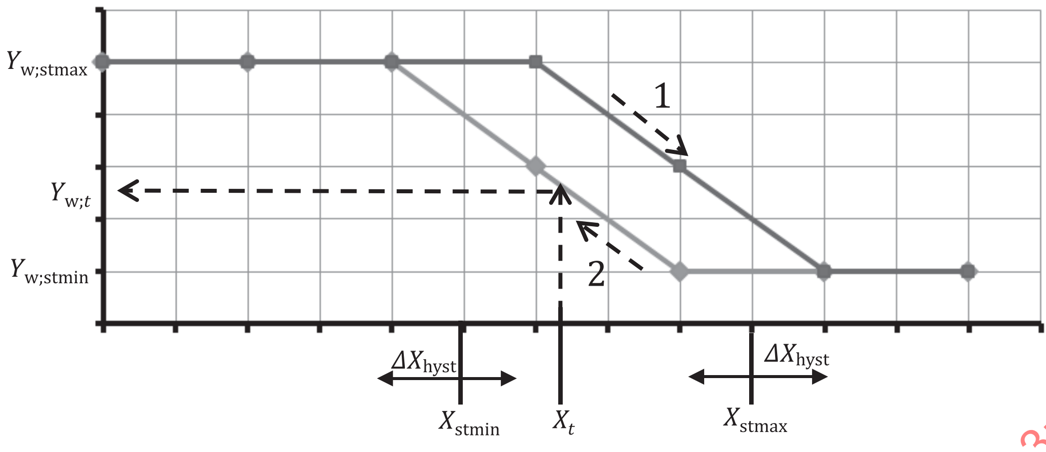
EXAMPLE 1 The optical properties change as the result of a change in glazing temperature (thermochromic, thermotropic) or as the result of a change in incident solar irradiance.

The optical properties are assumed to be a continuous linear function of the environmental conditions between a minimum and maximum value, leading to linear daylight and solar properties of the adaptive building envelope element.

However, a non-linear variation of such properties can be assumed, if manufacturer data are available, demonstrating that there is a significant difference from this linearity. In that case, the number of states shall be increased in such a way that linearization between two successive states can be assumed.

The properties shall be given for each state, *st*. The corresponding conditions shall be identified with the same subscript *st*.

The change between states can involve a hysteresis. In that case the property of the adaptive building envelope element is still a unique function of the environmental condition, but with different values depending on the direction of the change of the environmental condition. This is illustrated in Figure 1.



Key

Y property of the adaptive building envelope element

X environmental parameter

1 increasing X-values

2 decreasing X-values

Figure 1 — Different states of adaptive building envelope element with environmentally activated chromogenic glazing

NOTE A worked example for chromogenic glazing is presented in ISO/TR 52016-4.

In case of a stepwise instead of a gradual state change, X_{stmax} is equal to X_{stmin}.

The properties required as extra input for the calculation involving an environmentally activated glazing, are:

$Y_{w;st}$ is the property of the adaptive building envelope element at each state *st*; in case of a continuous linear function there are two states, corresponding to the minimum and maximum achievable by the chromogenic glazing.

The properties Y_w required to perform the calculation within this document are:

$g_{gl;st}$ is the total solar energy transmittance of the transparent part of the adaptive building envelope element, g_{gl}, which shall be determined according to ISO 52016-1:2017, 6.5.13.2, for each state *st* ;

$\tau_{V;gl;st}$ is the daylight transmittance of the transparent part of the adaptive building envelope element for each state *st*, which shall be determined according to the same procedure as used for the determination of $g_{gl;st}$.

X_{st} is the environmental conditions *X*, corresponding to the state of the property $Y_{w;st}$ of the adaptive building envelope element.

EXAMPLE 2 for a thermochromic glazing the environmental conditions X_i are the glazing temperatures (θ_{Ystmin} and θ_{Ystmax}, respectively), corresponding to the start and the end of the thermochromic cycle.

ΔX_{hyst} The difference in X_{st}-values due to hysteresis, to be obtained from manufacturers data. In case such data are not available, the following conservative default value shall be assumed.

For thermochromic glazing: ΔX_{hyst} = 30 K.

For photochromic glazing: ΔX_{hyst} = 150 W/m^2.

N_{st} is the number of states of the chromogenic glazing covering the range of variations in glazing properties.

In case of a continuous linear function: N_{st} = 2.

Otherwise, the value shall be determined as function of the technology (non-linear or discrete values).

6.4.3.2.2 Actively controlled chromogenic glazing

The optical properties of adaptive building envelope elements with actively controlled chromogenic glazing shall be assumed to be in discrete states between a minimum and maximum tinting level.

The properties required as extra input for the calculation involving an actively controlled chromogenic glazing, are:

$Y_{w;st}$ is the property of the adaptive building envelope element at each state *st*.

More specifically, the properties Y_w required to perform the calculation within this document are:

$g_{gl;st}$ is the total solar energy transmittance of the transparent part of the adaptive building envelope element, g_{gl}, which shall be determined according to ISO 52016-1:2017, 6.5.13.2, for each state *st* ;

$\tau_{V;gl;st}$ is the daylight transmittance of the transparent part of the adaptive building envelope element for each state *st*, which shall be determined according to the same procedure as used for the determination of $g_{gl;st}$.

N_{st} is the number of states covering the range of variations in properties.

The minimum number of states is N_{st} = 2, representing the minimum and maximum glazing properties achievable by the chromogenic glazing.

Otherwise, the value is which shall be determined as function of the technology (non-linear or discrete values).

The number of states shall not exceed the technical possibility to operate at intermediate states.

Alternatively, if technically possible and if the properties are known as a continuous function of the variation, the calculation can be performed with a continuous variation: $N_{st} = \infty$.

6.4.3.3 Adaptive building envelope elements with actively ventilated cavity

6.4.3.3.1 Ventilation properties and modes

An adaptive building envelope element with actively ventilated cavity is a building envelope element in which ventilation through one or more cavities of the building envelope element adds an extra dimension to the adaptive states.

Usually an adaptive building envelope element with actively ventilated cavity contains a combination of active solar shading as presented in 6.4.3.1 with a ventilated cavity or cavities. In this document the procedures are worked out for this combination.

The main parameter to define the different ventilation states is the direction of the air flow, as presented in Table 19.

NOTE 1 The mode depends on the need to harvest or to reject solar gain that is absorbed in the cavity, or to stay in a buffer mode. This is decided in 6.8 as part of the control scenario.

Table 19 — Basic ventilation modes

Name	Air flow direction	Intended effect during heating mode	Intended effect during cooling mode	Identifier AVF_Mode =
Buffer mode	No ventilation via the cavity	To create a thermal buffer to decrease heat transmission to the outside.	If outdoor air temperature higher than temperature in the thermal zone: to create a thermal buffer to decrease heat transmission to the inside.	AVF_BUF
Exhaust mode	From internal environment via the cavity to external environment	To use exhaust air to warm up the internal surface with air from the thermal zone.	If cavity warmed up by solar radiation: to use exhaust air to reject solar heat.	AVF_IE
Supply mode	From external environment via the cavity to internal environment	If cavity warmed by solar radiation: to use supply air to harvest solar heat.	If outdoor air temperature lower than temperature in the thermal zone and if cavity not heated by solar radiation: to use supply air to bring in cool air (ventilative cooling).	AVF_EI
Internal circulation	From internal environment via the cavity to internal environment	If cavity warmed by solar radiation, to harvest solar heat. Otherwise, to warm up the internal surface.	--	AVF_II
External circulation	From external environment via the cavity to external environment	--	If cavity warmed up by solar radiation: to reject solar heat. Otherwise, if outdoor air temperature lower than temperature in the thermal zone: to cool down the internal surface.	AVF_EE

The calculation of the air flow rate depends on the type of ventilation. The distinguished types are presented in Table 20.

