Technical Report

ISO/TR 52016-4

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

Part 4:
Explanation and justification of ISO 52016-3

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

Partie 4: Explication et justification de l'ISO 52016-3

Contents

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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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

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

0.1   Set of EPB standards and supporting tools

This document gives guidance to a set of international standards that is used to collectively assess the overall energy performance of buildings (EPB). Throughout this document, this group of standards is referred to as the "set of EPB standards".

All EPB standards follow specific rules to ensure overall consistency, unambiguity and transparency (see ISO 52000-1 , CEN/TS 16628 and CEN/TS 16629).

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.

One of the main purposes of the set of EPB standards is to enable laws and regulations to directly refer to the EPB standards and make compliance with them compulsory. This requires that the set of EPB standards consists of a systematic, clear, comprehensive and unambiguous set of energy performance procedures. The number of options provided is kept as low as possible, taking into account national and regional differences in climate, culture and building tradition, policy and legal frameworks (subsidiarity principle). For each option, an informative default option is provided (see Annex B).

0.2   Rationale behind the set of EPB technical reports

There is a risk that the purpose and limitations of the EPB standards will be misunderstood, unless the background and context to their contents, and the thinking behind them, is explained in some detail to readers of the standards. Consequently, various types of informative contents are recorded and made available for users to properly understand, apply and nationally or regionally implement the set of EPB standards.

If this explanation were attempted in the standards themselves, the result is likely to be confusing, especially if the standards are implemented or referenced in national or regional building codes.

Therefore, each EPB standard is accompanied by an informative technical report, e.g. this document, where all informative content is collected, to ensure a clear separation between normative and informative content (see CEN/TS 16629 for a more detailed explanation):

— to underscore the difference between the normative and informative content;

— to reduce the page count of the actual standard;

— to facilitate understanding of the set of EPB standards.

0.3   This document

This document gives guidance on ISO 52016-3. The role and the positioning of ISO 52016-3 in the set of EPB standards is defined in the introduction of ISO 52016-3. A brief article on the subject can be found in the REHVA Journal[21].

To fully understand this document, it is intended to be read in close conjunction, clause by clause, with ISO 52016-3. Essential information provided in ISO 52016-3 is not repeated in this document. References to a clause can refer to the combined content of that clause in both ISO 52016-3 and this document.

0.4   Accompanying spreadsheet

An extensive spreadsheet [35] has been prepared to test and demonstrate ISO 52016-1. For the purpose of testing and demonstrating ISO 52016-3, this spreadsheet has been extended with an (optional) sheet to cover adaptive building envelope elements with different states and different control scenarios according to ISO 52016-3.

Examples of calculations with adaptive building envelope elements are found in this document.

0.5   Background of this document and ISO 52016-3

ISO 52016-3 and the supporting technical report (this document) have been developed to respond to a strong need to include adaptive building envelope elements in the assessment of the energy performance of buildings. This inclusion aims to create a level playing field for conventional and promising techniques.

More extensive background information and history of the whole set of EPB standards is given in the introduction to ISO/TR 52000-2, the technical report accompanying the overarching EPB standard. Up-to-date information on the set of EPB standards can be found in the "public material" section of the ISO/TC 163 page on the ISO website.[1]

0.6   Application area of ISO 52016-3

ISO 52016-3 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 ISO 52016-1, with additions or modifications that are needed to incorporate adaptive building envelope elements in the calculation.

The main use of ISO 52016-3 is the assessment of the energy performance of buildings (energy performance labels and certificates), including comparison between buildings and for checking compliance with minimum energy performance criteria.

ISO 52016-3 is applicable to buildings at the design stage, to new buildings after construction and to existing buildings in the use phase.

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[1]   https://www.iso.org/committee/53476.html.

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

Part 4:
Explanation and justification of ISO 52016-3

1   Scope

This document provides explanation and justification to support the correct understanding and use of ISO 52016-3.

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 performance of buildings and building components — Physical quantities and definitions*

ISO 9488, *Solar energy — Vocabulary*

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

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

ISO 52016-3:2023, *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*

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 ISO 52016-3:2023 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/

4   Symbols, subscripts and abbreviations

4.1   Symbols

For the purposes of this document, the symbols given in ISO 52000-1, ISO 52016-1 and ISO 52016-3:2023 apply.

More information on key EPB symbols is given in ISO/TR 52000-2.

4.2 Subscripts

For the purposes of this document, the subscripts given in ISO 52000-1, ISO 52016-1 and ISO 52016-3:2023 apply.

More information on key EPB subscripts is given in ISO/TR 52000-2.

NOTE 1   ISO 52016-1 uses input data from many technology fields. In the exceptional cases that subscripts in ISO 52016-1 are different from subscripts in other EPB standards that produce output needed as input to ISO 52016-1, these differences are reported in a special column in the tables with the overview of input data in 6.3. This can occur when the source documents use subscripts that are crucial for that specific technology field, but conflict with subscripts that are crucial for another specific technology field.

EXAMPLE   Subscript g used for both "glazing" and for "ground".

NOTE 2   In ISO 52016-3 the subscript w (origin: "window"), used in ISO 52016-1 for transparent construction elements is also used for the adaptive building envelope element.

NOTE 3   For the solar and daylight properties the subscript gl (origin: "glazing"), is used as a rule to specifically refer to the projected area of the transparent part of the element.

4.3 Abbreviated terms

For the purposes of this document, the abbreviated terms given in ISO 52016-1 and ISO 52016-3:2023 apply.

More information on key EPB abbreviated terms is given in ISO/TR 52000-2.

5 Description of the method

5.1 Output of the method

The structure of ISO 52016-3:2023, Clause 5 conforms to the common template for the set of EPB standards. ISO 52016-3:2023, Clause 5 contains a brief (qualitative) description of the method, starting with the main output from the standard.

ISO 52016-3 covers the calculation of the energy need for heating and cooling and the internal temperature in case of a building or building zone with one or more adaptive building envelope elements.

The method covers also, as product information, the calculation of some energy performance characteristics of adaptive building envelope elements, applied in a specific (e.g. reference) building.

NOTE   Compare e.g. ISO 18292, that also uses a reference building for comparing the energy performance of windows.

This includes information on whether the building is smart ready in terms of adaptive building envelope elements.

5.2 General description of the method

5.2.1 General

The calculation procedures in ISO 52016-3 are an extension of the hourly calculation procedures specified in ISO 52016-1. ISO 52016-3 contains the additions and modifications that are needed to incorporate adaptive building envelope elements. Therefore, ISO 52016-1 is referenced accordingly throughout ISO 52016-3.

ISO 52016-1:2017 contains a normative Annex G that provides a framework for calculation procedures involving adaptive building envelope elements. ISO 52016-3 provides calculation procedures.

ISO 52016-3 fills a gap in the set of EPB standards.

The reasons for choosing an hourly calculation time interval are given in 6.2.

5.2.2 Distinction between ISO 52016-3 and ISO 52016-1

The calculation procedures of ISO 52016-3 can be seen as an extension of the procedures given in ISO 52016-1. The reasons for providing these in two separate documents are:

— If ISO 52016-3 was combined into ISO 52016-1, it can harm the acceptance and roll-out of ISO 52016-1, e.g. if a legal authority wants to adopt the calculation procedures of the current ISO 52016-1, but has hesitations to adopt ISO 52016-3.

— Maintenance of ISO 52016-1 would be more difficult and costly if combined with the content of ISO 52016-3. With a separate ISO 52016-3 it is easier to plan revisions, e.g. based on experiences by users or developing technologies.

— ISO 52016-3 requires specific expertise on the technologies and control scenarios involved.

— The parties interested in the details of ISO 52016-3 are quite specific. Combining all in one document would not be efficient from the user perspective.

5.2.3 Successive steps in the calculation procedures

In ISO 52016-3:2023, the actual calculation procedures are given in 6.9. However, that subclause is just one sentence:

"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."

ISO 52016-3:2023, 6.4 to 6.8 contain the procedures needed to prepare the calculation. In ISO 52016-3:2023, 5.4, these preparatory steps are introduced as six successive steps.

5.3 Technologies covered in ISO 52016-3

5.3.1 General

The technologies covered in ISO 52016-3 are selected on the basis of current or promising market share and distinction in functionality and control scenarios or passive response. Some technologies can be quite different in appearance but very similar in functionality and in options for control. For the purpose of ISO 52016-3 these are not categorized separately.

For example, for the purpose of ISO 52016-3 the physical model of a closed (unvented) cavity double skin façade is quite similar to a multiple glazing unit with integrated solar blinds.

Three main categories of technologies are covered in ISO 52016-3:

— Building envelope elements with dynamic solar shading (see 5.3.2).

— Building envelope elements with chromogenic glazing (see 5.3.3).

— Building envelope elements with an actively ventilated cavity (see 5.3.4).

For the sources used in the selection of technologies, see References 35, 28, 17, 18, 27, 34 and 38.

Examples of types of adaptive building envelope elements that are not covered in ISO 52016-3 are presented in 5.3.5.

5.3.2 Building envelope elements with dynamic solar shading

A building envelope element with dynamic solar shading can be described as a façade element (usually fitted to a window, door, curtain walling or façade, with one or more actively operated mobile parts) defined as the curtain that can (partially) obstruct solar radiation or sunlight. The aim of dynamic solar shading is to control solar radiation and daylight, to contribute to the thermal insulation, thermal comfort, cooling savings and visual comfort when combined to glazing.

Dynamic solar shading can be positioned at the internal or external side of the façade element or integrated in between two or more façade elements. These façade elements may form a sealed multiple glazing unit, or consist of an assembly of multiple glazings, or assembly of partly transparent and partly opaque elements.

If a single façade is doubled inside or outside by a second, essentially glazed façade, it is usually defined as a double skin façade. The width of the cavity between these two skins can range from several centimetres at the narrowest to several metres for the widest accessible cavities. As long as such a façade has no intentional ventilation provisions ("closed cavity façade") it fits into the description of the dynamic solar shading.

This contrasts with the third category, building envelope elements with an actively ventilated cavity.

The main technologies for the dynamic solar shading elements are:

— Venetian blind: blind where the curtain consists of horizontal slats which can be tilted and where the curtain may be retracted by accumulating the slats. The slat angle can be tilted in various positions. They are usually opaque, but can also be partly transparent or translucent.

— Roller blind: blind where the curtain consists of material (e.g. fabric) which is retracted by rolling. The curtain can be semi-transparent, semi-translucent or opaque, and sometimes thermally insulated (multilayer).

— Roller shutter: shutter where the curtain is retracted by rolling and consists of interconnected horizontal laths, that can be tilted or not, which run inside channels.

Examples are shown in Figure 1:

a) Windows with internal roller blinds

b) Windows with external venetian blinds. (Colour) photo by Samuel Zeller, CC0 1.0 DEED[2]

c) Closed cavity façade with integrated venetian blinds
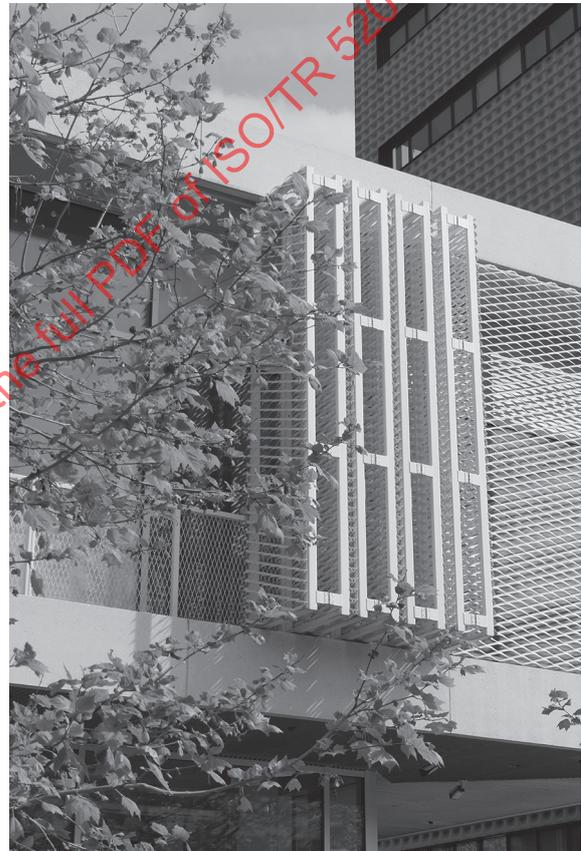
d) External folding-sliding shutters, Gerrit Rietveld Academie / Sandberg Instituut, Amsterdam

Figure 1 — Four examples of building envelope elements with dynamic solar shading

For movable blinds or shutters, a specific terminology is used to avoid confusion between the blind or shutter movement and other movements, such as slats and louvers:

— Extended/retracted: movement of the blind resulting in an increase/decrease in the surface area covered (see EN 12216:2018, 5.1)

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2)   No permission required. Credit: https://creativecommons.org/publicdomain/zero/1.0/

— Open/closed: terms used to describe the increase in light (opening) or reduction of light (closing) in an extended position for products with laths, slats or louvres which can be tilted or adjusted (see EN 12216:2018, 5.1).

See also examples in EN 12216.

5.3.3 Building envelope elements with chromogenic glazing

Chromogenic glazing can be described as an adaptive technology directly integrated in the glazing itself. The physical properties can reversibly change according to a specific active or passive trigger, changing the appearance of the glazing itself: making it more or less transparent, absorbing or reflecting for solar radiation and daylight.

The main technologies currently available on the market are:

— Thermochromic and thermotropic glazing (passive; based on the glazing temperature changing);

— Photochromic glazing (passive; based on the level of incident solar irradiance changing);

— Electrochromic glazing (active; based on the level of electric power changing);

— Gasochromic glazing (active, based on changing gas mixture in cavity);

— Liquid crystal chromogenic glazing (active; based on the level of electric power changing);

— Suspended particle devices.

However, other smart glazing technologies are being, or may be developed, that can be simulated in the same way, e.g. electrophoretic, fluidic glass, microshades and micromirror arrays.

Examples are shown in Figure 2:

a) High transmittance   **b) Low transmittance**

Key

SOURCE: Project Hamilton Bonaduz, Switzerland. Electrochromic Glass (SageGlass). Pictures by Ingo Rasp.

Figure 2 — Examples of building envelope with chromogenic glazing

5.3.4 Building envelope elements with an actively ventilated cavity

5.3.4.1 Distinctive feature

A building envelope element with an actively ventilated cavity is similar to a building envelope element with dynamic solar shading, except for the intentional and possibly controlled (i.e. natural, hybrid or mechanical) ventilation of the cavity or air circulation via the cavity.

In many cases it is a ventilated double skin façade, but also a ventilated window with the intention to capture heat from the cavity fits into this category.

In addition to achieving thermal and solar control as in the previous two categories, the technologies under this category have in common that air is deliberately circulated through the cavity, to gain solar either heat, increase thermal comfort, or both, when heating is required and to enhance thermal comfort and reject surplus solar load during warm periods. If this is not the case, then, for the purpose of this document, the adaptive building envelope element does not belong to this category.

The difference with operable solar shading in 5.3.2 is that the air circulation and ventilation is controlled, either mechanically or by operable vents, thus adding a dimension to the control strategy.

5.3.4.2   Variety of technologies

A wide variety of technologies exist. Typical examples are:

— Double skin façade

  — with integrated solar shading;

  — mechanically or naturally ventilated;

  — with fixed or adjustable vent openings;

  — with narrow or wide cavity.

— Ventilated windows

  — with integrated blinds;

  — to either harvest or reject solar heat, recover heat from ventilation air, or both.

See more examples below in this subclause such as a simplified façade with air extracted behind an internal screen instead of glazing.

Active ventilative cooling is outside the scope of ISO 52016-3 if there is no thermal interaction with the components of the façade, or if it is achieved by other air inlets than the air inlet via (and with thermal interaction with) the façades.

5.3.4.3   Ventilation modes

Several ventilation modes can coexist within a single ventilated double façade [34]:

a) Outdoor air curtain:
    In this ventilation mode, the air introduced into the cavity comes from the outside and is immediately rejected towards the outside. The ventilation of the cavity therefore forms an air curtain enveloping the outside façade.

b) Indoor air curtain:
    The air comes from the inside of the room and is returned to the inside of the room or via the ventilation system. The ventilation of the cavity therefore forms an air curtain enveloping the indoor façade.

c) Air supply:
    The ventilation of the façade is created with outdoor air. This air is then brought to the inside of the room or into the ventilation system. The ventilation of the façade thus makes it possible to supply the building with air.

d) Air exhaust:
    The air comes from the inside of the room and is evacuated towards the outside. The ventilation of the façade thus makes it possible to evacuate the air from the building.

e) Buffer zone:
This ventilation mode is distinctive inasmuch as each of the skins of the double façade is made airtight. The cavity thus forms a buffer zone between the inside and the outside, with no ventilation of the cavity being possible.

Several ventilation modes can coexist within a single ventilated double façade.

Generally, naturally ventilated double façades are those which present several ventilation modes, the shift from one ventilation mode to the other being done by motorized ventilation openings [34]. With motorized openings it possible to shift from one ventilation mode to another as a function of their position (in this case, from a scenario of outdoor air curtain, when the openings are open, to a buffer zone scenario, when they are in closed position).

The ventilation makes use of openings in either the inner or outer skin, or both, and can be mechanical or natural.

In general, mechanically ventilated double façades are not equipped with operable ventilation openings and are characterized by well-defined ventilation modes. In case of natural ventilation, the operation is (as a rule: actively) controlled by openable vents in either the inner or outer skin, or both, allowing a shift from one ventilation mode to another as a function of their position. In that case, determining the precise mode of ventilation is not always self-evident. Indeed, when an opening is placed in open position, the ventilation phenomena which take place depend on the pressure conditions inside the cavity. The latter in turn depends on a multitude of factors, including the climatic conditions, e.g. speed and direction of the wind, temperature difference, sunshine, mode of working of the building's mechanical ventilation system or opening of the inside doors.

5.3.4.4   Façades or windows

The term "ventilated double façades" also covers the concepts of ventilated double windows. The distinction between these two terms (façade and window) is only made when a proper understanding of the text makes it imperative.

The ventilation air flow rates are provided by the relevant standard(s) under EPB module M5-5 (ventilation).

5.3.4.5   Double skin façades

A double skin façade can be defined as a traditional single façade doubled inside or outside by a second, essentially glazed façade [34]. Each of these two façades is commonly called a skin. A ventilated cavity, having a width which can range from several centimetres at the narrowest to several metres for the widest accessible cavities, is located between these two skins.

The main difference between a double skin façade and an airtight multiple glazing, whether or not it integrates a shading device in the cavity separating the glazings, lies in the intentional and possibly controlled ventilation of the cavity of the double skin façade.

For that reason, and to be clear in the distinction, in the context of ISO 52016-3 the term "building envelope element" is used with an actively ventilated cavity, thus expressing the key distinctive physical feature.

There are façade concepts where the ventilation of the cavity is controllable, by either fans or openings or both, and other façade concepts where this ventilation is not controllable. The indoor and outdoor skins are not necessarily airtight (see, for example, the "louver" type façades). Automated equipment, such as shading devices, motorized openings or fans, are most often integrated into the façade.

If the cavity is extended over multiple rooms (horizontally) or floors (vertically) it becomes a more complicated variant, due to the mixing of the cavity air temperatures and air pressures. For the purpose of ISO 52016-3, the complication has no significant effect, because it requires "only" that, for each state, the correct spatially "mixed" thermal and optical properties of the façade are obtained from the appropriate standards that have to provide the façade properties.

Examples of building envelope elements with actively ventilated cavities are shown in Figure 3:

a) Antwerp Court House, Belgium, double skin façade with integrated ventilation system

b) ING House Amsterdam, The Netherlands, double skin façade with controlled natural ventilation

Figure 3 — Examples of building envelope elements with an actively ventilated cavity

5.3.5 Types of adaptive building envelope elements not covered in ISO 52016-3

Types of adaptive building envelope elements that are not covered in ISO 52016-3 comprise, for example:

— Building integrated PV (BIPV): If integrated in or added to the glazing, the PV elements permanently change the optical properties of the glazing as any other material integrated in or fixed to the glazing (e.g. screenprint, film). The only difference is that a percentage of the absorbed solar radiation is ("passively"; based on pre-programmed optimizers) converted into electricity instead of converted to heat.

— Building integrated solar thermal systems (BIST): Similar to BIPV, the only difference with a conventional building envelope element is that a percentage of the absorbed solar radiation is converted into heat that is extracted based on the control of the solar thermal system; the control does not intend to optimize the heat transfer through the building envelope element for the sake of the energy balance and comfort for the room behind.

— Green façade and roof: These (passive) technologies also obstruct sunlight; thus, they also achieve sunlight control and summer and winter comfort goals. However, their market share and potential is still limited, while the physical description would require special knowledge.

— Phase change materials: These (passive) technologies aim to solar gain control, reduce cooling needs, winter and summer comfort, heat and solar energy store. However, their market share and potential are still limited, while the physical description and integration in the thermal balance calculation of the building would requires extra effort.

An example of a type of adaptive building envelope element that is not covered in ISO 52016-3 is shown in Figure 4:
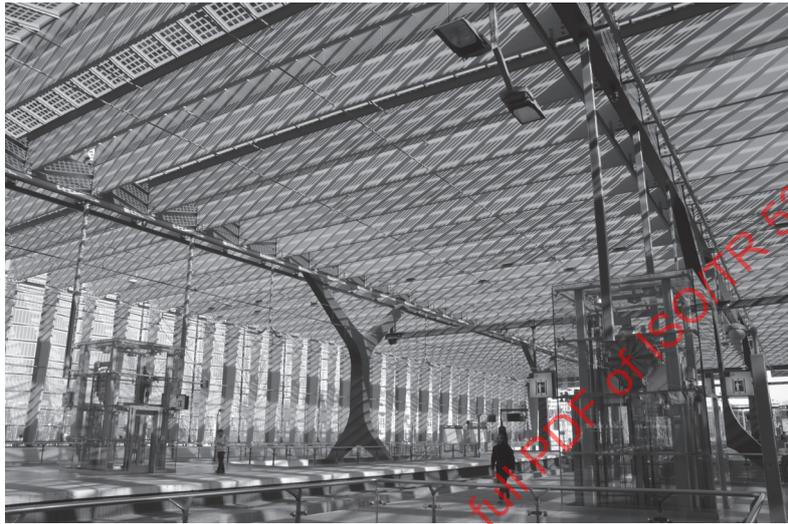
Key

SOURCE: (Colour) photo Steven Lek, CC BY-SA 4.0 DEED.

Figure 4 — Glazed roof with building integrated PV cells, Central Railway Station, Rotterdam, Netherlands

5.4   Control scenarios

When the work on ISO 52016-3 started, the high and increasing number of adaptive façade elements could not be assessed properly by using existing international standards.

No ready-to-use international standards exist for the assumptions on the control scenario. ISO 52120-1 is the key EPB standard on building automation and control. It provides a framework that needs to be worked out in each EPB calculation standard, for each controlled service or object separately. ISO 52016-3 fills this gap for what is called in ISO 52120-1 "blind control" (identifier: BLIND_CNTRL*): "*solar protection to avoid overheating and to avoid glaring".

However, there were several challenges and limitations to the work:

— There was a lack of information on optimized control scenarios and on the real use in practice. Nevertheless, wherever simulations are performed in which adaptive building envelope elements are involved, certain assumptions are needed and are made anyway. The advantage of ISO 52016-3 is that the assumptions are transparent and common, thus facilitating product comparison. Moreover, recent studies provided increasingly useful information.

— For more complex façades, with their wide diversity in approaches, there is a limit to what extent harmonization of the description and the assumed operation is feasible. Consequently, ISO 52016-3 concentrates on the most commonly used technologies.

— More complex control scenarios, with for instance either predictive algorithms or combined with control of heating, ventilation and air conditioning (HVAC) and lighting, or both, pose a number of additional challenges. For this level no reference control scenario is specified in ISO 52016-3. This means that for such applications, ISO 52016-3 can be used, but only in a customized way. In that case ISO 52016-3 requires that the customization is clearly reported (see ISO 52016-3:2023, 6.8.1). Otherwise there is no transparency on the grounds for comparing products or the energy performance of buildings.

Consequently, reference control scenarios are specified in ISO 52016-3, at different levels of either automation or integration, or both (see ISO 52016-3:2023, 6.8). These reference choices aim to create a level playing field as much as possible for different technologies without becoming over-simplified, or over-optimistic.

Customized control scenarios may be used instead. Again, in that case ISO 52016-3 requires that the customization is clearly reported. Otherwise there is no transparency on the grounds for comparing products or the energy performance of buildings.

The studies that have been used for the development of the reference control scenarios are introduced in 6.8.7.2.

6 Calculation method

6.1 Output data

This clause in ISO 52016-3 conforms to the common template for the set of EPB standards. It allows input-output relations to be checked between the EPB standards and availability of output data.

Further explanation is given in ISO/TR 52000-2.

6.2 Calculation time intervals

For all calculations, the time interval is hourly, because the control scenarios are hourly or sub-hourly. Sub-hourly calculations are possible, but for ISO 52016-3 hourly calculations are chosen, because the calculations in ISO 52016-1 are hourly and because all standard environmental conditions are hourly: For climatic conditions see ISO 52010-1 and for indoor environment conditions see ISO 17772-1 or EN 16798-1.

ISO 52016-1:2017, G.2.2.2 gives procedures to derive monthly average values and correction factors, if needed for a monthly calculation method.

However, a monthly calculation method is not provided in ISO 52016-3, because:

— A monthly calculation method cannot take into account the dynamics of the indoor and outdoor conditions and interactions. With a monthly method it is, for example, not possible to assess the impact of absent or undersized systems on energy and thermal comfort or to assess how much solar energy gained on-site is utilized on-site and how much is surplus or to assess the impact of source temperate and energy need on the performance of a heat pump system or to assess the impact of weekend interruption (office) or night-time temperature setback (dwellings).

— A work-around, as for example applied in the monthly method of ISO 52016-1, is to introduce correction or correlation factors. However, these correction factors are highly generic and are incapable to show and value the impact of specific measures and technologies that do take into account these dynamics.

— This is even more problematic, because, as demonstrated in ISO 52016-1, the amount of input data requested from the user are for the hourly method in ISO 52016-1 not more than for the monthly method: they are the same.

— For many technologies, the hourly calculation procedures are much more transparent and simpler.

 For example, in an hourly method, extending or retracting a movable solar shading device on the basis of solar irradiance on the given window requires only two IF statements: one for extension and one for retraction to provide for each hour in the year the total solar energy transmittance for the given window, based on the hourly solar irradiance for the given orientation and tilt angle, available from the weather

file. For the monthly method, many tables are needed to provide pre-calculated weighted average total solar transmittance values for various orientations, per month or season, for a specific climate. It is more complicated, less transparent, requires a pre-calculation using an hourly calculation method anyway and produces a monthly average value that does not reflect the actual dynamics over the various hours and days and cannot be used to check the impact on, e.g. hourly indoor temperatures (comfort). This is clearly shown in ISO 52016-1 by comparing ISO 52016-1:2017, Table B.24 on parameters for movable solar shading devices for the hourly method against ISO 52016-1:2017, Table B.44 on parameters for movable solar shading devices for the monthly method.

6.3 Input data

6.3.1 General

This clause in ISO 52016-3 conforms to the common template for each EPB standard. It allows input-output relations to be checked between the EPB standards and availability of input data from other sources.

It provides the overview of all input data. The tables in ISO 52016-3:2023, 6.3 are just a listing, the actual specification of the input is given further on in Clause 6, as part of the description of the calculation procedures.

The input data for the calculation are the thermal, solar and daylight properties of the building element for the different states (e.g. from open to closed, from dark to light and combinations of these). In case of gradually varying properties: for a number of representative discrete states.

The thermal, solar and daylight properties of the building element are the thermal transmittance (U-value), solar transmittance (g-value) and daylight transmittance(τ_V).

In order to be able to use these properties for energy and internal temperature calculations, the details of the (passive or active) control scenario are used as input for ISO 52016-3.

6.3.2 Input data of a simplified adaptive building envelope element

See 6.4.2.1 and 6.4.2.2 for explanation of the input data in case of a simplified adaptive building envelope element.

6.3.3 Input data of a detailed adaptive building envelope element

See 6.4.2.2 for explanation of the input data in case of a detailed adaptive building envelope element.

6.3.4 Control related input data

6.3.4.1 Applied control type

For the use of software tools, the introduction of harmonized identifiers adds to the transparency of the assessment procedures. This applies in particular to typologies, e.g. to distinct categories of technologies and control options.

6.3.4.2 Number and description of states

If an adaptive building envelope element can be adapted in different dimensions (e.g. venetian blinds can be extended/retracted, but also the slats can be tilted), then for the understanding it is convenient to distinguish these dimensions in the listing of the possible states. See ISO 52016-3:2023, Table 13. However, for listing the properties for the various states and making the link to the control scenarios a one-dimensional numbering system is more convenient, especially when it comes to look-up tables in software.

See 6.4.3 for specific explanation of the control related input data per category of adaptive building envelope element.

6.3.4.3 List of sensors

The list of sensors is directly related to the applied methods to identify the conditions or events that can lead to a change of state.

See 6.8.3 for the options. In many cases, different types of sensors can have the same effect.

6.3.4.4 Applied methods to identify the conditions or events

See 6.8.4 for the options.

6.3.5 Climatic input data

No additional information beyond ISO 52016-3.

6.3.6 Constants and physical data

No additional information beyond ISO 52016-3.

6.3.7 Input data from Annex A and Annex B

See Annex B for explanation and justification of specific choices.

6.4 Properties of the adaptive building envelope element

6.4.1 General

The term adaptive building envelope element (see Clause 3) is used for the product or assembly that comprises the adaptive component(s). Usually, the adaptive building envelope element is a product or assembly consisting of multiple layers. When possible, the properties used as input for the calculation according to ISO 52016-1, for each state of the adaptive element, are the properties for the whole product or assembly that are invariable for a given state. In that case it is defined in ISO 52016-3 as a simplified adaptive building envelope element.

If the properties are variable, because they depend on environmental conditions (for environmentally activated elements: other than the conditions that trigger the state changes), then it is defined as a "detailed adaptive building envelope element". In that case a more detailed model of the adaptive building envelope element is needed in ISO 52016-3. For example, if the U-value or g-value strongly depends on local temperatures. This can be specifically the case for layers between glazing and solar shading provisions that are naturally ventilated.

However, if the variable properties can be described as a (pre-determined) function of specific conditions, the simplified model can still be used, in combination with the pre-determined function to be applied at each hour of the calculation. For example: the g-value of a windows with venetian blinds, at certain slat angle, as function of the solar angle above horizon and ratio direct-diffuse solar irradiance. See examples in 6.4.3.1.

On the other hand, if one or more of the component properties of the adaptive building envelope element are needed as input for the control scenario in ISO 52016-3, it also requires the use of a detailed model of the adaptive building envelope element. This is described in ISO 52016-3:2023, 6.4.2.

The input data for the calculation are the thermal, solar and daylight properties of the adaptive building element for the different states (e.g. from extended to retracted, from open to closed, from dark to light and combinations of these); and in case of gradually varying properties: for a number of representative discrete states.

These properties are the thermal transmittance (U-value), (optional) air permeability (L-value), solar transmittance (g-value) and daylight transmittance (τ_V).

These properties can be determined according to the relevant standards listed in ISO 52016-3:2023, Table B.1:

— for EPB module M2-5 (thermal transmission): ISO 10077-1 or ISO 15099;

— for EPB module M2-8 (solar and daylight properties): ISO 9050, EN 410, ISO 52022-3 or ISO 15099.

Each of these standards covers a specific application area, as described in the third column of ISO 52016-3:2023, Table B.1.

As much as possible input data from all types of construction elements are collected in ISO 13789 to enable ISO 52016-1 to refer for these input data to this single EPB standard, ISO 13789. For example, the properties from ground floor and windows. However, when dealing with less conventional adaptive building envelope elements, it can be more efficient to get the data directly from the appropriate standards on thermal and solar window properties listed above.

The standards that provide the solar and daylight properties can, in turn, require as input detailed (e.g. spectral or detailed directional) component properties.

In any case, if (only) detailed (e.g. spectral or detailed directional) properties are available as output from these standards, ISO 52016-3 requires that these are aggregated to become suited as input for ISO 52016-3.

In some cases, ISO 52016-3 requires more detailed information, for instance the properties per component, e.g. thermal resistance and air permeability per component, solar absorptance and solar and daylight transmittance and reflectance per component. In this case the simple model used in ISO 52016-1 for the transparent building envelope element (typically: the window) is not suited. A more detailed model is needed to describe the adaptive building envelope element. This is described in the next clause (6.4.2).

Figure 5 illustrates the different paths of linking a simple and a detailed adaptive building envelope element to the ISO 52016-1 calculation of heating and cooling load and internal temperatures.
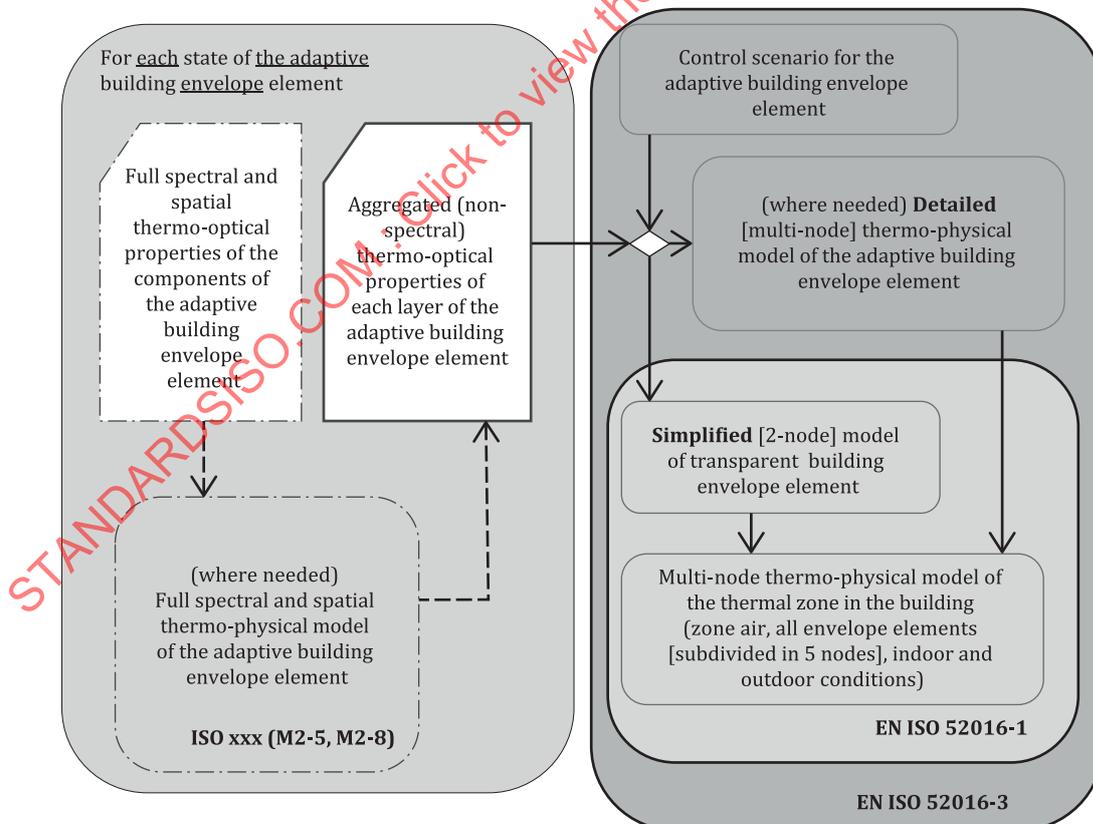

Figure 5 — Illustration of a simple and a detailed adaptive building envelope element linked to ISO 52016-1 calculation procedures

6.4.2 Simplified or detailed adaptive building envelope element

6.4.2.1 Simplified adaptive building envelope element

In case the solar or daylight properties are angle dependent, but approximated by fixed properties for representative conditions (e.g. angle of solar incidence and ratio direct: diffuse), the procedures as described for windows in ISO 52016-1:2017, E.2.2.1 are taken into account.

ISO 52016-1:2017, E.2.2.2 gives procedures in case of movable parts (e.g. shading, shutters), butthose procedures are overruled by the more detailed procedures in ISO 52016-3.

6.4.2.2 Detailed adaptive building envelope element

No additional general information beyond ISO 52016-3.

Explanation on the multi-node model for the adaptive building envelope element is given in 6.4.4.

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 Direct and secondary solar energy transmission; simplification in ISO 52016-1

The total solar energy transmission consists of four parts (see ISO 52022-3 or ISO 15099):

— the direct part, τ_{sol}: the short wave solar radiation passing through the adaptive building envelope element to the internal environment (thermal zone), including the portions that enter the internal environment after re-reflection in one or more layers of the element;

— the secondary part, consisting of heat from solar radiation absorbed in one or more layers of the element that enters the internal environment by a) conduction), b) thermal radiation or c) ventilation.

In ISO 52016-1 the secondary solar energy transmission is approximated as a contribution to the direct solar energy transmission to the internal environment (thermal zone).

This approximation leads to an error in the surface temperature of the internal layer of the adaptive building envelope element. The error is small if the secondary solar heat gain is only a small portion of the total solar energy transmission (g-value) as is the case for windows without solar shading provision in place.

The reason for simplification in ISO 52016-1 was 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, while the main purpose of going from monthly to hourly calculations was to catch the dynamic effects and interactions, as explained briefly in 6.2.