Table 20 — Type of ventilation

Name	Description	Identifier AVF_Type =
Natural ventilation	Natural ventilation through the cavity, with air flow rate being a function of the geometry and local conditions (air pressure difference, temperatures), actively controlled by movable vents	AVF_NAT
Hybrid ventilation	Partly natural, partly mechanical ventilation	AVF_HYB
Mechanical ventilation	Mechanical ventilation through the cavity, with air flow rate actively controlled by the ventilation system	AVF_MECH

Depending on the type of ventilation, the following parameters define the ventilation related states:

If AVF_Type = NAT — A discrete number of N_{vest} states, with for each state the size of the ventilation openings in inner and outer skins, aiming at a specific air flow mode (see Table 16).

NOTE 2 The calculation of the actual air flow rate is described in 6.4.4.

If AVF_Type = MECH — A discrete number of N_{vest} states, with for each state the air flow direction (covering one or more of the modes of Table 16) and air flow rate as specified below.

NOTE 3 The modes require certain ventilation openings. It is assumed that these are set correctly for each individual state.

If AVF_Type = HYB — Combination of properties for natural and mechanical ventilation.

NOTE 4 See further explanation in ISO/TR 52016-4.

where:

N_{vest} is the number of ventilation related states of the adaptive building envelope element.

In case of a double skin facade, with one of the skins being partly opaque, the facade shall be modelled as two separate segments, each representing a cross section of the facade.

In case of a cavity that extends over the two segments, this simplification can lead to a bias in the estimation of the heat exchange; in that case it is recommended to model the cavity as a whole. This is however, not foreseen in ISO 15099. For such facades a more adequate approach can be to model the facade as two or more coupled zones, using a detailed building simulation tool.

6.4.3.3.2 Thermal and solar properties

In general, the adaptive building envelope element with actively ventilated cavity falls in the category of detailed adaptive building envelope elements: the thermal and solar properties cannot be pre-calculated, but have to be calculated each hour using the complex model and component properties as described in 6.4.4.

NOTE The cavity ventilation leads to heat exchange inside the cavity, which in turn leads to a change in thermal and solar properties of the adaptive building envelope element. This change in thermal and solar properties is a non-linear function of air flow rate and in case of natural ventilation the air flow rate, it interacts dynamically and non-linearly with the cavity temperatures.

Only if the thermal, daylight and solar properties can be pre-calculated for each state, does this type of adaptive building envelope element fall in the category of simplified adaptive building envelope elements. This requires some simplifications, which is acceptable if clearly reported.

In this case, the pre-calculated thermal, daylight and solar properties of the adaptive building envelope element shall be given as input data for each combination of states. This includes the ventilation related states, presented in the form of the ventilation modes and (optionally), different levels of air flow rates within a given mode. The impact of the heat exchange due to the air flow circulation shall be included in the thermal and solar properties.

The properties required as extra input for the calculation involving an adaptive building envelope element with actively ventilated cavity, if approximated as a simplified adaptive building envelope element, are:

$U_{w;st}$ is the thermal transmittance of the adaptive building envelope element including the impact of the heat exchange due to the air flow circulation, in state *st*, which shall be determined according to the procedure in ISO 15099, in W/(m²·K);

$g_{gl;st}$ is the total solar energy transmittance of the transparent part of the adaptive building envelope element, including the impact of the heat exchange due to the air flow circulation, in state *st*, which shall be determined according to the procedure in ISO 15099;

$\tau_{V;gl;st}$ is the daylight transmittance of the transparent part of the adaptive building envelope element in state *st*, which shall be determined according to the same procedure as used for the determination of $g_{gl;st}$;

N_{st} is the number of states covering all combinations of variations of the dynamic solar shading and the actively ventilated cavity.

6.4.4 Model and properties of a detailed adaptive building envelope element

The complex model for a detailed adaptive building envelope element implies that one or more of the thermal, daylight or solar properties depends on the actual conditions. Consequently, the thermal, daylight and solar properties of the adaptive building envelope element for a given state cannot be precalculated. As a consequence, the component properties shall be given as input instead of the thermal, daylight or solar properties of the adaptive building envelope element as a whole.

Except for thermal capacity, such a model can be found in ISO 52022-3, or, if a wider application range is needed, in ISO 15099.

NOTE 1 The application ranges of these two documents are described in ISO/TR 52016-4.

For the purpose of this document, a simplification compared to ISO 15099 or ISO 52022-3 is justified: the spectral and detailed directional optical properties shall be aggregated to non-directional and non-spectral component properties, to make them fit as input for this document.

Simplified formulae can replace the detailed angular optical models from ISO 52022-3 and ISO 15099 and the detailed optical modelling of parallel slats (ISO 15099) can be replaced by an approximating formula.

NOTE 2 Angle dependent optical properties are simplified to fixed optical properties for a representative situation (solar incidence angle and ratio direct:diffuse radiation), unless more specific data are imperative for the technology. When relevant and feasible, to avoid errors due to different angle dependent properties of the individual components, the aggregation is done at the level of the whole assembly including the adaptive component and other transparent components such as glazings. In addition, approximating formulae can be used for the optical properties (transmittance, reflectance) of venetian blinds as function of the sun position and slat angle . See examples in ISO/TR 52016-4, including reference to the results of a Swiss research on this topic.

In case of an adaptive building envelope element with actively ventilated cavity, the air cavity can, depending on the specific design and purpose, be connected to the exterior or interior environment or to other cavities.

NOTE 3 The calculation of the thermal and solar properties of building elements in ISO 15099 includes this calculation of the impact of the air circulation in a cavity on the heat transfer and, for a naturally ventilated cavity, the calculation of the air flow rate.

NOTE 4 This impact is also included in the calculation procedures of ISO 52022-3, but not for the calculation of the thermal properties, such as the *U*-value.

NOTE 5 Input data for ISO 52022-3 or ISO 15099 are the size of the vents, the cavity width and height and the porousness of the skin. For natural ventilation, the air flow rate is calculated as an intrinsic function of the environmental conditions [e.g. temperature, wind (if applicable)] and geometry (e.g. opening sizes, cavity width).

NOTE 6 The ventilation needs for the building zone are determined in the relevant standard under module M5-5 (Table A.1). This determines the need of air supply or air exhaust or no air supply or exhaust via the adaptive building envelope element.

Thermal capacity can be added to each node of the model as described in the formulae for opaque building elements in ISO 52016-1:2017, 6.5.6.3.

6.5 Connection of the model of the adaptive building envelope element to the model of the thermal zone of ISO 52016-1

6.5.1 Simplified adaptive building envelope element

The model of the adaptive building envelope element is integrated in the model for the calculation of the overall thermal balance of a thermal zone as given in ISO 52016-1:2017, 6.5.7.