6.4.3.1.2 Variable properties

Within a specific state, the thermal and solar properties are often assumed to be constant, but this may not always be the case, as already stated in 6.4.1. The amplitude of variations strongly depends on the configuration and type of components: venetian blinds have a higher directional variation of solar and daylight transmittance than roller blinds. Building elements with naturally vented cavities (stack effect) have a g-value (or even U-value, depending on the configuration) that can be more strongly temperature dependent than in case of unvented cavities.

Whether or not to take this variability into account depends on the balance between the overall accuracy of the calculations on the one hand and the uncertainty in the physical process and uncertainty in the use in practice on the other.

The extreme is to use only a fixed value for the whole year, which is for instance common practice for the total solar energy transmittance (g-value) in case of a window with venetian blinds fully extended, while actually the natural air circulation along the blinds is a function of the temperatures of the blinds and

adjacent glazing (in turn: function of solar irradiation), environment temperature and e.g. wind. The ratio between direct and diffuse solar irradiance and the solar incidence angle has a significant effect on the *g*-value of a building envelope element (window) with venetian blinds.

A research result that is very relevant in this respect is the study by Zweifel [43] providing a new model (approximating formulae) for the optical properties (transmittance, reflectance) of venetian blinds as function of the sun position and slat angle. In this way, the simplified model for the adaptive building envelope element as used in ISO 52016-1 can be kept, with such function applied each hourly calculation interval to take the variability of the properties into account.

6.4.3.2 Adaptive building envelope elements with chromogenic glazing

6.4.3.2.1 Environmentally activated chromogenic glazing

The value of the total solar energy transmittance of the adaptive building envelope element changes as a result of a change of the optical property of the glazing laminate where the functional smart layer is integrated. Usually this is the solar absorption of the outer laminate of an insulated glazing unit, so: $a_{\text{sol;gl;1}}$. This component property is not an input parameter for ISO 52016-3, as described in 6.4.2, unless for specific reasons, such as to determine the conditions that set the state of the adaptive building envelope element. In that case ISO 52016-3 requires a detailed model of the adaptive building envelope element (see 6.4.4).

For information on properties of thermochromic glazing, see Reference [31]. For information on commercial materials, see Reference [29].

6.4.3.2.2 Actively controlled chromogenic glazing

No additional information beyond ISO 52016-3.

6.4.3.3 Adaptive building envelope elements with actively ventilated cavity

6.4.3.3.1 Ventilation properties and modes

No additional general information beyond ISO 52016-3.

One specific issue concerns the terms "cavity" versus "gap". The term cavity is usually reserved for the space between two parallel impermeable components (layers), such as a cavity wall, a double window, double skin façade or a sealed double-glazing unit. The cavity is filled with air or a gas-mix. In a closed cavity, the air or gas-mix can circulate, depending on the geometry, temperature and temperature difference between the surfaces of the planes ("Nusselt-Raileigh relations"). In a cavity with openings, air can move in and out, as result of forced ventilation, or naturally, as function of wind or stack effect, or both.

If a blind (e.g. roller blind or venetian blind) is placed inside a cavity, it is, as a rule, modelled as a layer similar to glazing, but with specific air permeability. In this case the cavity is split in two gaps, with air exchange depending on the conditions. See ISO 15099 or ISO 52022-3 for all details of the modelling of vented cavities. ISO 52022-3 uses the term gas spaces instead of cavities or gaps. ISO 15099 uses the terms cavity and gap also for the space between a glazing and a solar shading layer, without discrimination.

See 5.3.4 for a detailed description. See 6.8.5.5 for the various control modes.

6.4.3.3.2 Thermal and solar properties

No additional information beyond ISO 52016-3.

6.4.4 Model and properties of a detailed adaptive building envelope element

In order to understand the model and properties of a detailed adaptive building envelope element, it is necessary to understand the thermal balance model in ISO 52016-1.

See Annex E for relevant details on:

— the thermal balance model in ISO 52016-1;

— the simplified model of a transparent building element in ISO 52016-1, used for the simplified adaptive building envelope element;

— examples of the detailed adaptive building envelope element, including the formulae needed in ISO 52016-3 for making the connection to the thermal balance model of ISO 52016-1.

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

See also Annex E for relevant details on:

— building envelope element, including the formulae needed in ISO 52016-3 for making the connection to the thermal balance model of ISO 52016-1.

6.6 Selection of control type

No additional information beyond ISO 52016-3.

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

Discretization of a continuous range of states

For environmentally activated building envelope elements the function $Y = f(X)$ can be used directly at each hourly time interval. Consequently, discretization of a continuous range of states is not needed in ISO 52016-3, which makes the calculation procedure less complex.

For actively controlled building envelope elements the discretization can be "programmed" and is not a linear function of environmental conditions anyway.

Just in case discretization is needed in ISO 52016-3 for specific situations, the discretization procedures are given anyway.

The following is the procedure to calculate the property $Y_{gl;t}$, of the adaptive building envelope element at environment condition $X_{st;t}$, using a discrete number of states, N_{st}., assuming a linear relation:

Step 1: Define the number of discrete states, N_{st}:

N_{st} is the number of states of the adaptive building envelope element covering the range of variations in properties;
Minimum value: $N_{st} = 2$
Maximum value: ISO 52016-3 states that the number of states shall not exceed the technical possibility to operate at intermediate states. Under this condition, the default number is $N_{st} = 4$ and, or practical reasons, the maximum value is:
$N_{st} = ([Y_{w;stmax} - Y_{w;stmin}] * 100 + 1)$

Step 2: Determine the discrete values of the environment condition and the property:

$$\Delta X_{st} = \frac{X_{stmax} - X_{stmin}}{N_{st}}, \quad \Delta Y_{w} = \frac{Y_{w;max} - Y_{w;min}}{N_{st} + 1} \tag{1}$$

Step 3: Search the discrete value of $X_{st;i}$ ($i=1,...,N_{st}$) that is the closest to $X_{st;t}$ and determine the corresponding discrete value of $Y_{w;i}$:

$$\text{For} \quad i = 1,...,N_{st} \quad \text{find } X_{st;I} \quad \text{until} \left| X_{st;t} - X_{st;i} + \left(\frac{\pm\Delta X_{st;hyst}}{2} \right) \right| < \Delta X_{st} \tag{2}$$

$$\text{If} \quad X_{st;t} - X_{st;i} \left(\frac{\pm\Delta X_{st;hyst}}{2} \right) \geq 0 \text{ then } Y_{w;i} = Y_{w;max} - N_{st;i} \cdot (\Delta Y_w) \tag{3}$$

$$\text{if} \quad X_{st;t} - X_{st;i} \left(\frac{\pm\Delta X_{st;hyst}}{2} \right) < 0 \text{ then } Y_{w;i} = -(N_{st;i} - 1) \cdot (Y) \tag{4}$$

with $\left(\dfrac{\pm\Delta X_{st;hyst}}{2} \right)$: is

$+\left(\dfrac{\Delta X_{st;hyst}}{2} \right)$ if $X_{st;t}$ is higher than the value at the previous time interval, or

$-\left(\dfrac{-\Delta X_{st;hyst}}{2} \right)$ if $X_{st;t}$ is lower than the value at the previous time interval.

In Figure 6 the procedure is illustrated for $Y_{gl;t} = g_{w;t}$ and $X_{st;t} = I_{sol;w;t}$. Compare with the continuous function as illustrated in ISO 52016-3:2023, Figure 1.
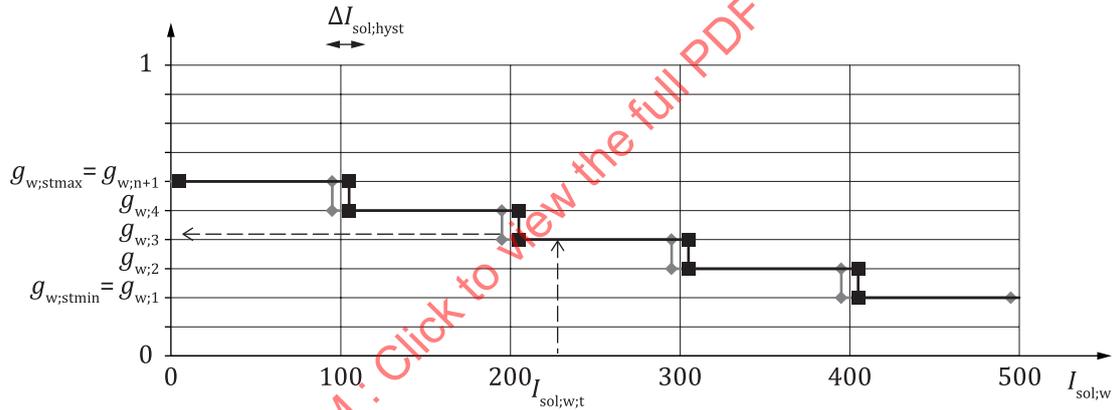
Key

$I_{sol;w;min} = 0$ W/m², $I_{sol;w;max} = 400$ W/m², $\Delta I_{sol;w} = 10$ W/m²

$g_{w;st;max} = 0{,}6$, $g_{w;st;min} = 0{,}2$

Figure 6 — Example of application of the discretization procedure (normally not needed)

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

6.8.1 General

No additional information beyond ISO 52016-3.

6.8.2 Selection of conditions and events

No additional information beyond ISO 52016-3.

6.8.3   Selection of sensors

No additional information beyond ISO 52016-3.

6.8.4   Selection of methods to identify the conditions or events

6.8.4.1   General

No additional information beyond ISO 52016-3.

The following is additional information on specific topics:

6.8.4.2   Glare (ISO 52016-3:2023, Table 29):

6.8.4.2.1   General

There is a multitude of methods to assess glare risk, ranging from simple to detailed. The choice between the methods depends on the situation, such as availability and reliability of detailed data of the external and internal environment plus the occupants and the available equipment. Three typical methods are presented in ISO 52016-3.

6.8.4.2.2   Glare method MM1, AM1 (=AC1)

For many aspects, relatively simple and reliable tools and descriptors are available, but not for discomfort glare from windows. Several different equations describing the subjective sensation of discomfort glare experienced by an observer have been published (see Reference [41]). In general, all these equations draw upon four physical quantities: the luminance and solid angle of the source, background luminance (adaptation) and position (line of sight).

The majority of existing glare equations were developed for the evaluation of discomfort glare from small (artificial) light sources and cannot be used for the assessment of discomfort glare from windows, because of the mostly large source size and sometimes complex nonuniform glare sources.

An approach to overcome the difficulties of how to treat individual differences in perceived glare was to use the probability that a person was disturbed instead of using the glare magnitude itself. For that reason, the glare scale was reduced to two categories: a category ''disturbed'' was used if the subject rated the glare source to be ''disturbing'' or ''intolerable''. The new probability function was called ''daylight glare probability, DGP''.

Based on comprehensive user assessment studies in test rooms, Wienold [42] suggests using an upper limit value of DGP = 0,45 to avoid disturbance by glare.

In Wienold and Christoffersen,[41] it is shown that the most simple formula gives already a reasonable correlation between DGP and the glare perception. This simplified DGP (named DGPs) can be derived as a linear equation with the vertical illuminance at eye level, E_v.

In ISO 52016-3 DGP had to be renamed. The following symbol and subscript was chosen instead of DGP: P_{dglare}: probability of daylight glare.

$$P_{dglare} = 6,22 \cdot 10^{-5} E_{V;e;w} + 0,184 \tag{5}$$

However, this equation formula omits the influence of individual glare sources. Therefore, the DGPs can be applied only if no direct sun or specular reflection of it hits the eye of the observer. Enhanced DGP formulae were developed, (see References [30] and [31]) based on vertical eye illuminance and the other parameters mentioned above, allowing individual glare sources to be identifies and quantified.

But without knowledge on the details of the space (e.g. geometry, material properties) and position of the occupants, these enhanced models are not applicable as default choice for the calculations in ISO 52016-3.

Moreover, for ISO 52016-3, the vertical illuminance at eye level itself had to be obtained, somehow, from the illuminance on the external surface of the façade, $E_{V;e;w}$.

NOTE   This is also true for assessing the DAYL-mode, but for that mode it is less critical for the comfort of the occupants.

In a conservative estimation, the vertical illuminance at eye level can be estimated to be not more than 0,25 of the illuminance on the external surface of the façade. In that case, the formula for DGPs would reach the limit value to avoid glare disturbance (DGP = 0,45), at external illuminance of 17 100 lx. This is equivalent to an irradiance of 150 W/m^2.

In building simulations, this irradiance level is also often used as an indicator that blinds should be closed to avoid or decrease the disturbance of direct solar (beam) radiation.

Consequently, in ISO 52016-3:2023, Formula (6) the external irradiance level of 150 W/m^2, converted into illuminance level of 17 250 lx is used as default limit value for glare:

$$P_{\text{dglare}} = 0,25 \text{ x } 6,22 \text{ } 10^{-5}E_{v;e;w} + 0,184 \tag{6}$$

In any case this limit value should be regarded as a rough indication for a first preliminary evaluation and to demonstrate that the control procedures work correctly. Other, more precise methods are listed in ISO 52016-3. Those are applicable if more detailed information is used, see 6.8.4.2.3 (Glare method AC2).

6.8.4.2.3   Glare Method AM2 (=AC2)

This concerns 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, daylight transmittance of the adaptive building envelope element and background luminance (walls, floor, ceiling), using formulae (rule based control) or separate tools (model based control). See References [42] and [30].

6.8.4.2.4   Optimized position of blind

The rules or models mentioned above can also be complemented with calculation of the optimum position of the adaptive element. For instance, the level of retraction of roller blinds to interrupt the line between the eyes and the sun, or the slat angle in case of Venetian blinds, or the window sections that need to be darkened in case of chromogenic glazing.

Recent studies provide algorithms to adjust the position (state) of a solar blind to avoid glare, while maintaining as much as possible incoming daylight and view out, for example:

— Angelina Katsifaraki et al,[33] with a daylight optimized simulation-based shading controller for venetian blinds;

— Zweifel[43],[44] providing formulae and scenarios for the control of the slat angle of venetian blinds;

— de Vries and Loonen[40] on optimization of the level of retraction of roller blinds.

6.8.4.2.5   Glare method AM3 (=AC3)

Estimation of the glare risk by direct measurement (e.g. indoor CCD camera into direction of the window).

6.8.4.3   Low daylight (ISO 52016-3:2023, Table 30)

6.8.4.3.1   Low daylight method MM1, AM1 (=AC1)

As default approach, the internal illuminance at desk level, $E_{V;int;desk}$ is roughly estimated with a simplified linear formula involving the external daylight illuminance on the adaptive building envelope element, the

daylight transmittance of the transparent part of the adaptive building envelope element and the height of the transparent area of the adaptive building envelope element above 1 m from the floor.

$$E_{V;int;desk} = a_{dayl} \cdot \tau_{V;gl} \cdot H_{gl;1m} \cdot E_{V;e;w} + b_{dayl} \tag{7}$$

With the two coefficients a_{dayl} and b_{dayl} the result can be adapted to the type of sky and sun angle, geometry and material properties of the room.

As default parameter values are chosen: a_{dayl} = 0,02 m^{-1}, b_{dayl} = 30 lx and $H_{gl;1\,m}$ = 1,4 m.

Taking the limit value of 300 lx (see 6.8.7.1), the limit is reached, for example according to Table 1.

Table 1 — Daylight mode default criteria

$\tau_{V;gl}$ (-)	With the default parameters: Low daylight mode if illuminance or irradiance lower than:		
	$E_{V;e;w}$ (lx)	$I_{sol;w}$ (W/m^2)
0,8	12 000	105
0,4	24 000	210
0,1	96 000	840

6.8.5 Basic rules for the reference control scenario

6.8.5.1 General

For the reference control scenarios, the following basic assumptions and rules apply.

6.8.5.2 Individual modes

No additional information beyond ISO 52016-3.

6.8.5.3 Combinations of choices

No additional information beyond ISO 52016-3.

6.8.5.4 Limit values of the control parameters

No additional information beyond ISO 52016-3.

6.8.5.5 Adaptive building envelope elements with actively ventilated cavity

For active ventilated façades, the ventilation through the façade is controlled.

This is illustrated in Figure 7.

To harvest solar heat
Typical for natural ventilation only

To cool down internal glazing
For natural or mechanical ventilation

To warm up internal glazing
For natural or mechanical ventilation

a) Heating mode

To cool down cavity (ventilative cooling)
Typical for natural ventilation only

b) Cooling mode

Key
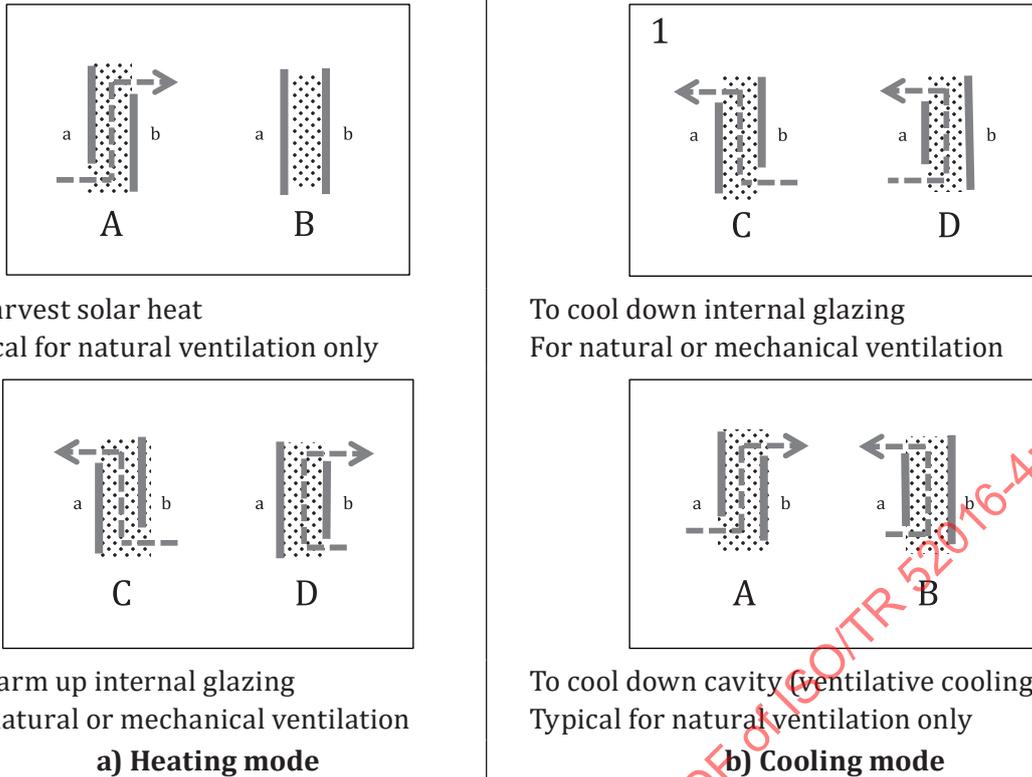
a	External.	A	if air supply wanted
b	Internal.	B	if no air supply wanted
1	if possible	C	if air exhaust wanted
		D	if no air exhaust wanted

Figure 7 — Illustration of additional basic reference control scenario for active ventilated façades (applicable only if technically possible)

6.8.6 Modelling of the user behaviour

One of the key simplifications in the control scenarios in ISO 52016-3 is, that for manual and motorized operation the different behaviour of different possible occupants with regard to the position of the blind is averaged (see also Annex D). Ideally, a high number of hourly calculations would be chosen, each with different occupant types (= different blind positions), together leading to a statistically representative set. However, this is currently not feasible.

See 6.8.7 for more explanation of the reference control scenarios, including the modelling of the user behaviour.

6.8.7 Reference control scenarios

6.8.7.1 General parameter values

The reference control scenarios provide the actual state as function of a number of conditions.

The options for the conditions are (see Table C.1 for explanation of all identifiers):

DAY-mode: DA, NI

HC-mode: HE, NE, CO

TINT-mode: TN, TH, TV

RAD-mode: RL, RH

DAYL-mode: LN, LL

GLARE-mode: GN, GY

In total this gives 144 combinations.

However, not each combination is physically possible (e.g. NI with RH) or relevant. In the latter case, these are clustered together (e.g.: GX means that it applies to both GN and to GY).

In the end 23 relevant combinations remained, as shown in the flow chart in ISO 52016-3:2023, 6.8.7.

For a specific combination of type of adaptive element, control type and space type, the corresponding state properties are specified. This is done in ISO 52016-3:2023, Annex C.

The generic control scenario, illustrated with the flow chart in ISO 52016-3:2023, 6.8.7, with its 23 possible states looks complicated. However, not all choices are always applicable, and the resulting states are not necessarily all different. In Annex C of this document flow charts are presented for specific combinations of adaptive element type, space category and control type. These flow charts show that the actual number of states for a specific combination is sometimes much less than 23.

The obvious question is then: why use this generic scenario instead of directly introducing the specific scenarios for each combination? The answer is that using the generic scenario as starting point, the specific scenarios can be modified and expanded to other combinations by just changing the input data: the thermal, solar and visual transmittance of the adaptive element for each of the 23 states. There is no need for any re-programming of software or spreadsheet and consequently no risk of introducing programming errors, ambiguities or conflicts.

6.8.7.2 Parameter values specified for the reference control scenarios

6.8.7.2.1 General

In ISO 52016-3:2023, Table 33, parameter values are specified for the reference control scenarios, as far as not dependent on the space type or adaptive element type (these latter parameters are provided in Annex C of the standard). This applies to:

6.8.7.2.2 HC-mode

In case of absence of heating or cooling system or in case of longer than 24 h zero heating or cooling needs due to holidays or weekend interruption (e.g. in an office), the 24 h average value of the heating or cooling needs is not available to decide on the HC-mode. In that case the internal operative temperature or the external air temperature is used as criterion, see Table 2.

Table 2 — HC-mode parameters

MM1, AM1	$\theta_{\text{int;op;24;limHE}}$	20	°C
	$\theta_{\text{int;op;24;limCO}}$	23	°C
AM2 [b]	$\theta_{\text{e;a;24;limHE}}$	12	°C
	$\theta_{\text{e;a;24;limCO}}$	16	°C

The MM1, AM1 methods are the default choice; the indoor operative temperature needed for this method is available and therefore this method is a better choice than the method AM2 that uses the external air temperature as criterion for the HC-mode.

The AM2 method is not the default choice in the standard; the limit values for the external air temperature are based on the study described in Annex D.

6.8.7.2.3 TINT-mode

See Table 3.

Table 3 — TINT-mode parameters

MM1, AM1	$\theta_{int;op;limTN}$	22	°C
	$\theta_{int;op;limTV}$	24	°C

These values are based on the study described in Annex D.

6.8.7.2.4 GLARE-mode

See Table 4.

Table 4 — GLARE-mode parameters

MM1	$P_{DGP;limGY}$	0,45	--
AM1	$P_{DGP;limGY}$	0,45	--

The $P_{DGP;limGY}$ limit of 0,45 is based on Wienold 2009[42] as the threshold for disturbing glare (see 6.8.4, explanation of the methods MM1, AM1).

6.8.7.2.5 DAYL-mode

See Table 5.

Table 5 — DAYL-mode parameters

MM1	$E_{V;int;desk;limLL}$	300	lx
AM1	$E_{V;int;desk;limLL}$	300	lx

These values are based on the study described in Annex D. See 6.8.4 for the explanation of the methods MM1, AM1.

6.8.7.3 Reference control scenarios for adaptive building envelope elements with dynamic solar shading or chromogenic glazing

The detailed specification of states are based on recent studies.

In particular, the European Solar Shading Organisation (ES-SO) has conducted a study to analyse the results from recent international research on the use of solar shading devices. The analyses led to control schedules for manual versus motorized versus automated control. These control schedules were then tested in series of building simulation, to obtain insight in the sensitivity of the choices on the calculated energy and comfort.

Adjustments were made to find a balance between simplicity and sensitivity, taking into account the uncertainty and large variation that exist on the actual user behaviours in practice.

Details of the ES-SO study are presented in Annex D.

First draft control scenarios were also evaluated as part of a study led by TNO to develop an innovative adaptive climate façade (See Reference [32]).

As follow-up and partly in parallel with the ES-SO study, simulations have been performed to test and evaluate control scenarios e.g. as described in the draft of ISO 52016-3 that was published for enquiry in 2022, by:

— Department of Architecture and Design, Politecnico di Torino, Turin, Italy.

— Sustainable Building Design Lab, Dept. UEE, Faculty of Applied Sciences, Université de Liège, Belgium (see References [37] and [20]).

— Politecnico di Milano, Italy.

However, most of these studies were ongoing at the time of completion of ISO 52016-3 and this document. Their results and other experiences could be highly valuable for a future update of ISO 52016-3.

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

No additional information beyond ISO 52016-3.

6.9 Hourly calculation procedures

During the hourly calculation, at each hour of the year it is assessed which of the 23 combinations applies. This does not immediately lead to the corresponding state, because:

— For automated control, if occupants present and awake, the corresponding state can *lead to* low daylight. In that case the combination changes (LN → LL).

— Some state changes are only applied after a specific delay:

  — An existing state remains unchanged if the control is manual or motorized and as long as occupants are not present or asleep.

  — "LL" (which is a manual override of the automated control) changes only back to "LN" if there is another (automatic) change requested.

6.10 Post-processing —Performance characteristics

6.10.1 General

ISO 52016-3:2023, 6.10 gives an overview of the postprocessing procedures and the resulting performance characteristics.

A new performance characteristic that has been developed with the intention to be proposed for future versions of ISO 17772-1 and EN 16798-1 is the seasonal thermal comfort score. See 6.10.2

ISO 52016-3:2023, 6.10 mentions also statistics on the use of the different states of the adaptive building envelope element. See 6.10.3 for some details.

6.10.2 Thermal comfort score

The absence of a system (e.g. cooling) can lead to better energy performance with poorer indoor environment quality (IEQ). Improving IEQ by installing the system (e.g. cooling) can lead to poorer energy performance. Passive solutions leading to low energy consumption while ensuring a good thermal comfort needed to be rewarded in the evaluation of the example cases.

Therefore, a thermal comfort score has been developed within the European ALDREN project, to be reported together with the energy performance indicators and the energy class. This will make it possible to compare the energy performance of building with regard to IEQ.

The calculated thermal comfort score is dedicated for comparing buildings and it is not linked to a specific use or a specific room of the building.

This thermal comfort score is selected to support the evaluation of examples of the calculations according to ISO 52016-3 as presented in Clause 9, for example in Table 9.

The protocol for calculating the thermal comfort score for simulated energy performance is described in full detail in Table 10 of the ALDREN D2.2 report [19] and summarized in Reference [23].

There are two issues when it comes to application for our example cases. More information on the issues and their solutions can be found in Reference [23].

— For our calculations that use the setpoints from EN 16798-1:2019, Annex C the thermal comfort score during spring/fall should not be taken into consideration, because this score is based on adaptive comfort criteria.

— There is no rule defined for occupied hours with night time temperature setback. As solution, it has been decided to allow a four Kelvin decreased value for the lower temperature limit during night setback.

Examples of the thermal comfort score are given for the worked-out examples in 9.6.

6.10.3 Statistics on the use of the different states of the adaptive building envelope element

In the report on example calculations in Clause 9 some additional indicators are shown, that have been included in the spreadsheet. For example:

— The average number of hours between change of thermal or solar properties of the adaptive element a) over the year and b) only counted during occupation. This is an indication of the frequency of the state change: if high (during occupation), it will be considered as annoying; if very low, it can be an indication of bad control.

NOTE   This indicator is important for two reasons [30]: first, decreasing the working hours of the actuators engines decreases their wear; in addition, it has been demonstrated that too frequent façade control results in distraction and a drop-in concentration by the users [33].

Not every change of state results in a change of properties: the thermal, solar and visual transmittance can be the same for different states.

— The number of hours that each state occurred over the year.

7   Quality control

The aim of this common clause for the set of EPB standards is to provide procedures to increase confidence in correct implementation of the calculation procedures of ISO 52016-3, e.g. in a software tool.

The following are suggestions:

— Make an analysis comparable to the analyses carried out on the example cases [23] summarized in Clause 9, which will increase the confidence in the reliability of the calculations.

— For example: 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.

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

— Use the space types and climates used in the example calculations, and for instance expanded with one or more basic BESTEST cases (see ISO 52016-1 and ANSI/ASHRAE 140 [16]) for comparison, using the detailed specifications in the case study reports (see EPB Center Case Study reports in References [23], [25]) and ISO 52016-1.

— Take advantage of the detailed analyses of specific results in the case study report [23], to help to understand which possible issues may require attention.

8   Conformity check

The aim of this common clause for the set of EPB standards is to provide procedures that enable to check if the calculation procedure is either applicable or has been applied correctly, or both, by the end user and that the calculation assumptions, in particular the input data, are correct. In ISO 52016-3, most of the input

is gathered through other EPB standards; relevant procedures for compliance check are provided in those standards. If serious errors are made in the input data, this often shows quickly in the results, such as hourly plots of the main quantities for a few selected weeks as presented. See examples in Clause 9.

See also ISO 52016-3:2023, Clause 8.

9 Worked out examples

9.1 General

This clause describes the worked out examples.

An overview of all specifications, considerations and detailed results are given in the related EPB Center case study report, [23] one of a set of case studies on selected key EPB standards.[25]

9.2 Purpose

Example calculations have been worked out, using the spreadsheet tool to test and demonstrate the ISO 52016-3 calculation procedures including the control scenarios. The calculation procedures took into account the proposed changes for ISO 52016-3:2023, Annex C, as proposed in September 2023 to amend ISO 52016-3:2023.

9.3 Spreadsheet tool

For the calculation of the examples, the spreadsheet tool has been used that was developed to demonstrate the calculation procedures and to perform example calculations on ISO 52016-1. The first version of this spreadsheet is described in ISO/TR 52016-2. This spreadsheet is one of a series of similar spreadsheet tools developed and published to test and demonstrate individual EPB standards.[35]

A specific sheet has been added that contains input data and control scenarios needed to perform a calculation according to ISO 52016-3, with the purpose to test and demonstrate that standard and to report it in this document.

The spreadsheet developed to demonstrate ISO 52016-1 is primarily intended to validate and demonstrate the standard in a transparent way. In the spreadsheet, each step in the calculation can be followed.

As a result, the spreadsheet is not suited (but also not intended) for use in daily practice.

In any case, for use in the daily practice of EPB assessment, a software tool is needed, with user-friendly interface and connecting the different modules for the overall EPB calculation. The spreadsheet is very suitable for software developers to check the calculation algorithms in their programs.

For these example calculations, a new indicator has been added to the spreadsheet of ISO 52016-1: the seasonal thermal comfort score developed under the European ALDREN project (see Table 10 in the ALDREN reportD2.2[19]), derived from the hourly calculation results.

9.4 Calculation cases

9.4.1 General

The selected calculation cases are based on the cases used in 2017 for the verification and validation of ISO 52016-1 and the cases used for the demonstration presented in ISO/TR 52016-2, but updated as part of the series of example case calculations by the EPB Center in 2021.(see case study reports[25]). More details can be found in these referenced documents.

9.4.2   Building types

9.4.2.1   General

As used in EPB Center case study reports[25];

— single-family house (SFH);

— single office space (Soff);

A difference with the earlier case studies is:

— improved input for the night time temperature setback for the SFH case; therefore, it is renamed SFHn in this document.

— Different thermal and solar properties of the large south window, the candidate for the adaptive transparent building element.

9.4.2.2   Single-family house (SFHn)

A detached single-family house is shown in Figures 8 and 9 as described in ISO/TR 52016-2:2017, Example 1[9], accompanying ISO 52016-1:
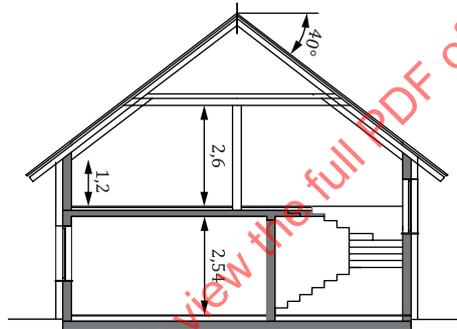
Figure 8 — Detached single-family house; vertical cross section
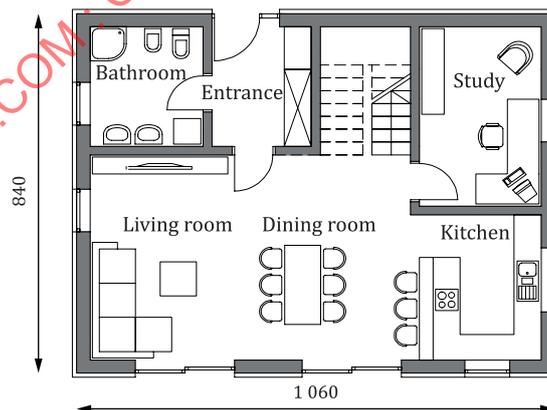
a) First floor
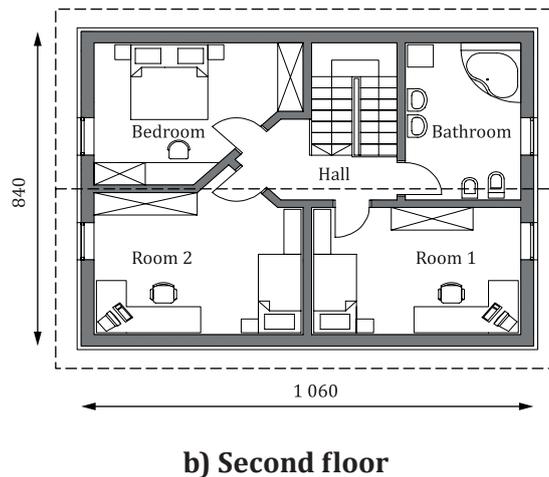
b) Second floor

Figure 9 — Detached single-family house; cross section first and second floor

9.4.2.3 Single office space (SOoff)

An office room with geometry based on the BESTEST "shoebox" model (see Reference [16]) is shown in Figure 10:
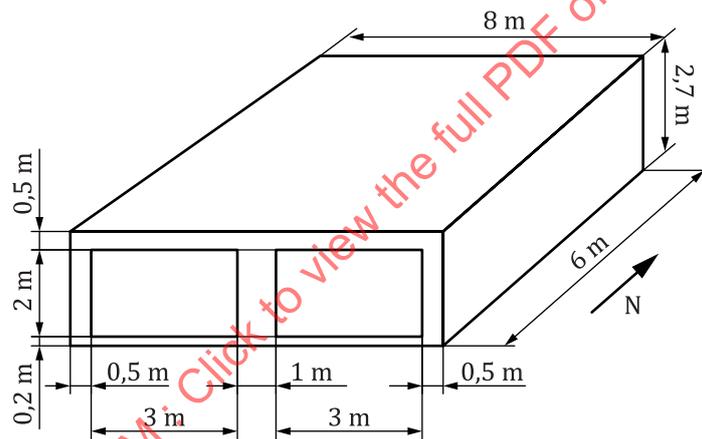
Figure 10 — Single office room

See description in ISO/TR 52016-2 and in the case studies preparation document[25].

9.4.3 Climates

The following were selected because of the significantly different outdoor air temperatures and solar radiation intensity:

— Oslo;

— Strasbourg;

— Athens.

Details are discussed in Reference [23].

9.4.4 Operation and use profile

— Night or day time temperature setback (residential);

— Office hours and weekend interruption (office).

The pattern of use affects not only the temperature settings, but also the thermal comfort scores (only relevant during presence of occupants), and also the required and assumed ventilation, internal heat gains and operation of movable blinds.

One of the EPB Center spreadsheets[26] generates hourly use profiles based on EN 16798-1 for various types of spaces. One of the sheets with output data is tailored to be fit as input for ISO 52016-1. This sheet can be simply copied and pasted as input data sheet of the ISO 52016-1 spreadsheet.

More details are discussed in Reference [23].

9.4.5   Selected adaptive building envelope elements

The adaptive building envelope element selected for this case study is a high-performance double glazing with:

— non-adaptive building envelope element (UnProt);

— external venetian blinds (ExVen);

— internal venetian blinds (InVen);

— external roller blinds (ExRbl).

The specifications of these assemblies were copied from the ES-SO study [24], the study initiated by the ES-SO, that formed a major basis for the reference control strategies in ISO 52016-3, as explained in Annex D.

Chromogenic glazing was not among the selected types. Actively operated chromogenic glazing follows the same reference control scenarios as roller blinds, so the roller blind variants are also applicable for active chromogenic glazings, if the differences in the thermal, solar and visual properties, and in the possibilities to vary between different states are taken into consideration.

Environmentally controlled (passive) adaptive building elements are disregarded in this case study (and in the spreadsheet), because they are much more straightforward and trivial to calculate.

For details on all adaptive elements specified in the ES-SO study, see Reference [23] and in a small library in the spreadsheet itself.

9.4.6   Control of adaptive building envelope elements

The variations with respect to the control type are:

— adaptive building envelope element in a fixed state (FIX);

— adaptive building envelope element, with reference control scenarios, manual (MAN), motorized (MOT) or automated (AUT).

In the spreadsheet tool, various control scenarios can be easily modelled and tested, with impact on energy and thermal comfort.

9.5   Overview of selected cases and variants

The following cases have been specified, each with specific variants. By successively comparing two variants the effect of a single parameter change can be analysed.

Base case 1: Single family house in Strasbourg, no adaptive transparent building element, only heating (no mechanical cooling system). Case code: SFHn_Sbg_UnProt_FIX_HE

SFH Base case and variants are shown in Table 6:

Table 6 — SFH Base case and variants

SFHn	Sbg	UnProt	FIX	HE
SFHn	Sbg	InVen	MAN	HE
SFHn	Sbg	ExRbl	MOT	HE
SFHn	Sbg	ExVen	MAN	HE
SFHn	Sbg	ExVen	MOT	HE
SFHn	Sbg	ExVen	AUT	HE
SFHn	Sbg	ExVen	AUT	HECO

Base case 2: Office space in Strasbourg, no adaptive transparent building element, heating and cooling. Case code: SFHn_Sbg_UnProt_FIX_HECO.