6.5.2 Detailed adaptive building envelope element

The model of the adaptive building envelope element can also be integrated in the model for the calculation of the overall thermal balance of a thermal zone as given in ISO 52016-1:2017, 6.5.7, but with a few modifications:

— In case the internal surface of the adaptive building envelope element is not opaque for long-wave radiation, extra thermal radiation links from the nodes of the adaptive building envelope element to the other internal surfaces of the thermal zone shall be made.

— In case of a ventilated cavity:

  — the heat transfer to the internal environment shall be extended with a term $q_{V,k}$ for the heat transfer by ventilation by air coming from cavity k.

  — the air flow rate that originates from the external environment shall be counted as contribution to the air flow coming from outside. The effect on the thermal balance is already taken into account by the previous list item.

The calculation of the variable component properties as a function of the parameters defining the state, shall be performed iteratively until convergence is reached on the calculated properties less or equal to 0,03.

NOTE The value of 0,03 is chosen to reflect manufacturing tolerances.

6.6 Selection of control type

Four control types are distinguished, each with a different level of complexity, in line with the four classes in ISO 52120-1.[9] See Table 21.

Table 21 — Control types

Level	**Name**	**Description**	**Identifier** CNTRL_TYPE =
0	Environmentally activated control	Also known as passive control: activated by a specific environment condition.	CNTRL_PAS
1	Manual operation with manual control	Manual operation requiring an effort or a force. EXAMPLE 1 By crank or cord.	CNTRL_MAN
2	Motorized operation with manual control	The operation is motorized but requires a manual activation. EXAMPLE 2 Remote or wall switch. For active chromogenic glazing, manual operation is not applicable and ‘motorized’ shall be read as ‘driven by electric power’.	CNTRL_ MOT

Table 21 *(continued)*

Level	Name	Description	Identifier CNTRL_TYPE =
3	Automated control	Rule based, open or closed loop control, using one or more input variables. In an open-loop controller the control action from the controller is independent of the "process output": the state of the adaptive building envelope element that is being controlled. It does not use feedback to determine if its output has achieved the desired goal of the input command(s) or process set point(s). Usually the automated control allows a manual override by the occupant(s).	CNTRL_AUTO
4	Integrated control	More complex functions, with e.g. predictive algorithms or combined with control of HVAC and lighting, including feedback to determine if its output has achieved the desired goal.	CNTRL_INTEGR

From these four control types, the type that applies best to the adaptive building envelope element and how it is controlled, shall be selected for the calculation.

For level 4, integrated control, no reference control scenario is specified in this document.

6.7 Modelling of the control of the environmentally activated adaptive building envelope element

Depending on the technology, the change of states can be discrete or continuous.

If the optical properties of the adaptive building envelope element can be described as a continuous linear function of the environmental conditions, the optical property of the adaptive building envelope element $Y_{w;t}$ as function of the environmental conditions at time t is given in Formula (1):

$$Y_{w;t} = \frac{X_t - X_{stmin} + \left(\frac{\pm \Delta X_{st;hyst}}{2}\right)}{X_{stmin} - X_{stmax}} * \left(Y_{w;stmin} - Y_{w;stmax}\right) + Y_{w;stmin} \tag{1}$$

where:

Y_w is the adaptive building envelope element property as introduced in 6.4.3.2.1;

X is the environmental parameter as introduced in 6.4.3.2.1.

$\Delta X_{st;hyst}$ is the hysteresis in the environmental parameter as introduced in 6.4.3.2.1, with:
$\pm\Delta X_{st;hyst}$ is + $\Delta X_{st;hyst}$ if $X_{st;t}$ is higher than the value at the previous time interval and
$\pm\Delta X_{st;hyst}$ is - $\Delta X_{st;hyst}$ if $X_{st;t}$ is lower than the value at the previous time interval.

This is illustrated in Figure 1 in 6.4.3.2.1.

NOTE A worked example with $X_{st} = I_{sol}$ is presented in ISO/TR 52016-4.

If the change of states is discrete, the optical property of the adaptive building envelope element $Y_{w;t}$ changes if the environmental condition at time t has reached the next state.

6.8 Modelling of the control scenario for the actively controlled adaptive building envelope element

6.8.1 General

Reference control scenarios are specified in 6.8.7 for different control types, different adaptive building envelope elements and different space categories (residential and non-residential).

The reference control scenarios shall be used to compare different options.

NOTE 1 In practice, the control scenarios of actively controlled adaptive building envelope elements vary widely in complexity. They also vary with the aim to optimize for a specific building or space category, orientation or composition of the adaptive building envelope element. The reference control scenario aims to create a level playing field.

A minimum control time frequency of 1 h is considered, according to the time interval of the calculation procedure in this document.

A customized control scenario may be used instead of the reference control scenarios given in 6.8, under the following conditions in order to safeguard a fair comparison:

— the user shall perform and report the calculation for the reference control scenario as a baseline;

— details of the customized scenario shall be included in the report.

NOTE 2 Some details can be privileged information that is sensitive for competition.

Each of the control scenarios is composed of conditions and events (6.8.2) that, in a specified combination, can lead to a change of the state of the adaptive building envelope element.

In case of manual control, the conditions and events are detected by the occupant(s). In the calculation, the detection by the occupant is simulated by the detection by one or more sensors (6.8.3).

In case of automated control, the conditions and events are detected by one or more sensors (6.8.3).

The methods used for the detection of the conditions and events are specified in 6.8.4.

6.8.2 Selection of conditions and events

The conditions and events that are used in this document for the control scenarios are listed in Table 22.

Table 22 — Conditions and events distinguished for the control, with identifiers

Description	Identifier	Value1	Value2	Value3	Comment
Daytime or night time	DAY-MODE	DA	NI	n.a.	Daytime (DA; after sunrise) or night time (NI; after sunset)
Heating or cooling mode of the thermal zone	HC-MODE	HE	NE	CO	Heating (HE) or cooling (CO) load; in absence of heating or cooling system: thermal zone temperature exceeding lower resp. upper limit NE = neutral: no heating or cooling load or only small heating or cooling load During cooling mode, an additional parameter can be the internal operative temperature exceeding a specific threshold value.
Operating temperature	TINT-MODE	TN	TH	TV	Operating temperature of the thermal zone: TN = no excess, TH = high; TV = very high
Level of solar irradiance or illuminance	RAD-MODE	RL	RH	n.a.	Low (RL) or high (RH) solar irradiance or illuminance with values depending on control type (see 6.6). If in between: no state change.
Occupancy	OCC-MODE	OCC-AW	OCC-SLP	UNOCC	OCC-AW = space is occupied, occupants are awake OCC-SLP = space is occupied, occupants are sleeping UNOCC = space is unoccupied NOTE Difference between OCC-SLP and UNOCC: during OCC-SLP the occupants still require thermal comfort and indoor air quality
Glare occurrence	GLARE-MODE	GY	GN	n.a.	Protection against glare is needed (GY), not needed (GN)
Daylight level	DAYL-MODE	DN	DL	n.a.	Daylight level is fine (DN) or low (DL)
Heat flow direction	HFLOW-MODE	HFLIN	HFLOUT	n.a.	Inward (HFLIN) or outward (HFLOUT) heat flow.
Conditions that can be imposed, if applicable:					
Peak shaving required	PEAK-MODE	PKY	PKN	n.a.	PKY = peak shaving is required [a] PKN = peak shaving is not required
Protection against view in required	NOVIEW-IN-MODE	NVWY	NVWN	n.a.	Protection against view in is required (NVWY) or not (NVWN)

[a] Peak shaving: energy gets the highest priority, for instance to avoid that a certain peak of electricity extracted from the grid becomes exceeded. This requires input from the energy meter and the maximum allowed peak. This can be a predetermined value (e.g. based on a contract) or a dynamic value imposed by the electricity company. In the control scenario it will, if applicable, override, e.g. the daylight and view out requirements.