Soff Base case and variants are shown in Table 7:

Table 7 — Soff Base case and variants

Soff	Sbg	UnProt	FIX	HECO
Soff	Sbg	UnProt	FIX	FF
Soff	Sbg	UnProt	FIX	HE
Soff	Sbg	ExVen	MOT	HE
Soff	Sbg	ExVen	AUT	HE
Soff	Sbg	ExVen	MOT	HECO
Soff	Sbg	ExVen	AUT	HECO
Soff	Osl	ExVen	AUT	HE
Soff	Osl	ExVen	AUT	HECO
Soff	Ath	ExVen	AUT	CO
Soff	Ath	UnProt	FIX	HECO
Soff	Ath	ExVen	AUT	HECO

9.6   Results

Table 8 provides a summary of all identifiers used in the example cases.

Table 8 — Summary of identifiers used in the example cases

Description	Identifier	Explanation
Space	**SFHn**	Single family house with night time temperature set-back for heating
	Soff	Single office room
Climate	**Sbg**	Strasbourg
	Osl	Oslo
	Ath	Athens
Heating and/or cooling	**HE**	With heating system
	CO	With cooling system
	HECO	With heating and cooling system
	FF	Free floating conditions: no heating or cooling system

Table 8 *(continued)*

Description	Identifier	Explanation
Glazing type	**SG**	Single glazing
	DG	Double glazing
	SCG	Solar control glazing
	TG	Triple glazing

In Table 9 the main results of all example cases are summarized.

Table 9 — Main results all example cases

	Identifier	Heating need $Q_{H;nd}$	Cooling need $Q_{C;nd}$	Heating and cooling need $Q_{HC;nd}$	Thermal comfort score [a]		Avg number of hours without properties change [b]
		kWh/an	kWh/an	kWh/an	Winter	Summer	
1	SFHn_Sbg_UnProt_FIX_HE	7 911	0	7 911	1,6	3,5	N.A.
2	SFHn_Sbg_InVen_MAN_HE	8 507	0	8 507	1,7	2,6	6,2
3	SFHn_Sbg_ExRbl_MOT_HE	8 201	0	8 201	1,6	2,0	23,5
4	SFHn_Sbg_ExVen_MAN_HE	8 081	0	8 081	1,6	1,9	6,2
5	SFHn_Sbg_ExVen_MOT_HE	8 084	0	8 084	1,6	1,8	5,9
6	SFHn_Sbg_ExVen_AUT_HE	7 872	0	7 872	1,6	1,9	6,8
7	SFHn_Sbg_ExVen_AUT_HECO	7 871	445	8 316	1,6	1,4	6,5
8	Soff_Sbg_UnProt_FIX_HE	2 127	0	2 127	2,2	4,8	N.A.
9	Soff_Sbg_UnProt_FIX_FF	0	0	0	4,3	4,8	N.A.
10	Soff_Sbg_ExVen_MOT_HE	2 741	0	2 741	1,9	4,4	4,2
11	Soff_Sbg_ExVen_AUT_HE	3 923	0	3 923	2,0	2,8	4,0
12	Soff_Osl_ExVen_AUT_HE	7 177	0	7 177	2,0	2,6	4,4
13	Soff_Sbg_UnProt_FIX_HECO	2 143	2 503	4 646	2,2	1,9	N.A.
14	Soff_Sbg_ExVen_MOT_HECO	2 748	1 054	3 802	1,9	1,8	3,8
15	Soff_Sbg_ExVen_AUT_HECO	3 927	220	4 147	2,0	2,2	4,0
16	Soff_Ath_ExVen_AUT_CO	0	1 339	1 339	5,0	2,2	4,5
17	Soff_Ath_ExVen_AUT_HECO	920	1 339	2 259	2,0	2,2	4,5
18	Soff_Osl_ExVen_AUT_HECO	7 179	81	7 260	2,0	2,1	4,5
19	Soff_Ath_UnProt_FIX_HECO	52	6 431	6 483	3,0	2,0	N.A.

[a] See explanation in 6.10.2 (also why spring/fall is not reported here); the lower the number the better, with classes: "green" for a value ≤ 2;

"yellow" for a value > 2 but ≤ 2,5;

"orange" for a value > 2,5 but ≤ 3;

"red" for a value > 3.

[b] Average number of hours without state change during occupation, non-sleeping hours

The results should 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).

The following are observations on the results of these examples (more details can be found in Reference [23]):

— As to be expected, with (even internal) venetian blinds, the energy need for heating is increased to "pay" for higher thermal and visual comfort.

— The winter thermal comfort score without blinds is slightly better than with blinds. This is not as expected intuitively. However, this can be simply explained: the heating setpoint is based on IEQ Category II (EN 16798-1[15]). However, the thermal comfort score also appreciates if the temperature during the winter season exceeds the setpoint for the higher class, IEQ Category I. Without blinds the indoor temperature meets this higher threshold more often than with blinds.

— During summer the internal venetian blinds lead to a significantly better thermal comfort compared to the situation without any blinds.

— For the case with internal venetian blinds, the annually average number of hours without state change during active occupation is 6,2. This means that the frequency of state changes is quite low, as expected for manual operation.

— The lower energy needs for heating in case of external venetian blinds compared to internal venetian is unexpected, taking into account that internal venetian blinds, when extended, lead to higher solar heat gains than external venetian blinds. The cause is the difference in behaviour that is assumed in the reference control scenario, both during daytime and during night-time. This leads for instance to a (slightly) lower U-value for the window with external venetian blinds during the long winter nights. All effects combined, the heating needs are lower in case of external venetian blinds (in these examples).

— The summer thermal comfort score in case of external venetian blinds is much better than in the case of internal venetian blinds, as expected, due to its lower g-value. This is also clear from the more traditional metric for thermal comfort: the number of hours that the operative temperature exceeded a specific upper limit, see Figure 11.

— In case of office space with automated control and mechanical cooling, the summer thermal comfort score is reasonable, but less good than in case of motorized control. However, this is not due to too high operative temperature, but due to operative temperatures that are sometimes (e.g. in the morning) below the lower limit for IEQ categories I, II and sometimes "even" III. For these example calculations the fixed heating and cooling setpoints from EN 16798-1 have been chosen, and not the adaptive comfort criteria (see introduction of the thermal comfort score in 6.10.2), which are also not intended for fully airconditioned spaces.

a) Internal venetian blinds   b) External venetian blinds
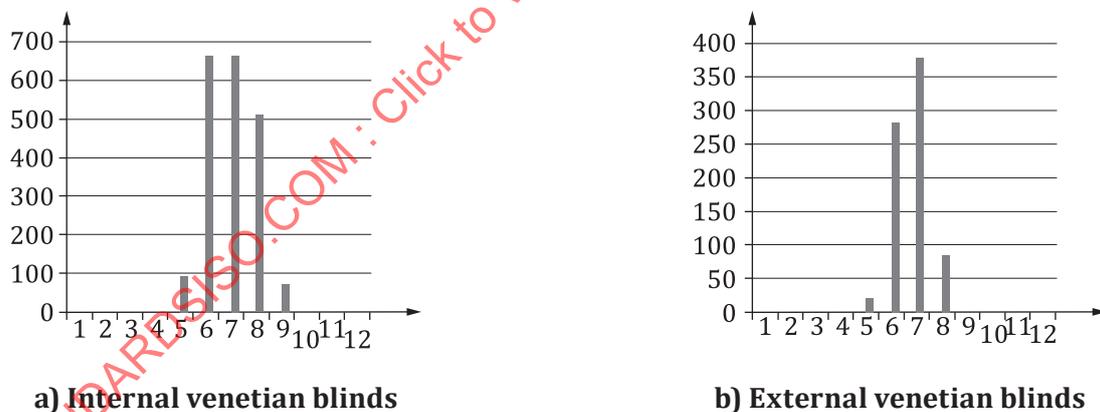
Key

■ Temp. weighted time above base temp.2

Figure 11 — Number of hours in a month that the operative temperature exceeds 26 °C during hours that thermal comfort is required (single family house, Strasbourg)

Figure 12 shows, as an example for the single-family house, the time sequence for an arbitrarily selected week in winter and in summer, in Strasbourg.

First, Figure 12 a) shows the assumed occupancy density (according to EN 16798-1) and the external air temperature. The occupancy varies during the working days and weekend.

Figure 12 b) shows the *g*-value of the adaptive element, together with the solar irradiance on this South vertical window, for manual control and operation. During sleeping hours, the occupants do not manually operate the blinds.

Figure 12 c) shows the same for automated control. In particular, during summer the operation of the blinds is quite different as in case of manual control.
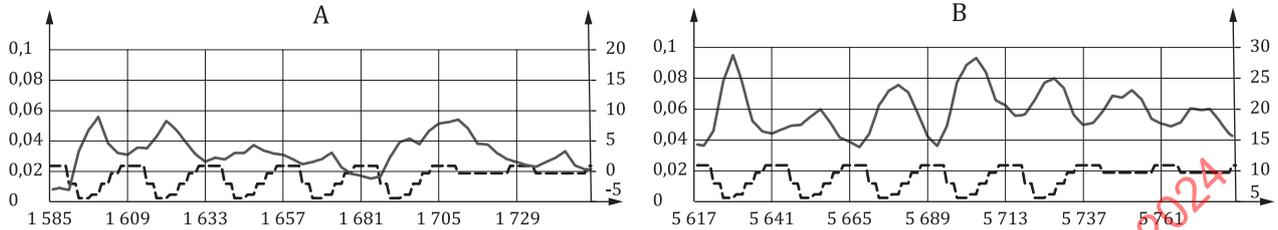

Key

A   SFHn_Sbg, wk 6

B   SFHn_Sbg, wk 30

_ _ _ _   Occup. density (p/m2)

_____ ϑ e;air (°C)

**a) Assumed occupancy density and the external air temperature**

Key
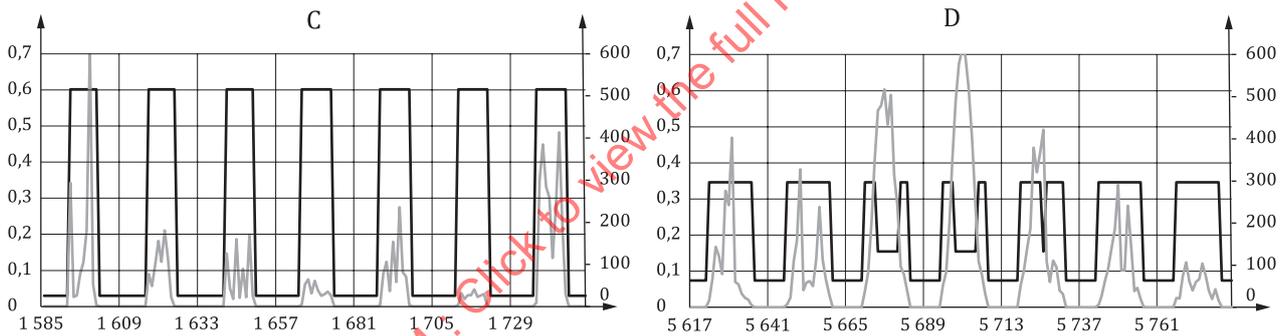
C   SFHn_Sbg_ExVen_MAN_HE, Feb (wk 6)

D   SFHn_Sbg_ExVen_MAN_HE, July (wk 30)

_____   g-value (-)

_____   Isol (W/m2)

b) Solar irradiance and the *g*-value of the adaptive element, manual
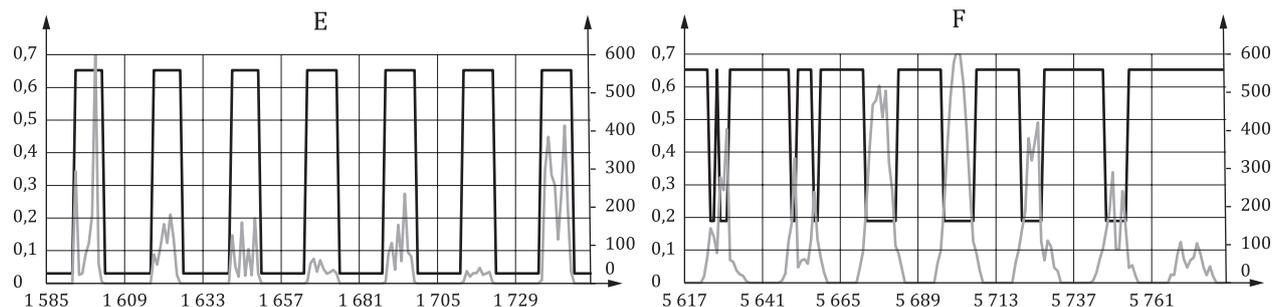
Key

E   SFHn_Sbg_ExVen_AUT_HE, Feb (wk 6)

F   SFHn_Sbg_ExVen_AUT_HE, July (wk 30)

——   g-value (-)

——   Isol (W/m2)

c) Solar irradiance and the *g*-value of the adaptive element, automated

Figure 12 — Illustration of the hourly time sequence (single family house, Strasbourg)

However, the possible states for various conditions does not mean that they really occur, in a given climate, orientation and pattern of use. Figure 13 illustrates, both for external venetian blinds a) as for external roller blinds c) to what extent their properties are different for each of the 23 states. Figure 13 b) shows the frequency that the different states occur during the year, for the venetian blinds.
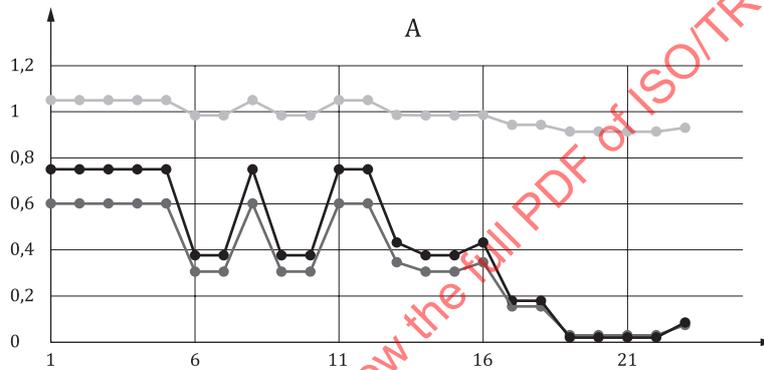
a) Properties for each state; external venetian blinds
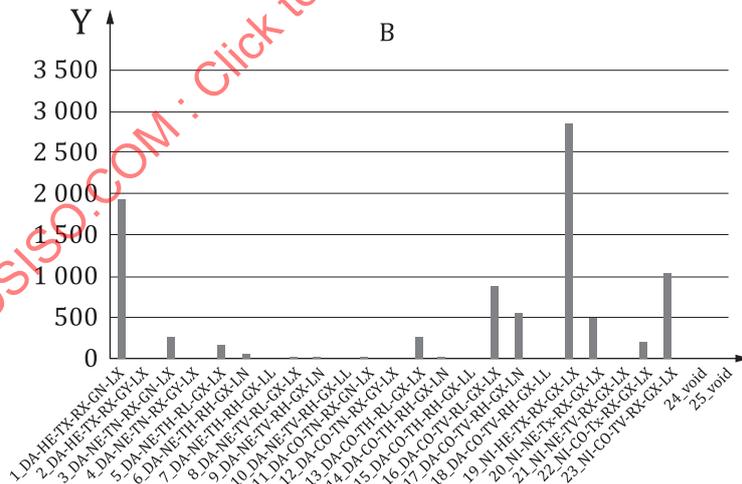
b) Occurrence of each state; external venetian blinds
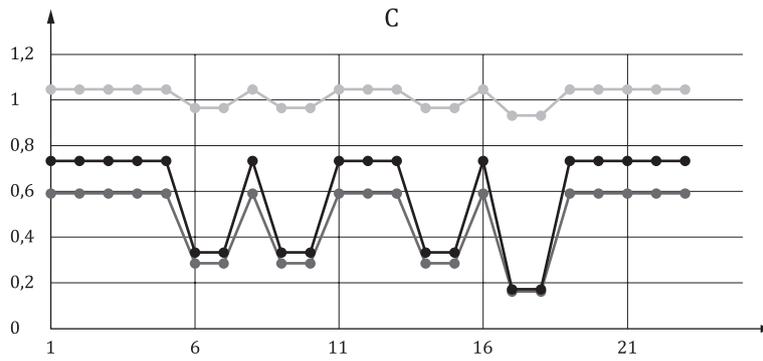
c) Properties for each state; external roller blinds

Key

Y	number of hours
A	ExVen-MOT-RES
B	occurrence of each state over the year
C	ExRbl-MOT-RES
—•—	$U_{w;Wadapti;sti}$
—•—	$g_{w;Wadapti;sti}$
—•—	$\tau_{vis;w;Wadapti;sti}$

Figure 13 — Illustration of properties and occurrence for each state over the year, motorized, residential space

Figure 14 illustrates, for external venetian blinds in a heated only office, a) for motorized control, c) for automated control, to what extent their properties are different for each of the 23 states. Figure 14 b) shows the frequency that the different states occur during the year, for the motorized control.
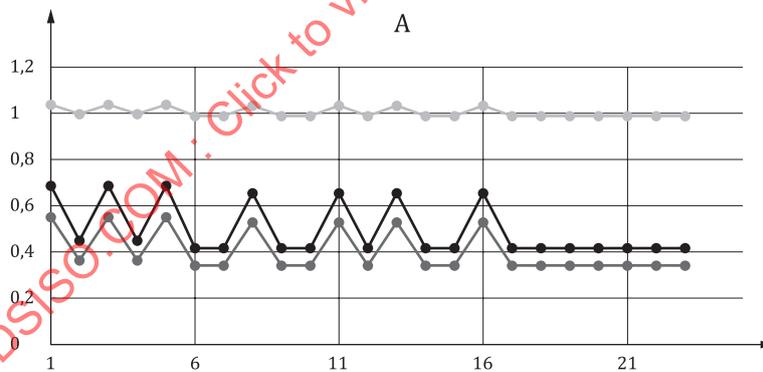
a) Properties for each state; motorized
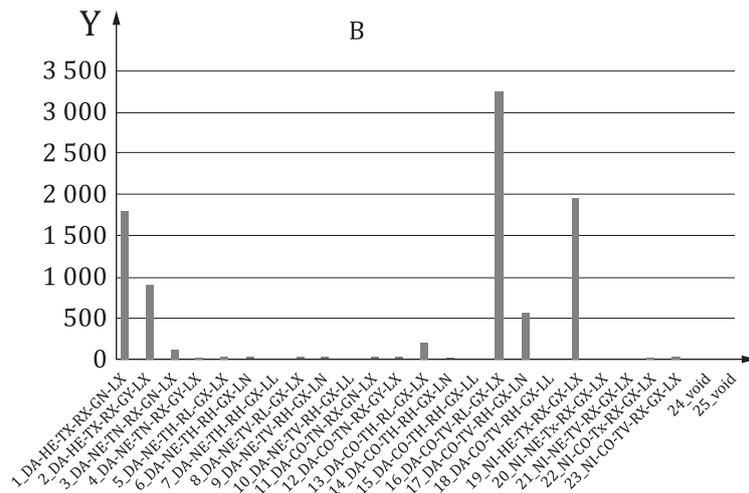
b) Occurrence of each state; motorized
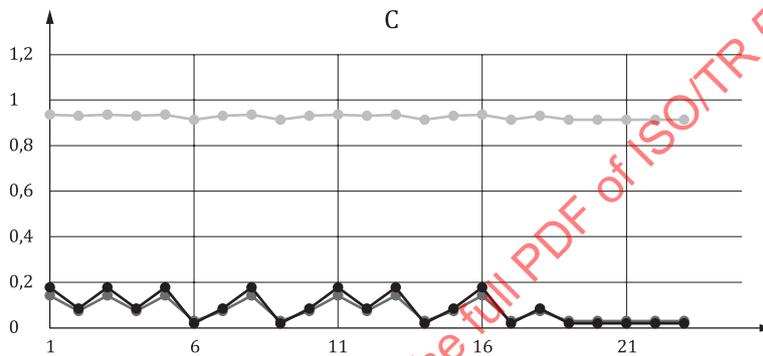
c) Properties for each state; automated

Key

Y	number of hours
A	ExVen-MOT-OFFHE
B	occurence of each state over the year
C	ExVen-AUT-OFFHE
—●—	Uw;Wadapti;sti
—●—	gw;Wadapti;sti
—●—	τvis;w;Wadapti;sti

Figure 14 — Illustration of properties and occurrence for each state over the year, example case with external venetian blinds, office; heated only (Soff_Sbg_ExVen_AUT_HE)

Finally, Figure 15 illustrates the time sequence for an arbitrarily selected week in winter and in summer, for an office space with external venetian blinds in Strasbourg. This figure can be compared with Figure 12 for a single-family house.

Figure 15 a) shows the assumed occupancy density (according to EN 16798-1) and the external air temperature. The occupancy varies during the working hours. There are no occupants after working hours and during the weekend.

Figure 15 b) shows the g-value of the adaptive element, together with the solar irradiance on this south vertical window, for manual control with motorized operation. Upon leaving the office the blinds are kept in position until the occupants arrive again.

Figure 15 c) shows the same for automated control. The operation continues during unoccupied hours and days. At specific hours in summer when occupied, the g-value is higher than during hours before and after.

This may be due to the intervening occupant if the daylight level at the desk is too low. Whether it is this or another effect can be seen when looking into the hourly results more in detail. These results are available and can be studied step-by-step in the spreadsheet.
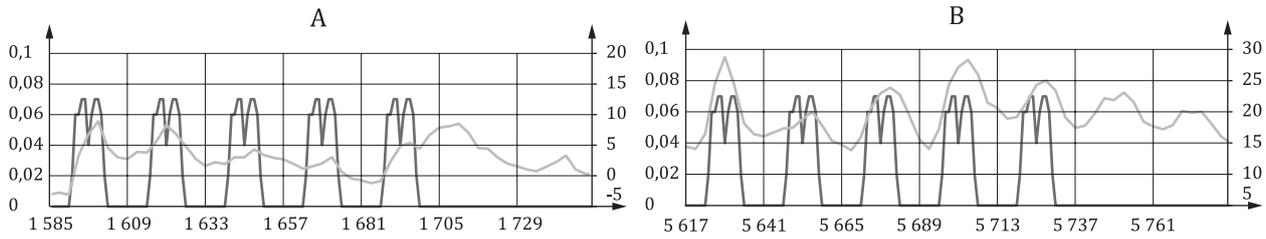
Key

A   Soff_Sbg, wk 6

B   Soff_Sbg, wk 30

⎯⎯   Occup. density (p/m2)

⎯⎯ ϑ e;air (°C)

a) Assumed occupancy density and the external air temperature
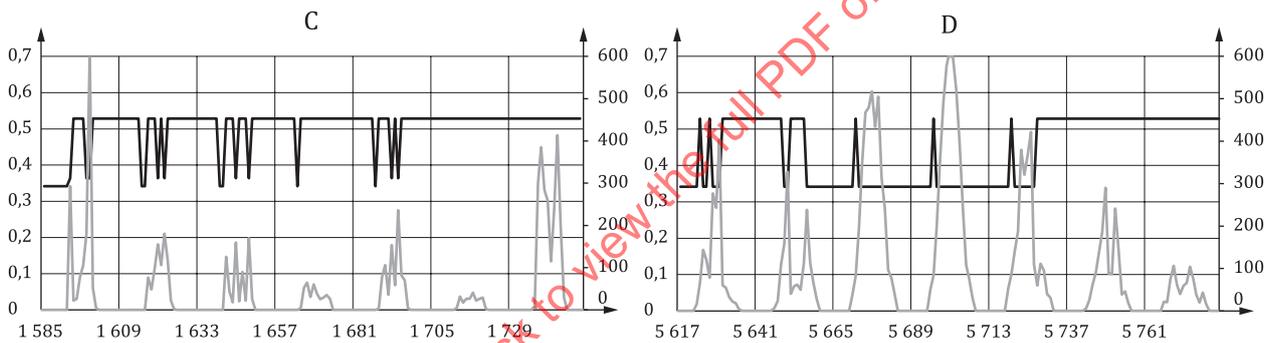
Key

C   Soff_Sbg_ExVen_MOT_HECO, Feb (wk 6)

D   Soff_Sbg_ExVen_MOT_HECO, July (wk 30)

⎯⎯   g-value (-)

⎯⎯   Isol (W/m2)

b) Solar irradiance and the *g*-value of the adaptive element, motorized
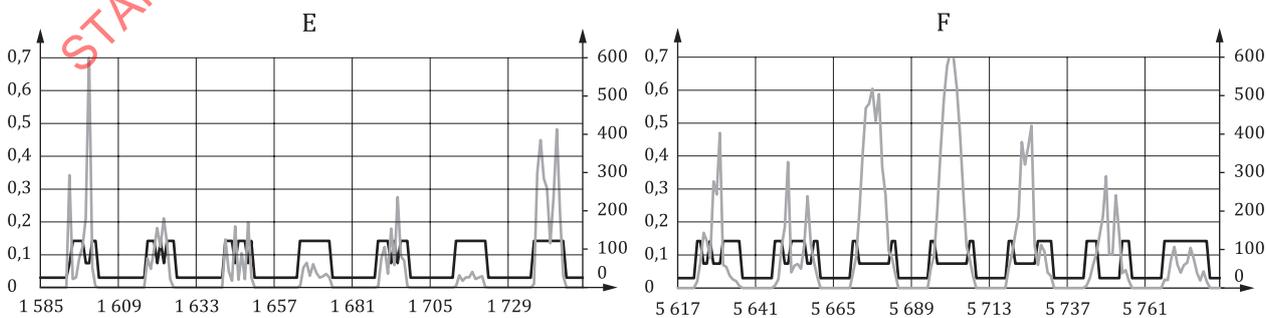
Key

E   Soff_Sbg_ExVen_AUT_HECO, Feb (wk 6)

F   Soff_Sbg_ExVen_AUT_HECO, July (wk 30)

———   g-value (-)

———   Isol (W/m2)

c) Solar irradiance and the *g*-value of the adaptive element, automated

Figure 15 — Illustration of an hourly time sequence, external venetian blinds, office room, Strasbourg

The results should 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).

For more details, see Reference [23].

9.7   Conclusions

9.7.1   General

The updated spreadsheet on ISO 52016-1 with the added sheet for (optional) application of ISO 52016-3 enabled to check and demonstrate the functionalities of ISO 52016-3 and the interaction with the calculation procedures of ISO 52016-1.

The examples show that ISO 52016-3 covers the scope adequately: on the basis of available input data and choices with respect to adaptive building envelope elements and the type of control, it produces results that can be integrated in the calculation according to ISO 52016-1, for different categories of spaces, with or without heating or cooling systems.

The spreadsheet works well to demonstrate, validate and illustrate the calculation procedure of ISO 52016-3. In particular, because each step of the calculation is visible and can be tracked and traced, as has been demonstrated with the example cases.

It is essential to assess the thermal comfort, at the same level as the energy performance, to avoid that, e.g. in case of undersized or absent heating or cooling system, the energy performance is rated as very good, at the cost of the thermal comfort. A recently internationally developed (overall and seasonal) thermal comfort score (See Reference [16]) has been built in the spreadsheet and proved its usability in these example calculations.

9.7.2   Limitations of the spreadsheet tool and example cases

— As the spreadsheet tools on other EPB standards, this spreadsheet tool is not suited for application in daily practice. It has not been developed for that purpose. For daily use in practice, software tools can be used that have a user-friendly interface and that make the connections to other parts of the overall EPB calculation.

— Conclusions on the difference between the example cases should not be extrapolated to other cases, because there is a multitude of combined effects (e.g. climate, orientation, window size, space type, insulation level, building mass) that lead to the final result, in terms of energy and comfort. That is why the set of EPB standards adopted the holistic approach: the performance of a component or product can only be properly appreciated in the full and dynamic context of the specific building.

— One of the objectives of adaptive building envelope elements is to optimize lighting and visual comfort conditions, including the positive influence of natural lighting. Consequently, this is an intrinsic element in the control scenarios. However, in the spreadsheet, the visual aspects have been treated in a simplified way. A more detailed way to assess the lighting quality requires more detailed information on the room's geometry and properties, occupant's position and luminance distribution of the sky. For testing and

demonstrating ISO 52016-3 through the spreadsheet tool a simplification is acceptable. This also goes for the evaluation of the calculation results in terms of performance indicators for the lighting quality.

— Chromogenic glazings are not explicitly covered in this case study. Actively operated chromogenic glazing follows the same reference control scenarios as roller blinds, so the roller blind variants are also applicable for active chromogenic glazings. The thermal, solar and visual properties for each state can be specified as input data so that it is easy to run additional, tailored, example cases with specific chromogenic glazing products.

— Environmentally controlled (passive) adaptive building elements are disregarded in this case study (and in the spreadsheet), because they are much more straightforward and quite trivial to calculate.

— Building envelope elements with an actively ventilated cavity have not been included in this case study, because it would have added many additional choices and variations. In addition, for a proper assessment it requires a dynamic coupling of the calculations according to ISO 52016-1 with the EPB standard on the natural ventilation air flow calculations (EN 16798-7). Such a dynamic (hourly) coupling has been demonstrated in an earlier case study (see Reference [22]). Such coupling, however, is more the task of a software tool that covers and connects the major EPB standards.

10 Validation of the calculation procedures

This is a common clause for the set of EPB technical reports.

The set up and results of validation and verification are provided in Clause 7 (parallel to ISO 52016 3:2023, Clause 7). This concerns validation of the correct implementation of the calculation procedures, e.g. in a software tool.

Annex A
(informative)

ISO 52016-3 input and method selection data sheet — Template

A.1 General

ISO 52016-3:2023, A.1 is a common subclause for all EPB standards. In ISO 52016-3 it is a normative annex.

More information and explanation on the concept of Annex A and Annex B for all EPB standards is given in ISO/TR 52000-2.

A.2 References

The structure of ISO 52016-3:2023, A.2 conforms to the common template for the set of EPB standards.

If ISO 52016-3 is adopted (e.g. in national regulations), then also all the normative references (in Clause 2) to other standards are adopted, including the (referenced parts of the) standards that are not or not yet published or do not have a national data sheet yet. Sometimes this causes a problem.

To solve this problem, the references to other EPB standards are placed in the input and method selection data sheet. In the normative Annex A, the template for the normative references to other EPB standards is given (Table A.1), and the default references (in casu: the EPB standards) are provided in the informative Annex B (Table B.1), according to the template in Annex A.

These informative default choices can be replaced by a national datasheet according to the template in Annex A, replacing the references in Annex B. This national data sheet can replace the default choices by references to national standards that are in line with the set of EPB standards, or to tables or with other alternatives. However, this can only be done if the input-output matches.

More information and explanation on the concept of the normative references to other EPB standards via Table A.1 (normative template) and Table B.1 (informative default choices) of the accompanying standard is given in ISO/TR 52000-2.

In ISO 52016-3 the format has been evolved compared to the format used until now: Column 3 of ISO 52016-3:2023, Table A.1 does not ask for the title of the document, because the reference and title of the document is given in the Bibliography or in ISO 52016-3:2023, Clause 2.

Instead, column 3 of ISO 52016-3:2023, Table A.1 asks to specify the application(s), if different documents apply in different contexts. For instance, this makes the Annex obsolete that was used, for example in ISO 52016-1, to specify which reference applies to the CEN area and which outside the CEN area. See ISO 52016-3:2023, Table B.1.

Annex B
(informative)

ISO 52016-3 input and method selection data sheet — Default choices

B.1 General

ISO 52016-3:2023, B.1 is a common subclause for all EPB standards.

More information and explanation on the concept of Annex A and Annex B for all EPB standards is given in ISO/TR 52000-2.

B.2 References

The structure of ISO 52016-3:2023, B.2 conforms to the common template for the set of EPB standards.

The references, identified by the module code number, are given in ISO 52016-3:2023, Table B.1.

It is possible for each module to replace an EPB standard with a national standard or even a table with fixed input and output values, as long as all input and output data from the replaced standard are available. The input and output data can be found in Clause 6 of each EPB standard.

See A.2 for the explanation of the rules with regards to Table A.1 and Table B.1.

Concerning the content of ISO 52016-3:2023, Table B.1 (see also 6.4.1):

ISO 52022-3 shares a number of features with ISO 15099. The main differences are:

— ISO 52022-3 is not aimed to calculate the thermal resistance (although the formulae are there), but only solar and light transmittance. ISO 15099 covers the calculation of thermal resistance and U-value, as function of the temperature difference.

— ISO 52022-3 covers solar and light transmittance only for normal incidence of sun and for vertically placed windows. ISO 15099 covers any angle of incidence of the sun and includes tilted windows.

— ISO 52022-3 covers for venetian blinds, only indirect solar and light transmittance (via multiple reflections) between the slats, thus always assuming that the slats block the sun. In ISO 15099 the solar and light transmittance, e.g. for venetian blinds, includes both direct (between the slats) and indirect (via multiple reflections) solar and light transmittance.

— ISO 15099 contains a detailed model for the calculation of the thermal and solar transmittance through frames.

Annex C
(informative)

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

C.1   General

ISO 52016-3:2023, Annex C contains the tables with reference control scenarios for different control types, different adaptive building envelope elements and different space categories (residential and non-residential).

Explanation and justification on these scenarios are given in 6.8.7. More background information and justification of these scenarios is given in Annex D.

In this Annex C the reference scenarios from ISO 52016-3:2023, Annex C are presented in the form of flow diagrams (see C.3). Each of these flow diagrams shows clearly which path leads to a specific state number.

But first, to facilitate reading, Table C.1 in the next subclause (C.2) provides an overview of the identifiers from ISO 52016-3 that are used in the diagrams.

C.2   Overview of identifiers

Table C.1 — Overview of identifiers used in the diagrams; conditions or events

Description	Identifier	Values	Explanation
General		**X**	Placeholder for any option EXAMPLE RX
		x	Placeholder for any but one option EXAMPLE Tx
Day or night	**DAY-MODE**	**DA**	Daytime (after sunrise)
		NI	Night time (after sunset)
Heating or cooling mode of the thermal zone		**HE**	Heating mode
	HC-MODE	**NE**	Neutral mode
		CO	Cooling mode
Operating temperature	**TINT-MODE**	**TN**	Normal operating temperature level of the thermal zone
		TH	High operating temperature level of the thermal zone
		TV	Very high operating temperature level of the thermal zone
Level of solar irradiance or illuminance	**RAD-MODE**	**RL**	Low solar irradiance or illuminance
		RH	High solar irradiance or illuminance
Occupancy	**OCC-MODE**	**OCC-AW**	Space is occupied, occupants are awake
		OCC-SLP	Space is occupied, occupants are sleeping
		UNOCC	Space is unoccupied
Glare occurrence	**GLARE-MODE**	**GN**	Protection against glare not needed
		GY	Protection against glare needed

Table C.1 *(continued)*

Description	Identifier	Values	Explanation
Daylight level	**DAYL-MODE**	**LN**	Daylight level is fine
		LL	Daylight level is low
Adaptive element, position of adaptive component		**Ex**	External or integrated
		In	Internal
Adaptive element, type of adaptive component		**UnProt**	None
		RoChr	Roller blinds or chromogenic glazing
		Shu	Shutters
		Ven	Venetian blinds
Control type	**CONTRL**	**FIX**	Fixed properties (no control)
		MAN	Manual control, manual operation
		MOT	Manual control, motorized operation
		MM	Manual control, manual or motorized operation
		AUT	Automated control
Space type		**RES**	Residential
		OFF	Office
		OFF-HE	Office, heated only
		OFF-HECO	Office, heated and cooled

C.3   Flow diagrams

The flow chart in ISO 52016-3:2023, 6.8.7 (Figure 2) with its 23 possible states may look complicated. Each specific reference control scenario, for each combination of the type of adaptive element, control and space (ISO 52016-3:2023, Tables C.2 to C.8) is based on this generic reference control scenario with 23 states.

Consequently, these Tables (ISO 52016-3:2023, Tables C.2 to C.8) are also quite complicated. However, not all choices are always applicable, and the resulting states are not necessarily all different, so the actual number of choices are in many combinations much smaller. This can be seen more clearly in the flow diagrams in this subclause, see Figure C.2 to Figure C.8, that are presented after the generic flow diagram in Figure C.1.

Each of these flow diagrams shows clearly which paths from the generic scheme are applicable and which are not, that therefore lead to simplifications in the form of combined paths. So, by combining different paths from the generic scheme, also specific states are combined: different state numbers, with an identical state.

Each flow diagram can be further simplified, by aggregating the identical states resulting from a specific path. This has been done in the next subclause (C.4).

This raises the question of why not simply present, in ISO 52016-3:2023, Annex C, these simplified flow diagrams instead of the ISO 52016-3:2023, Tables C.2 to C.8.