6.8.3 Selection of sensors

The types of sensors that are assumed in this document to detect specific conditions or events are presented in Table 23.

NOTE Some of the sensors serve more than one purpose. For example, a solarimeter, as input for detecting daytime, detecting glare and detecting a specific level of solar irradiance.

Table 23 — Possible sensors for the control

Variable	Symbol	Unit	Comment
External			
External solar irradiance on adaptive building envelope element (total hemispherical, perpendicular to adaptive building envelope element)	$I_{sol;w}$	W/m^2	Part of climatic input data
External global horizontal solar irradiance	$I_{sol;hor}$	W/m^2	Part of climatic input data
External global illuminance on adaptive building envelope element (total hemispherical, perpendicular to adaptive building envelope element)	$E_{V;e;w}$	lx	Calculated from irradiance
External global horizontal Illuminance	$E_{V;e;hor}$	lx	Calculated from irradiance
External (outdoor) air temperature	$\theta_{e;a}$	°C	Part of climatic input data
Cloudiness of the sky		okta	Part of climatic input data
Wind speed at location	u_{wind}	m/s	Part of climatic input data
Internal			
Indoor air temperature	$\theta_{int;a}$	°C	Calculated
Internal operative temperature	$\theta_{int;op}$	°C	Calculated
Temperature set-point for heating	$\theta_{int;set;H}$	°C	Part of input data
Temperature set-point for cooling	$\theta_{int;set;C}$	°C	Part of input data
(Sensible) hourly heating load	$\Phi_{H;ld}$	W	Calculated
(Sensible) hourly cooling load	$\Phi_{C;ld}$	W	Calculated
Occupancy	Oc	-	Part of input data
Internal horizontal daylight illuminance on work plane	$E_{V;int,wp}$	lx	Calculated [a]
Internal daylight illuminance behind the adaptive building envelope element	$E_{V;int;w}$	lx	Calculated [a]
Any other building parameter depending on the technology (i.e. surface temperature of the glazing, amount of transmitted direct solar radiation)			Calculated [a]
[a] Special calculation.			

6.8.4 Selection of methods to identify the conditions or events

Tables 24 to 31 provide, for each of the possible modes, the methods that can be chosen to identify a specific condition or event. The choice depends on the conditions and functionality of the applied technology.

NOTE 1 As Tables 24 to 31 show, different methods are possible to identify a specific condition or event. A method can be simple or more complex, depending on the function and on the type and position of sensor(s). A method can be replaced by an alternative method with the same function and applicability.

A distinction has to be made between the control process assumed in practice (MC1, MC2, ...; AC1, AC2, ...) and the way this process is modelled in the calculation (MM1, MM2, ...; AM1, AM2, ...).

NOTE 2 If this distinction would not be made, the calculation model could make use of detailed knowledge that in practice does not exist, e.g. the actual occupancy, specific temperatures (that are calculated by the model, but that are in practice not measured). This would not lead to a realistic control scenario.

In case of manual control, the methods MM1, MM2, ... describe how the condition or event that is noticed by the occupant(s) (MC1, MC2, ...) is simulated in the calculation.

In case of automated control, the methods AM1, AM2, ... describe how the condition or event that is noticed by the automated control (AC1, AC2, ...) is simulated in the calculation.

The tables provide default options. If another option than a default option is chosen, and if this option is not worked out in detail in this document, the details shall be described in the calculation report.

Table 24 — Methods to identify the conditions and events for daytime or night time (DAY-MODE: DA or NI)

Manual control, manual or motorized operation	
Assumed occupant's observation	**Modelled as**
Method MC1: The occupant visually observes daylight or darkness.	**Method MM1 (default):** One of the following equivalent methods: — Sunrise and sunset time is calculated daily. — The solar height above or below zero is calculated hourly. — The solar irradiance is calculated hourly, using an arbitrary low value as indicator. **Method MM2:** — Fixed hours for daytime and night time are specified for the full year.
Method MC2: The occupant favours to keep fixed hours for daytime and night time for the full year.	**Method MM3:** Fixed hours for daytime and night time are specified for the full year.
Automated control	
Assumed automated control	**Modelled as**
Method AC1: The external global illuminance $E_{V;e}$ or solar irradiance I_{sol} is measured with a sensor on a horizontal or any other plane. For this application such sensor only needs to detect an arbitrary low threshold value.	**Method AM1 (default):** Same as Method AC1 for the assumed automated control, with calculated instead of measured external global illuminance or irradiance.
Method AC2: The sun path is calculated, based on location and time and determine if solar height is above (> sunrise) or below zero (> sunset). No sensor involved, except time.	**Method AM2:** Same as Method AC2 for the assumed automated control.
Method AC3: Fixed hours for daytime and night time are specified for the full year.	**Method AM3:** Same as Method AC3 for the assumed automated control.

Table 25 — Methods to identify the conditions and events for heating, neutral or cooling mode of the thermal zone (HC-MODE: HE, NE or CO)

Manual control, manual or motorized operation	
Assumed occupant's observation	**Modelled as**
Method MC1: The occupant remembers the mode from the previous day or over a longer period	**Method MM1 (default):** To simulate the occupant's observation, Method AM1 from automated control is used.
Automated control	
Assumed automated control	**Modelled as**
Method AC1: If during the previous day: — the heating needs of the thermal zone, $Q_{H;nd;24}$, were larger than the cooling needs $Q_{C;nd;24}$; — or, the indoor operative temperature $\theta_{int;op;24}$ is lower than a low limit, $\theta_{int;op;24;limHE}$. Then: Heating mode (HE) If during the previous day: — the cooling needs of the thermal zone, $Q_{C;nd;24}$, were larger than the heating needs $Q_{H;nd;24}$; — or, the indoor operative temperature $\theta_{int;op;24}$ is higher than a high limit, $\theta_{int;op;24;limCO}$. Then: Cooling mode (CO) Otherwise: Neutral mode (NE) The low limit $\theta_{int;op;24;limHE}$ and high limit $\theta_{int;op;24;limCO}$ of $\theta_{int;op;24}$ can vary as part of the specific control scenario in 6.8.6. The previous day is specified as the most recent completed 24 h period starting at 07h00 in the morning.	**Method AM1 (default):** Same as Method AC1 for the assumed automated control, with heating and cooling need or indoor temperature calculated by ISO 52016-1.
Method AC2: If during the previous day: — the time-average outdoor air temperature, $\theta_{e;a;24}$ is lower than a low limit, $\theta_{e;a;24;limHE}$, Then: Heating mode (HE). — the time-average outdoor air temperature, $\theta_{e;a;24}$ is higher than this low limit, $\theta_{e;a;24;limHE}$, but lower than a high limit, $\theta_{e;a;24;limCO}$ Then: Neutral mode (NE). — the time-average outdoor air temperature, $\theta_{e;a;24}$ is higher than this high limit, $\theta_{e;a;24;limCO}$ Then: Cooling mode (CO). The values for the low limit $\theta_{e;a;24;limHE}$ and high limit $\theta_{e;a;24;limCO}$ can vary as part of the specific control scenario in 6.8.6. The previous day is specified as the most recent completed 24 h period starting at 07h00 in the morning.	**Method AM2:** Same as Method AC2 for the assumed automated control.

Table 26 — Methods to identify the conditions and events for the operating temperature of the thermal zone (TINT-MODE: TN, TH or TV)

Manual control, manual or motorized operation	
Assumed occupant's observation	**Modelled as**
Method MC1: The occupant senses the operating temperature $\theta_{int;op}$ as fine (TN), as high (TH) or as very high (TV). The limit between TN and TH, $\theta_{int;op;limTN}$ and the limit between TH and TV, $\theta_{int;op;limTH}$ can vary as part of the specific control scenario in 6.8.6.	**Method MM1 (default):** To simulate the occupant's observation, the calculated operating temperature is used.
Automated control	
Assumed automated control	**Modelled as**
Method AC1: The operating temperature $\theta_{int;op}$ is measured. The limit between 'fine' and 'high, $\theta_{int;op;limTN}$ and the limit between 'high' and 'very high' $\theta_{int;op;limTH}$ can vary as part of the specific control scenario in 6.8.6.	**Method AM1 (default):** Same as Method AC1 for the assumed automated control, with calculated instead of measured operating temperature.

Table 27 — Methods to identify the conditions and events for the level of solar irradiance or illuminance (RAD-MODE: RL or RH)

Manual control, manual or motorized operation	
Assumed occupant's observation	**Modelled as**
Method MC1: The occupant visually observes the illuminance through the window as high or low.	**Method MM1 (default):** Specific levels of calculated external solar irradiance at the plane of the adaptive building envelope element are used (with hysteresis) as thresholds to decide if the irradiance or illuminance is high or low.
Automated control	
Assumed automated control	**Modelled as**
Method AC1: The external illuminance, $E_{V;e;w}$, is measured on the plane of the adaptive building envelope element and is considered low if it is lower than a lower limit, $E_{V;limRL}$, and high if it is higher than a high limit $E_{V;limRH}$. Alternatively, the external solar irradiance $I_{sol;tot;w}$ is measured. For the conversion from solar irradiance to illuminance and vice versa the following conversion formula, from ISO 52010-1, applies in Formula (2): $E_{V;e} = K_V \cdot I_{sol;tot}$ (2) Where $E_{V;e}$ is the external global illuminance on a surface, in lx; K_V is the global luminous efficacy, in lm/W; $I_{sol;tot}$ is the total solar irradiance on the same surface, in W/m^2. With K_V = 115 lm/W, the average value for different types of sky. The values for the low limit $E_{V;limRL}$ and high limit $E_{V;limRH}$ vary as part of the specific control scenario in 6.8.6.	**Method AM1 (default):** Same as Method AC1 for the assumed automated control, with calculated instead of measured external illuminance or irradiance.

Table 27 *(continued)*

Method AC2: As alternative to Method AC1, a horizontal sensor is used, to measure $E_{V;e;hor}$ or $I_{sol;tot;hor}$. This method has not been worked out in this document. NOTE In this case a larger uncertainty occurs in the conversion to irradiance or illuminance on a vertical or tilted plane, so more conservative criteria are needed.	**Method AM2:** Same as Method AC2 for the assumed automated control, with calculated instead of measured external illuminance or irradiance.

Table 28 — Methods to identify the conditions and events for occupancy (OCC-MODE: OCC-AW, OCC-SLP, UNOCC)

Manual control, manual or motorized operation	
Assumed occupant's observation	**Modelled as**
Method MC1: The occupant is actually present in the space and is capable to activity, or the occupants is actually present in the space but not capable to activity (e.g. sleeping), or the occupant is actually absent	**Method MM1 (default):** Actual occupancy detection is not possible, so an actual occupancy has to be modelled. The same method is used as Method AM1 for automated control.
Automated control	
Assumed automated control	**Modelled as**
Method AC1: A sensor is used that detects the presence of occupants. EXAMPLE A PIR-based motion detector. NOTE An assumed occupation schedule is an optional alternative method, but this method is ignored. It would lead to different results.	**Method AM1 (default):** Actual occupancy detection is not possible, so an actual occupancy has to be modelled. In this method this is done by using a pre-determined occupation schedule with superposed fixed pre-determined hours of absence. This method is included in ISO 52016-1 based on input regarding conditions of use (per space category) from EN 16798-1. NOTE This is also the reason for not simplifying the night time hours (Table 20). **Method AM2:** Actual occupancy detection is not possible, so an actual occupancy has to be modelled. In this method this is done by using a pre-determined occupation schedule with superposed pre-determined quasi randomly chosen hours of absence
Method AC2 It is assumed that the automated control contains a programmed occupancy schedule, which can include bedtime when relevant. NOTE This implies that the actual occupancy is ignored. However, the option of a user intervention is foreseen.	**Method AM3:** Same as Method AC2 for the assumed automated control.

Table 29 — Methods to identify the conditions and events for glare occurrence (GLARE-MODE: GN or GY)

Manual control, manual or motorized operation	
Assumed occupant's observation	**Modelled as**
Method MC1: It is assumed that the occupant has a specific position and visually experiences glare or not.	**Method MM1 (default):** To simulate the occupant's experience, the same method is used as Method AC1 for automated control. NOTE The threshold value can be different.
Automated control	
Assumed automated control	**Modelled as**
Method AC1: The daylight glare probability, P_{dglare}, is assessed, based on the external hourly daylight illuminance using Formula (3): $P_{dglare} = 0,25 \times 6,22 \cdot 10^{-5} E_{V;e;w} + 0,184$ (3) where $E_{V;e;w}$ is the external daylight illuminance on the adaptive building envelope element, in lx. If the P_{dglare} exceeds a specific limit, $P_{dglare;limGY}$, it is assumed that protection against glare is needed. The value of $P_{dglare;limGY}$ can vary as part of the specific control scenario in 6.8.6. NOTE See ISO/TR 52016-4 for background information.	**Method AM1 (default):** Same as Method AC1 for the assumed automated control, with calculated instead of measured external illuminance or irradiance
Method AC2: A simplified geometric approach, estimating the vertical illuminance on the occupant, using the estimated hourly solar illuminance level and direction, the position and view direction of the occupant, combined with the geometrical data and daylight transmittance of the adaptive building envelope element. This model only works if the position of the occupants is more or less predefined. In that case it can be calculated if the sun is in the line of sight of (one of) the occupant(s) and what is the level of illuminance on the occupant's eyes. This method has not been worked out in this document. NOTE See ISO/TR 52016-4 for examples	**Method AM2:** Same as Method AC2 for the assumed automated control, with calculated instead of measured external illuminance or irradiance
Method AC3: Estimation of the glare risk by direct measurement (e.g. indoor CCD camera into direction of the window). This method has not been worked out in this document. NOTE See ISO/TR 52016-4 for examples	**Method AM3:** Same as Method AC3 for the assumed automated control, with calculated instead of measured external illuminance or irradiance