The answer is, that adhering to this generic control scenario as the basis for each specific scenario has the tremendous advantage that the scenarios can be modified and expanded to other combinations, by just changing the input data: the thermal, solar and visual transmittance of the adaptive element for each of the 23 states. There is no need for any re-programming of software or spreadsheet and consequently no risk of introducing programming errors, ambiguities or conflicts. For the standard unambiguity (including: "machine readability") prevails over human-readability. In contrast with that, this document serves to improve human-readability.
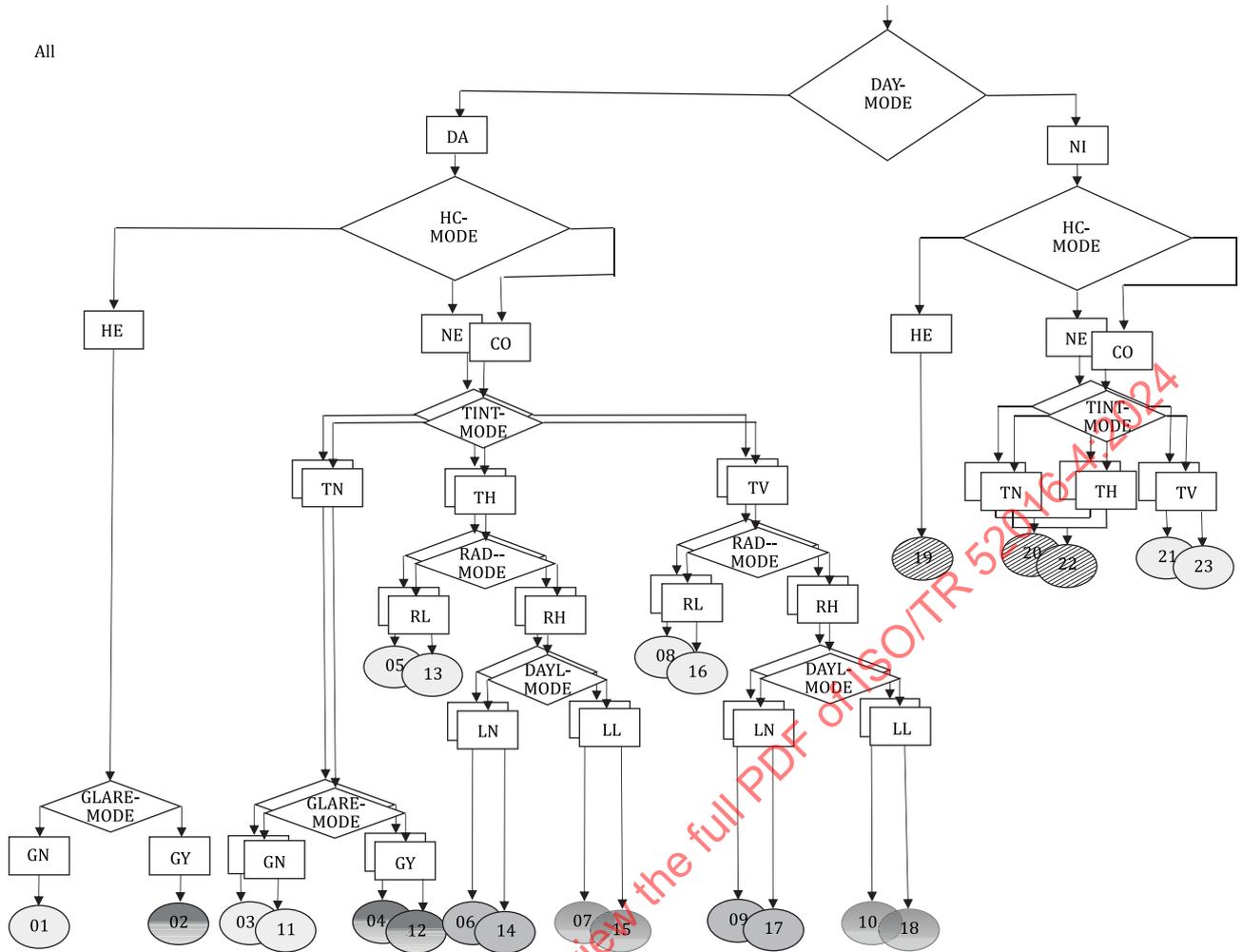
Key

see Table C.1

Figure C.1 — Main elements of the reference control scenarios (from ISO 52016-3)

Table C.2,ExRoChr-MM-RES
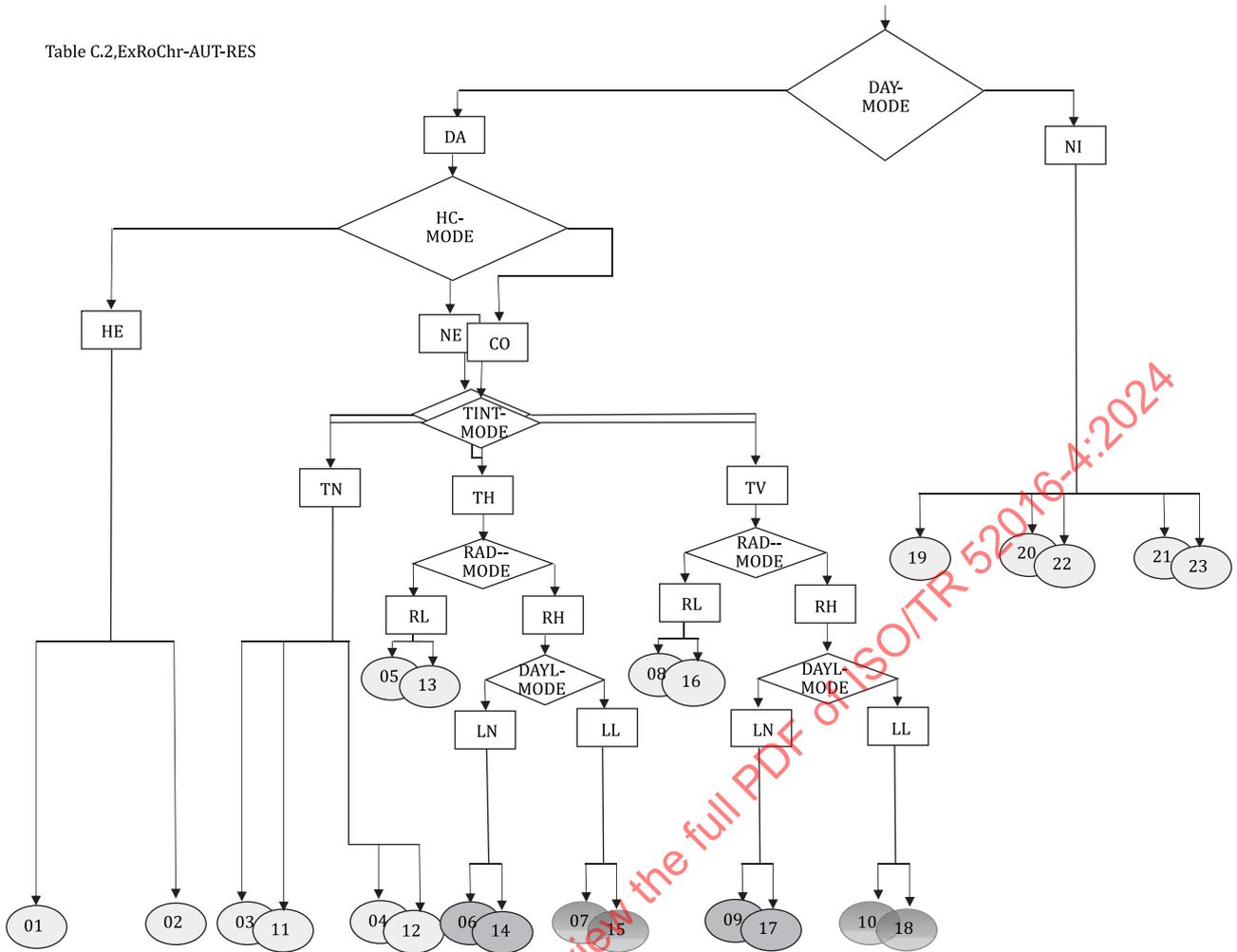
a) Manual control

b) Automated control

Figure C.2 — Diagram for ISO 52016-3:2023, Table C.2
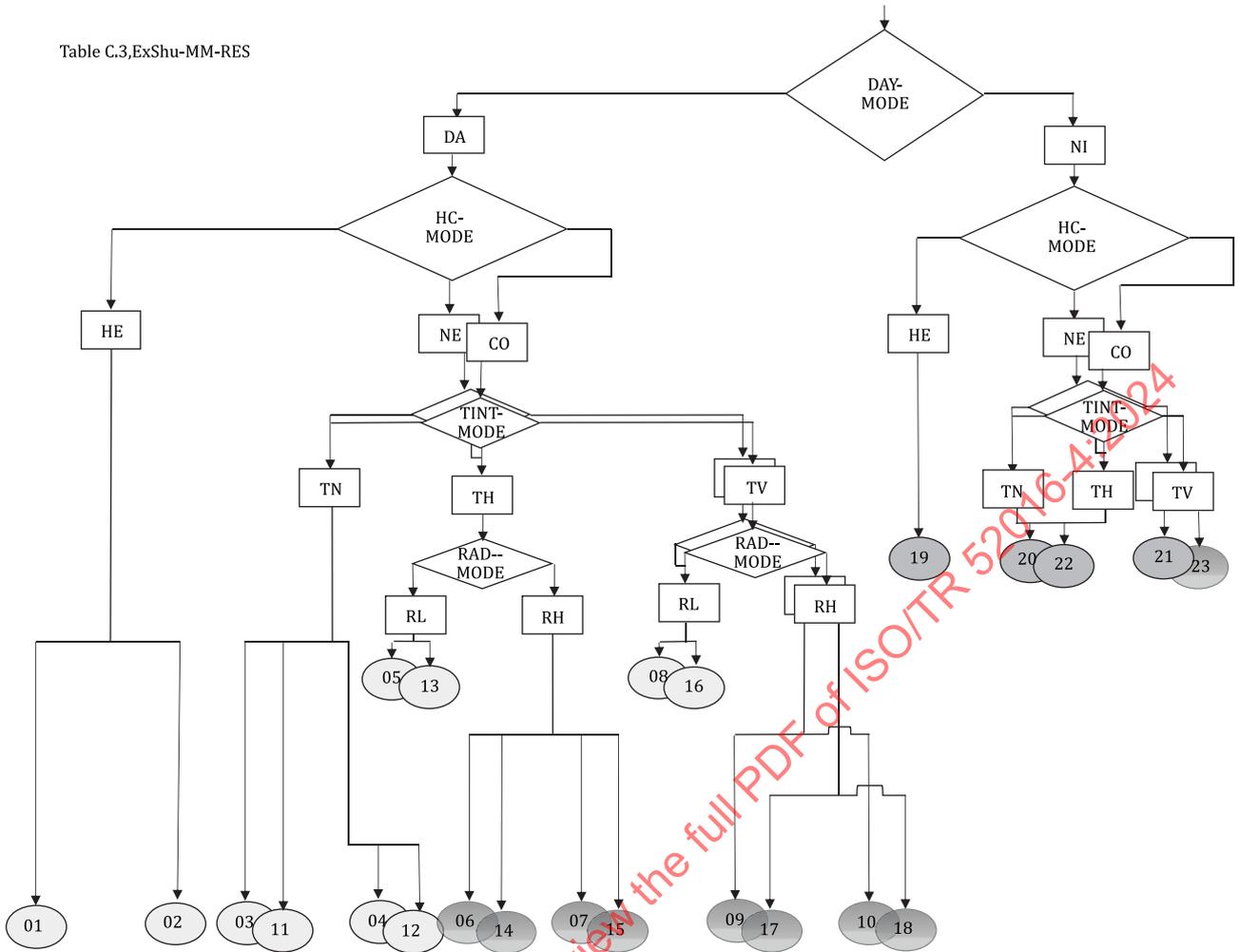
Table C.3,ExShu-MM-RES

a) Manual control

Table C.3,ExShu-AUT-RES
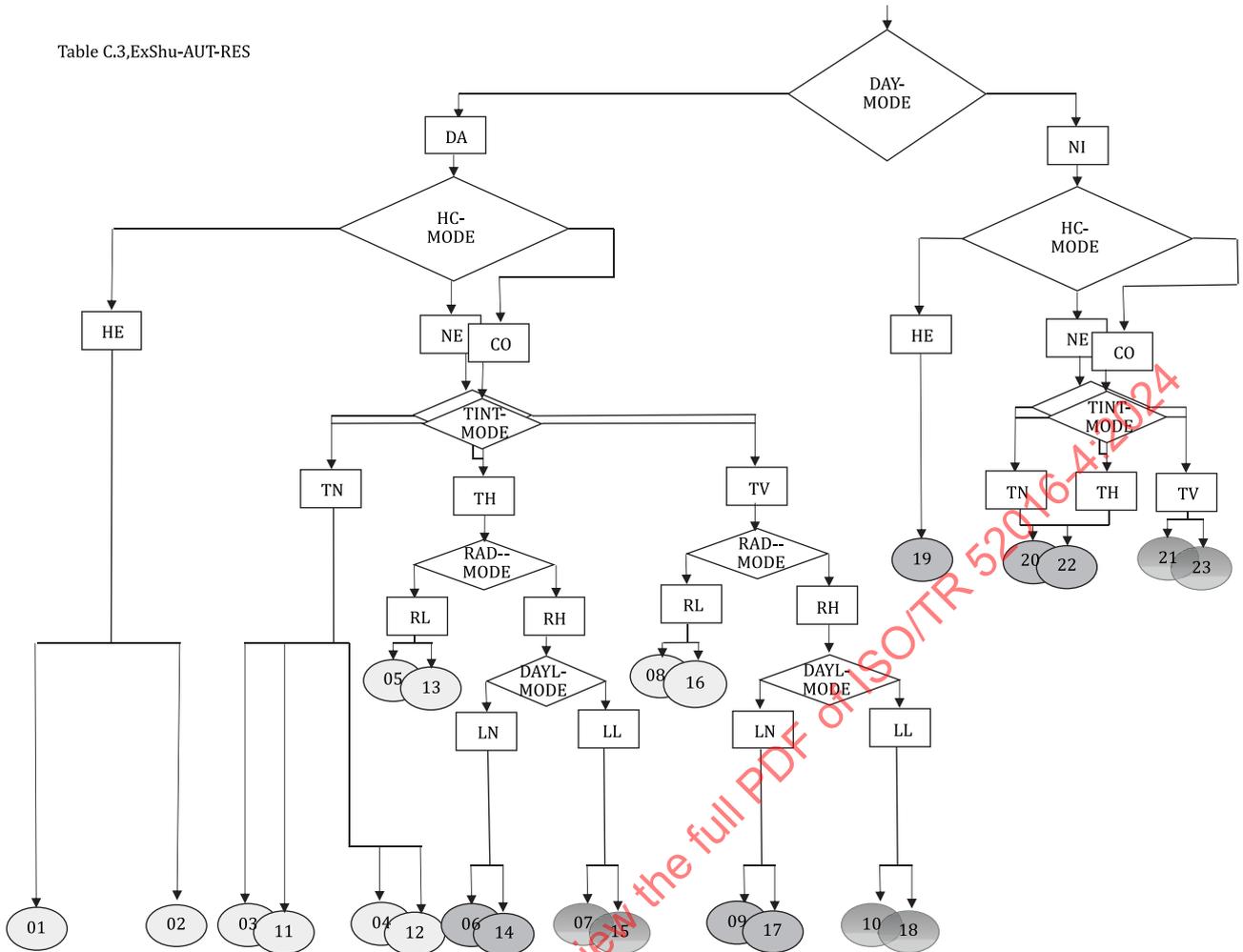
b) Automated control

Figure C.3 — Diagram for ISO 52016-3:2023, Table C.3
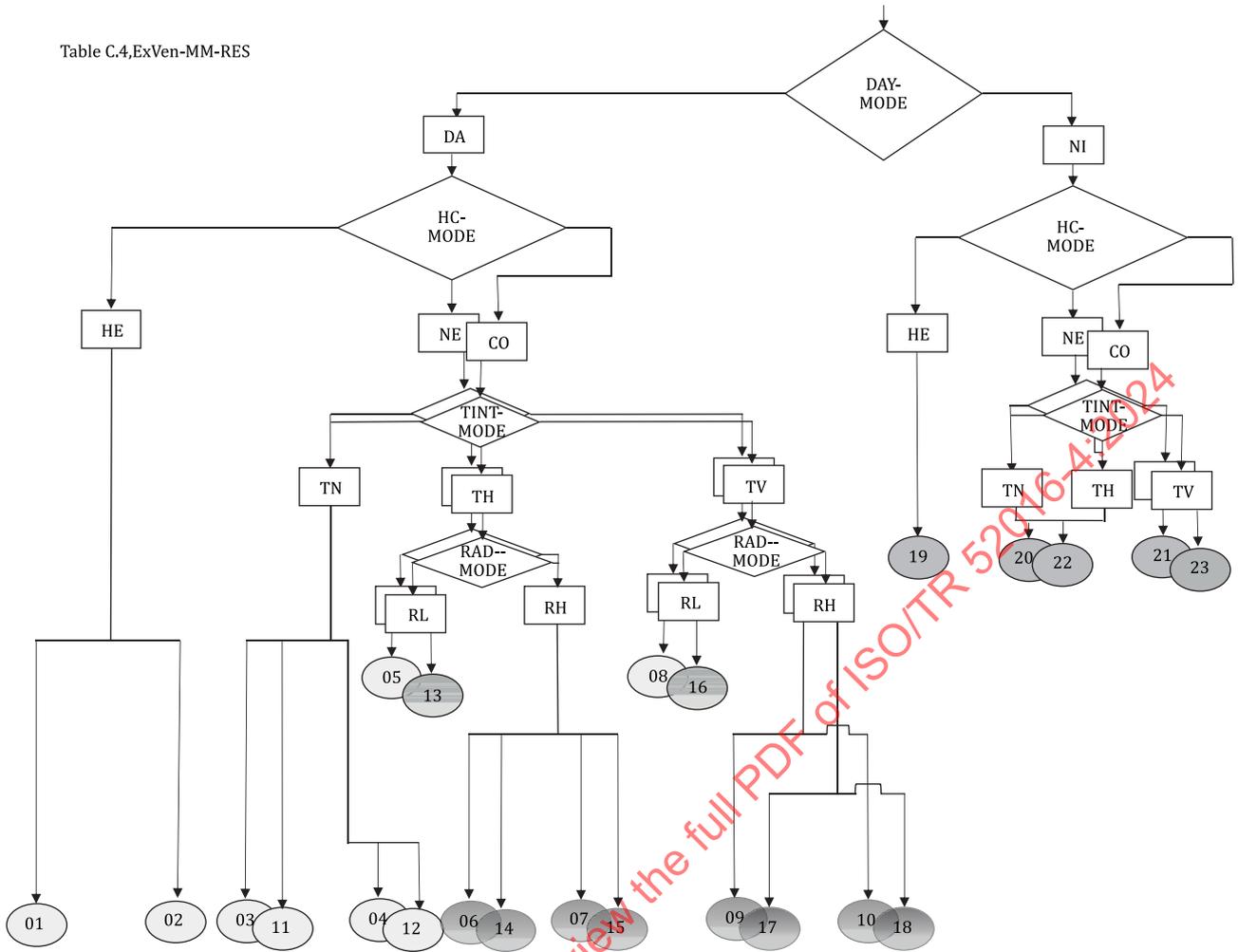
Table C.4,ExVen-MM-RES