Table 30 — Methods to identify the conditions and events for low daylight (DAYL-MODE: LN or LL)

Manual control, manual or motorized operation	
Assumed occupant's observation	**Modelled as**
Method MC1: It is assumed that the occupant has a specific position and visually experiences too low daylight level.	**Method MM1 (default):** To simulate the occupant's experience, the same method is used as Method AC1 for automated control. NOTE The threshold value can be different.
Automated control	
Assumed automated control	**Modelled as**
Method AC1: The internal illuminance at desk level, $E_{V;int;desk}$, (in lx) is estimated with a simplified formula: $E_{V;int;desk} = a_{dayl} \cdot \tau_{V;gl} \cdot H_{gl;1m} \cdot E_{V;e;w} + b_{dayl}$ (4) with maximum value $E_{V;int;desk}=E_{V;e;w}$ where $E_{V;e;w}$ is the external daylight illuminance on the adaptive building envelope element, in lx; $\tau_{V;gl}$ is the daylight transmittance of the transparent part of the adaptive building envelope element; a_{dayl} is a coefficient, in 1/m; b_{dayl} is a coefficient, in lx; $H_{gl;1m}$ is the height of the transparent area of the adaptive building envelope element above 1 m from the floor , in m. If $E_{V;int;desk}$ falls below a specific limit, $E_{V;int;desk;limLL}$, it is considered to be low. The value of $E_{V;int;desk;limLL}$ can vary as part of the specific control scenario in 6.8.6. NOTE See ISO/TR 52016-4 for background information.	**Method AM1 (default):** Same as Method AC1 for the assumed automated control, with calculated instead of measured external illuminance or irradiance

Table 31 — Methods to identify the conditions and events for heat flow direction (HFLW-MODE)

Manual control, manual or motorized operation	
Assumed occupant's observation	**Modelled as**
Method MC1: Not applicable.	**Method MM1:** Not applicable.
Automated control	
Assumed automated control	**Modelled as**
Method AC1: Simplified approach: the measured indoor operative temperature, $\theta_{int;op}$ and outdoor air temperature, $\theta_{e;a}$ are used to guess whether the heat flow through the window is inward or outward: If $\theta_{int;op} > \theta_{e;a}$: outward heat flow, otherwise: inward heat flow.	**Method AM1 (default):** Same as Method AC1 for the assumed automated control, but with calculated indoor operational temperature and outdoor air temperature as input data.

Table 31 *(continued)*

Method AC2:	**Method AM2:**
Detailed approach: a simplified thermo-optical model of the adaptive building envelope element is used to estimate if the heat flow at the given moment is inward or outward. Depending on the details of the chosen method this requires one or more sensors, such as indoor and outdoor temperature and solar irradiation. This method has not been worked out in this document.	Same as Method AC2 for the assumed automated control, but with calculated instead or measured sensor values as input data.

6.8.5 Basic rules for the reference control scenario

6.8.5.1 General

The reference control scenarios are based on the following assumptions and rules.

6.8.5.2 Individual modes

a) DAY-MODE, RAD-MODE, GLARE-MODE: No difference is made between measurement of external total solar irradiance or measurement of external global illuminance on the adaptive building envelope element. Formula (2) presented in Table 27 is used for the conversion between these two variables.

b) HC-MODE: during heating mode, solar heat is harvested and during cooling mode solar heat is rejected.

c) OCC-MODE:

   1) In case of manual control: if the space becomes unoccupied or occupied with occupants sleeping, the state remains unchanged.

   2) In case of the automated control:

      i. in case of residential spaces: the automated control does not have a presence detection. This implies that for residential buildings, during daytime, the need for daylight and view out is also taken into account if the space is unoccupied;

      ii. in case of non-residential spaces: the automated control has a presence detection. This implies that for non-residential buildings, during daytime, the need for daylight and view out is only taken into account if the space is occupied.

d) During daytime and if occupied with occupants awake the need for daylight and view out is taken into account, unless this is overruled by glare protection (GLARE-MODE) or by peak shaving (PEAK MODE).

e) But: Peak shaving (PEAK MODE) is ignored in the reference control scenario.

f) GLARE-MODE:

   1) for residential spaces glare is ignored, because of the possible variation in occupants' positions;

   2) for non-residential spaces: in case of glare problem, the adaptive building envelope element is darkened, in a way that depends on the technology.

g) NOVIEWIN-MODE: it depends on the space category whether protection against view in is taken into account.

h) User behaviour:

1) in case of manual control: if occupied with occupants awake, a fraction of the occupants does not respond; see 6.8.6 for more details;

2) in case of manual control: during daytime and if occupied with occupants awake. a fraction of the occupants changes the state to less dark, if the internal environment becomes too dark due to darkening of the adaptive building envelope element; see 6.8.6 for more details;

3) in case of automated control: during daytime and if occupied with occupants awake. a fraction of the occupants intervenes if the internal environment becomes too dark due to automatic darkening of the adaptive building envelope element; see 6.8.6 for more details.

6.8.5.3 Combinations of choices

a) The description and differentiation of states can be different for different types or compositions of adaptive building envelope elements.

b) The main combinations of choices during daytime, occupied, with occupants being awake, are presented in Table 32. The combinations of choices for unoccupied and night time are more diverse, but less complex. Therefore, those combinations are presented for each reference control scenario separately in 6.8.7.2.

Table 32 — Basic scheme for the reference control scenarios during daytime and occupied with occupants awake

HC-MODE	TINT-MODE	RAD-MODE	GLARE-MODE	DAYL-MODE	State (qualitative)	If manual control: Occupant fraction not-responding	If automated control: Occupant intervention fraction
HE	--	--	GN	--	Lightest	Fraction keeps dark	
			GY	--	Darkest	Fraction keeps light	
CO	TN	--	GN	--	Lightest	Fraction keeps dark	
			GY	LN	Darkest	Fraction keeps light	
				LL	Dark(est) [a]	Fraction keeps light	Fraction intervenes to get more daylight
	TH	RL	GN	--	Lightest	Fraction keeps dark	
		RH	GY	LN	Darkest	Fraction keeps light	
				LL	Dark(est) [a]	Fraction keeps light	Fraction intervenes to get more daylight
	TV	RL	--	--	Lightest	Fraction keeps dark	
		RH	--	LN	Darkest	Fraction keeps light	
				LL	Dark(est) [a]	Fraction keeps light	Fraction intervenes to get more daylight

[a] If manual control: with correction in case of too low daylight.

NOTE The identifiers are specified in 6.8.2, Table 23.

6.8.5.4 Limit values of the control parameters

a) The limit values for manual control and operation are the same or more conservative than for motorized operation.

b) The limit values for manual control and motorized operation are the same or more conservative than for automated control.

c) The limit values can be different for different space categories.

d) The limit values can be different for different types or compositions of adaptive building envelope elements.

6.8.5.5 Adaptive building envelope elements with actively ventilated cavity

a) If feasible, given the specific technology, the air flow through the cavity is guided as to either harvest solar heat, reject solar heat, or to warm up or cool down the internal surface, depending on the heating or cooling mode (HC-MODE), low or high solar irradiance level (RAD-MODE) and direction of the heat flow through the adaptive building envelope element (HFLOW-MODE).

b) (Part of) the ventilation air for the thermal zone can be supplied to or extracted from the thermal zone via the cavity or cavities of the adaptive building envelope element. Or the air is only circulating via the cavity or cavities to the same (internal or external) environment. This is decided in ISO 52016-1 as part of the overall energy and air quality considerations for the thermal zone and the type of ventilation system.

6.8.6 Modelling of the user behaviour

6.8.6.1 General

In case of manual control, the reference control scenario assumes a specific rational and active occupant behaviour. In practice, however, a certain fraction of occupants is less active. In the reference control scenario this is taken into account by assuming that a fraction of the occupants will not change the state of the adaptive building envelope element as otherwise assumed in the control scenario.

In case of automated control, the reference control scenario assumes that the occupants intervene if the internal daylight illuminance becomes too low due to the automated control. In practice, however, a certain fraction of occupants can be less active. In the reference control scenario this is taken into account by the option that a fraction of the occupants will not change the state of the adaptive building envelope element as otherwise assumed in the control scenario.

NOTE These considerations are based on international research as explained in ISO/TR 52016-4.

To take these less active occupants into account in the calculation, one of the following three approaches in 6.8.6.2, 6.8.6.3 and 6.8.6.4 can be chosen. If another option than the default approach 1 is chosen, the details of the used approach shall be described in the calculation report.

6.8.6.2 Approach 1 (default)

The fraction of occupants deviating from the assumed rule is translated into: the standard occupant(s) leave a fraction of the adaptive building envelope element unchanged.

NOTE This is the simplest approach. Although this is an approximation of the real situation, this approach is justified in absence of a better practical approach.

6.8.6.3 Approach 2

The fraction of occupants deviating from the (assumed) rule is translated into: the standard occupant(s) deviates from the assumed rule during a fraction of the calculation period, e.g. if the fraction is 1/N: for one day per each N days period.

Approach 2 has not been worked out in this document.

NOTE This is a similar approach as approach 1, but there is a risk that it will be less reproducible and less transparent.

6.8.6.4 Approach 3

The fraction of occupants deviating from the (assumed) rule is taken into account by having two separate calculations, one calculation with the standard occupant(s) following the assumed rules and a second calculation with the standard occupant(s) deviating from the assumed rules. In this approach the output of both calculations, in terms of the energy performance and thermal comfort, needs to be combined by taking the weighted average. In a more refined version, intermediate user behaviour can be taken into account by additional calculations with subsequent more refined weighting.

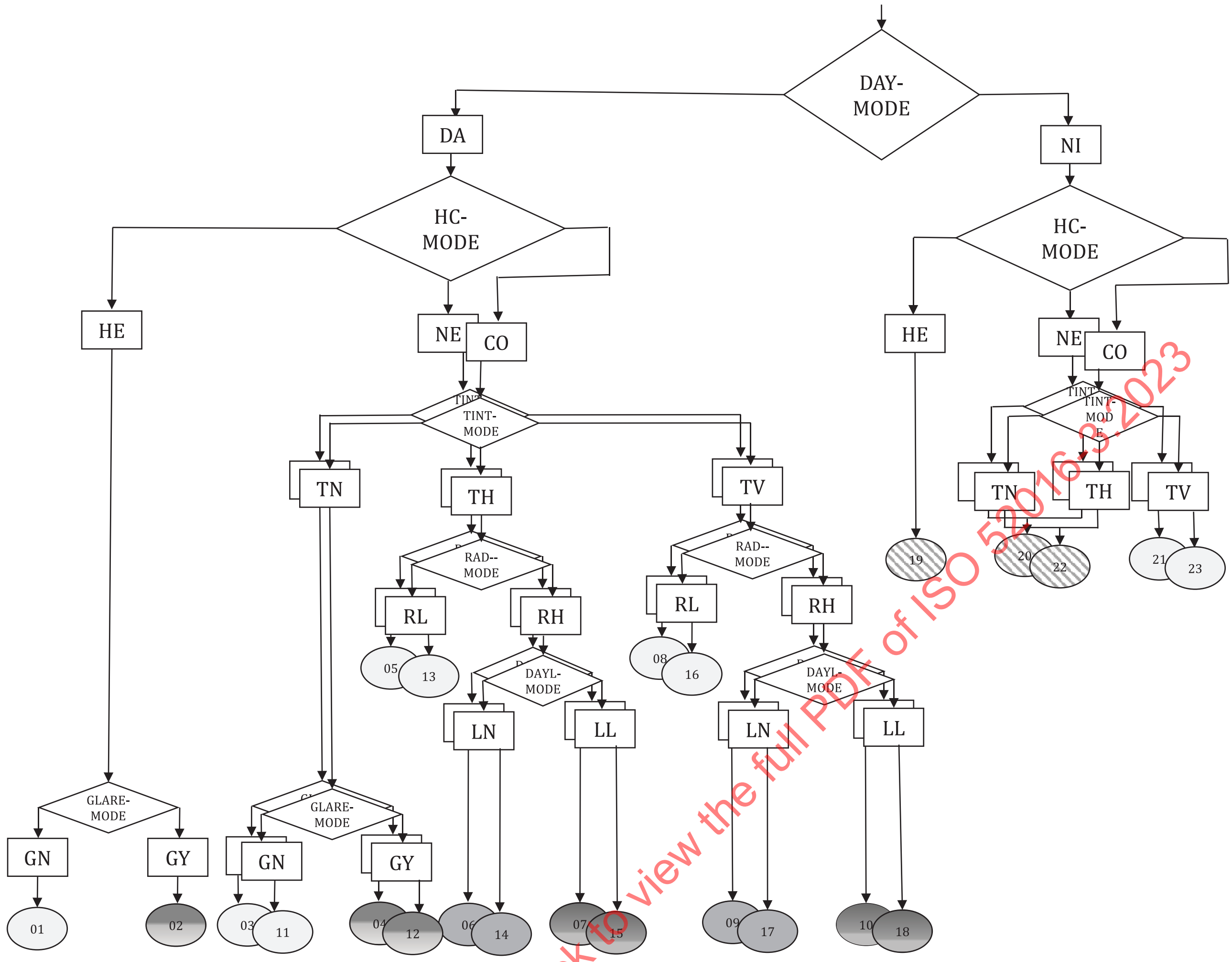
Approach 3 has not been worked out in this document.

NOTE This is a more detailed approach, but less practically feasible.

6.8.7 Reference control scenarios

6.8.7.1 General parameter values

Figure 2 shows a flow diagram with the main elements of the reference control scenarios: the various conditions that ultimately lead to a specific state. As shown in the diagram, the total number of possible states is 23. However, not all choices are always applicable, and the resulting states are not necessarily all different. This depends on the combination of type of adaptive transparent building envelope element, type of control and space category. Moreover, the actual change from one state to the other depends on specific rules related to occupants, as presented in 6.8.6. The combined result is presented in Annex C.



Key

The identifiers are specified in 6.8.2, Table 23.

Figure 2 — Main elements of the reference control scenarios

The parameter values that are specified for the reference control scenarios are given in Table 33.

NOTE Many are the same for all scenarios. These could have been integrated in the description of the methods in 6.8.4, but by specifying the values here it is easier to differentiate the values when needed in future versions of this document.

Table 33 — Parameter values specified for the reference control scenarios

Mode	For method	Parameter (see Table 21)	Value	Unit
DAY-MODE (see Table 24) Daytime or night time	--	No parameters		
HC-MODE (see Table 25) Heating, neutral or cooling mode of the thermal zone	MM1, AM1	$\theta_{int;op;24;limHE}$	20	°C
		$\theta_{int;op;24;limCO}$	23	°C
	AM2 [b]	$\theta_{e;a;24;limHE}$	12	°C
		$\theta_{e;a;24;limCO}$	16	°C
TINT MODE (see Table 26) Operating temperature	MM1, AM1	$\theta_{int;op;limTN}$	22	°C
		$\theta_{int;op;limTH}$	24	°C
RAD-MODE (see Table 27) Level of solar irradiance or illuminance	MM1, AM1	Varies per situation, see 6.8.6		
OCC-MODE (see Table 28) Occupancy	MM1, AM1	The occupancy pattern is defined in ISO 52016-1		
GLARE-MODE (see Table 29) Glare occurrence	MM1	$P_{dglare;limGY}$	0,45 [a]	--
	AM1	$P_{dglare;limGY}$	0,45 [a]	--
DAYL-MODE (see Table 30) Low daylight	MM1, AM1	a_{dayl}	[c]	1/m
		b_{dayl}	[c]	lx
	MM1	$E_{V;int;desk;limLL}$	300	lx
	AM1	$E_{V;int;desk;limLL}$	300	lx
HFLW-MODE (see Table 31 Heat flow direction	--	No parameters		

[a] This corresponds with $E_{V;e;w}$ = 4 500 lx.

[b] Not a default choice.

[c] To be determined.

6.8.7.2 Reference control scenarios for adaptive building envelope elements with active solar shading or chromogenic glazing

The reference control scenarios for adaptive building envelope elements with active solar shading or chromogenic glazing are specified in Annex C, for different combinations of control types, types of adaptive building envelope elements and space categories (residential and non-residential).

6.8.7.3 Additional reference control scenarios for adaptive building envelope elements with actively ventilated cavities

For adaptive building envelope elements with actively ventilated cavities, Table 34 provides a set of default rules for the ventilation modes. These default rules may be replaced by rules that fit to the intended and possible functionalities of the technology.

Table 34 — Default basic scheme, adaptive building envelope elements with actively ventilated cavity; manual or automated control

DAY-MODE	HC-MODE		RAD-MODE	HFLOW MODE	Main function	AVF-MODE =	NOTES
DA	HE		RL	--	Warm up internal surface	AVF-IE or [a] AVF-II	
			RH	--	Harvest solar heat	AVF-EI or [a] AVF-II	
	CO		RL	Outward flowing	Cool down cavity	AVF-EI or [a] AVF-EE	
				Inward flowing	Cool down internal surface	AVF-IE or [a] AVF-II	
			RH	--	Reject solar heat	AVF-IE or [a] AVF-EE	
NI	HE			--	Warm up internal surface	AVF-IE or [a] AVF-II	
	CO			Outward flowing	Cool down cavity	AVF-EI or [a] AVF-EE	
				Inward flowing	Cool down internal surface	AVF-IE or [a] AVF-II	

[a] Depending whether (part of) the ventilation air for the thermal zone is to be supplied or extracted via the cavity or cavities of the adaptive building envelope element, according to ISO 52016-1.

NOTE Worked out examples are given in ISO/TR 52016-4.

6.9 Hourly calculation procedures

Apply the hourly calculation procedures according to ISO 52016-1:2017, 6.5, with the additions and adaptations specified in the previous clauses of this document.

6.10 Post-processing: performance characteristics

The post-processing of the calculation results can include for instance:

— “statistics” on the use of the different states of the adaptive building envelope element;

— impact indicator (for a specific application or reference situation);

— indicator for smartness or smart readiness.

Key performance indicators are:

For the thermal zone with the adaptive building envelope element, zt:

The difference between the calculated annual energy needs for heating and cooling against a reference element or against the same adaptive building envelope element but with different control strategies, expressed as:

— Difference in annual heating needs, absolute: $\Delta Q_{H;nd;zt}$ [kWh/(m^2.a)] and relative: $dQ_{H;nd;zt}$ [%].

— Difference in annual cooling needs, absolute: $\Delta Q_{C;nd;zt}$ [kWh/(m^2.a)] and relative: $dQ_{C;nd;zt}$ [%]).

— Difference in annual heating plus cooling needs, absolute: $\Delta Q_{HC;nd;zt}$ [kWh/(m^2.a)] and relative: $dQ_{HC;nd;zt}$ [%]).

Difference between the calculated thermal comfort against a standard reference element, expressed as for example:

— low temperatures: accumulated hours of indoor operative temperature during occupancy below 20 °C, absolute: $\Delta T_{low/zt;an}$ [K.h] and relative: $dT_{low;zt;an}$ [%].

— high temperatures: : accumulated hours of indoor operative temperature during occupancy above 25 °C, absolute: $\Delta T_{high;zt;an}$ [K.h] and relative: $dT_{high;zt;an}$ [%].

NOTE In the context of the improvement of the set of EPB, standards specifications for a winter and summer thermal comfort score is under preparation, based on EN 16798-1, to replace this performance indicator in the future. See ISO TR 52016-4 for more details.

Annual or monthly time average value of the thermo-solar properties of the transparent part of the adaptive building envelope element, weighted by a relevant parameter indicating the conditions. In particular:

— Mean thermal transmittance or $\underline{U}$-value of the adaptive building envelope element, in W/(m^2 K), weighted by indoor-outdoor temperature difference, in K;

— Mean solar transmittance or g_{gl}-value of the transparent part of the adaptive building envelope element, weighted by incident total solar irradiance $I_{sol;gl}$ in W/m^2;

— Mean daylight transmittance, $\tau_{V;gl}$ of the transparent part of the adaptive building envelope element, weighted by incident externa; global illuminance, $E_{V;e;gl}$ in lx.

However, these key performance indicators shall not be regarded as product information. They are only valid for the given combination of building, climate, conditions of use and control (type and specifications).

7 Quality control

The following checks can be made to increase confidence in correct implementation of the calculation procedures of this document:

— Perform one or a few calculations with a fixed extreme state of the adaptive building envelope element to check if the result is plausible.

— Analyse during representative short time series the subsequent changes of the state of the adaptive building envelope element as a function of the parameters in the control scenario, to check the plausibility of the changes.

8 Conformance check

A conformance check shall be done to see if the calculation procedure is applicable and has been applied correctly and that the calculation assumptions and the input data are correct.

For input data gathered through other EPB documents, conformance checks shall be done according to each document.

Specific additional procedures are as follows:

— Include in the report a general description of the building, the adaptive building envelope element, the control type and the set of indoor and outdoor conditions.

— List all input data and selected options and additional details (see 6.8.1, 6.8.4) to ensure traceability.

— Report basic intermediate results in the calculation report.