a) Manual control

Table C.4,ExVen-AUT-RES
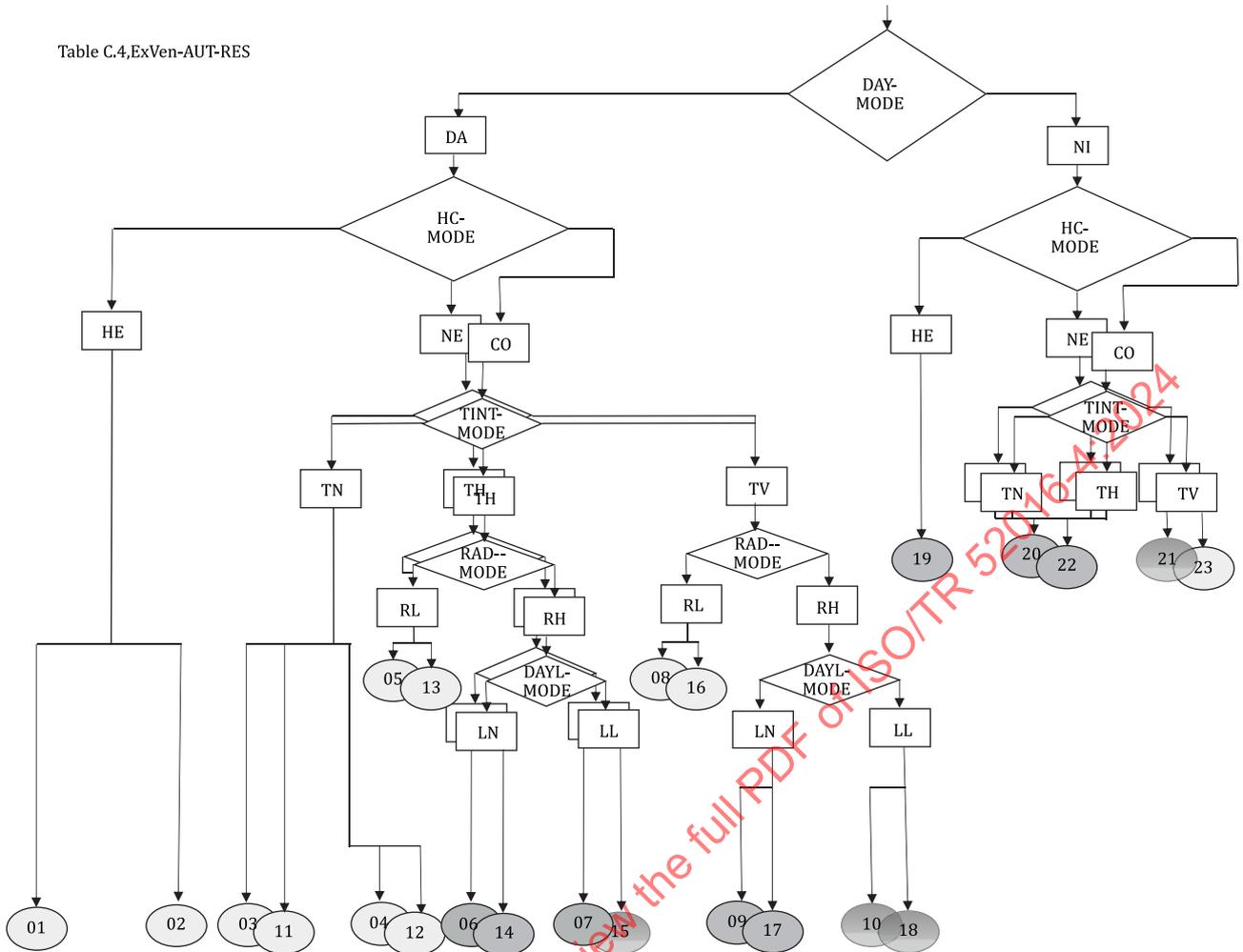
b) Automated control

Figure C.4 — Diagram for ISO 52016-3:2023, Table C.4
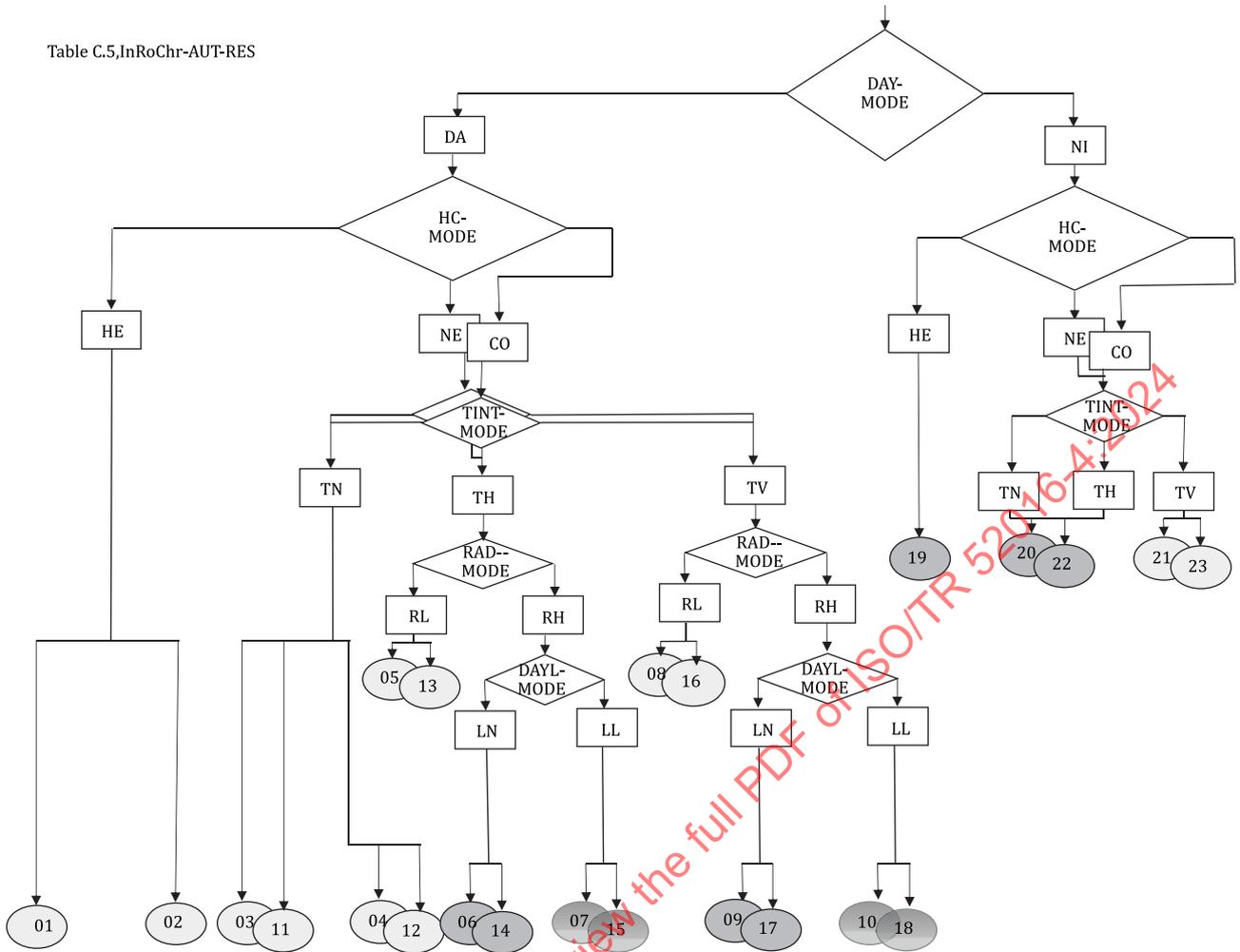
Table C.5,InRoChr-AUT-RES

a) Manual control

Table C.5,InRoChr-MM-RES
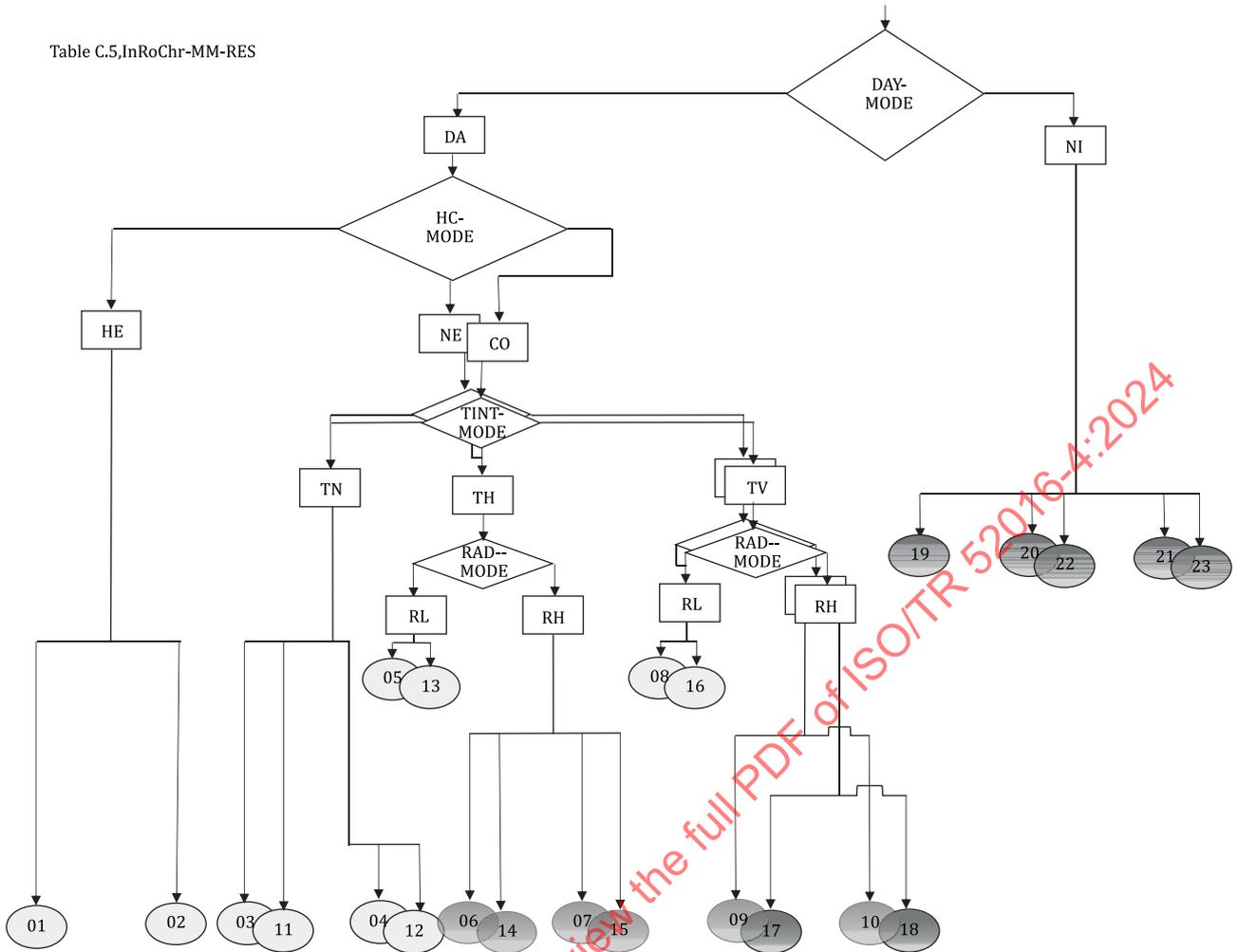
b) Automated control

Figure C.5 — Diagram for ISO 52016-3:2023, Table C.5
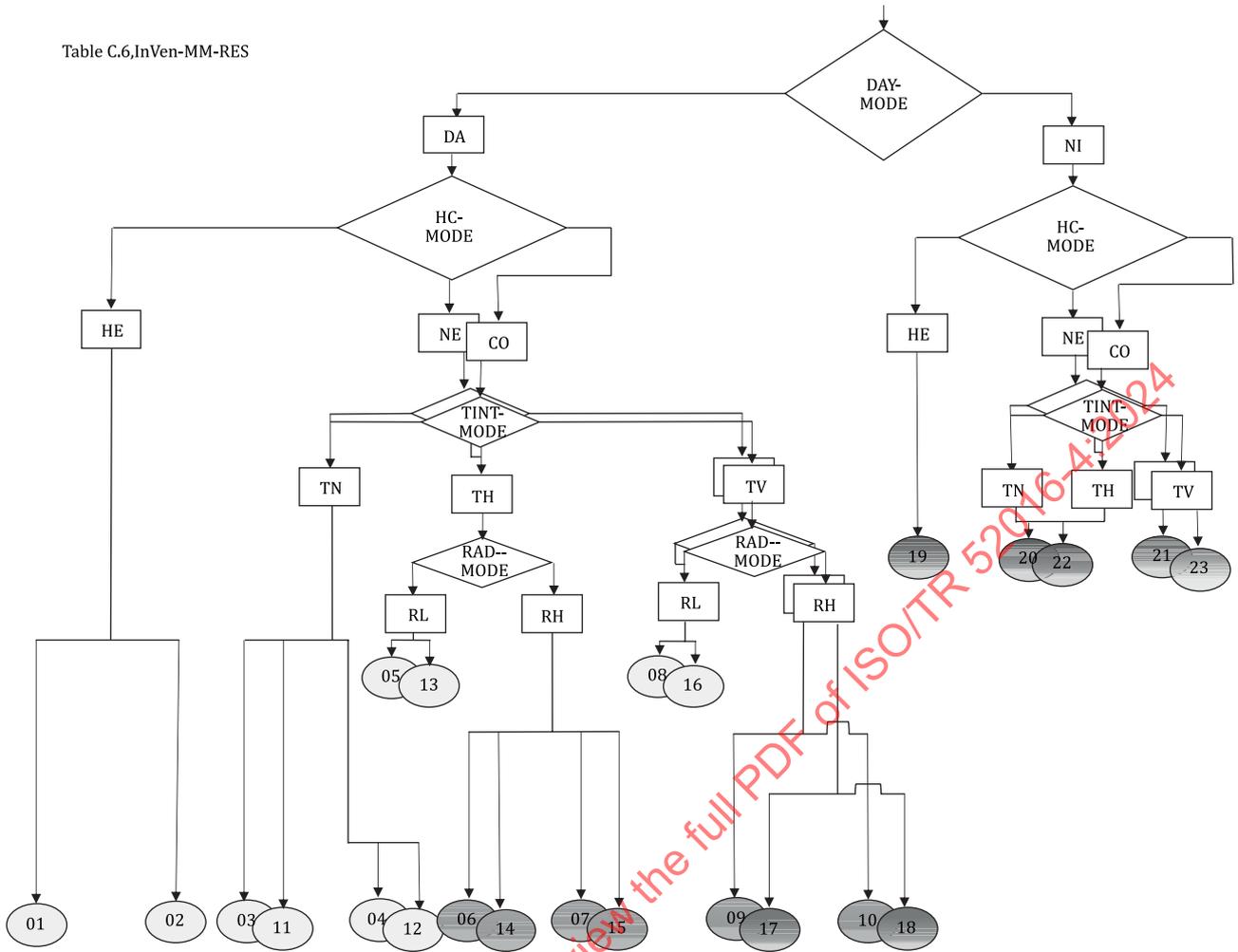
Table C.6,InVen-MM-RES

a) Manual control

Table C.6,InVen-AUT-RES
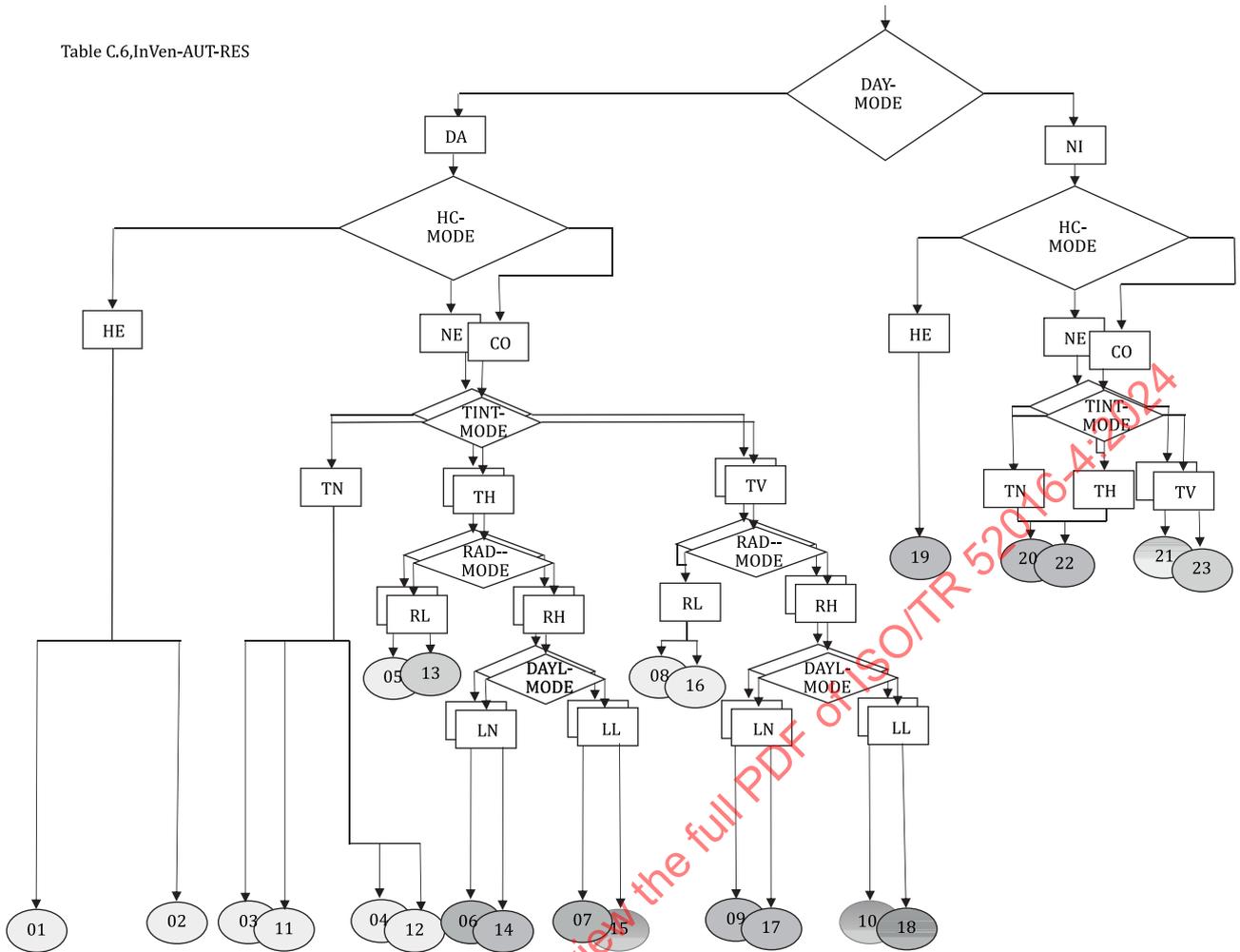
b) Automated control

Figure C.6 — Diagram for ISO 52016-3:2023, Table C.6
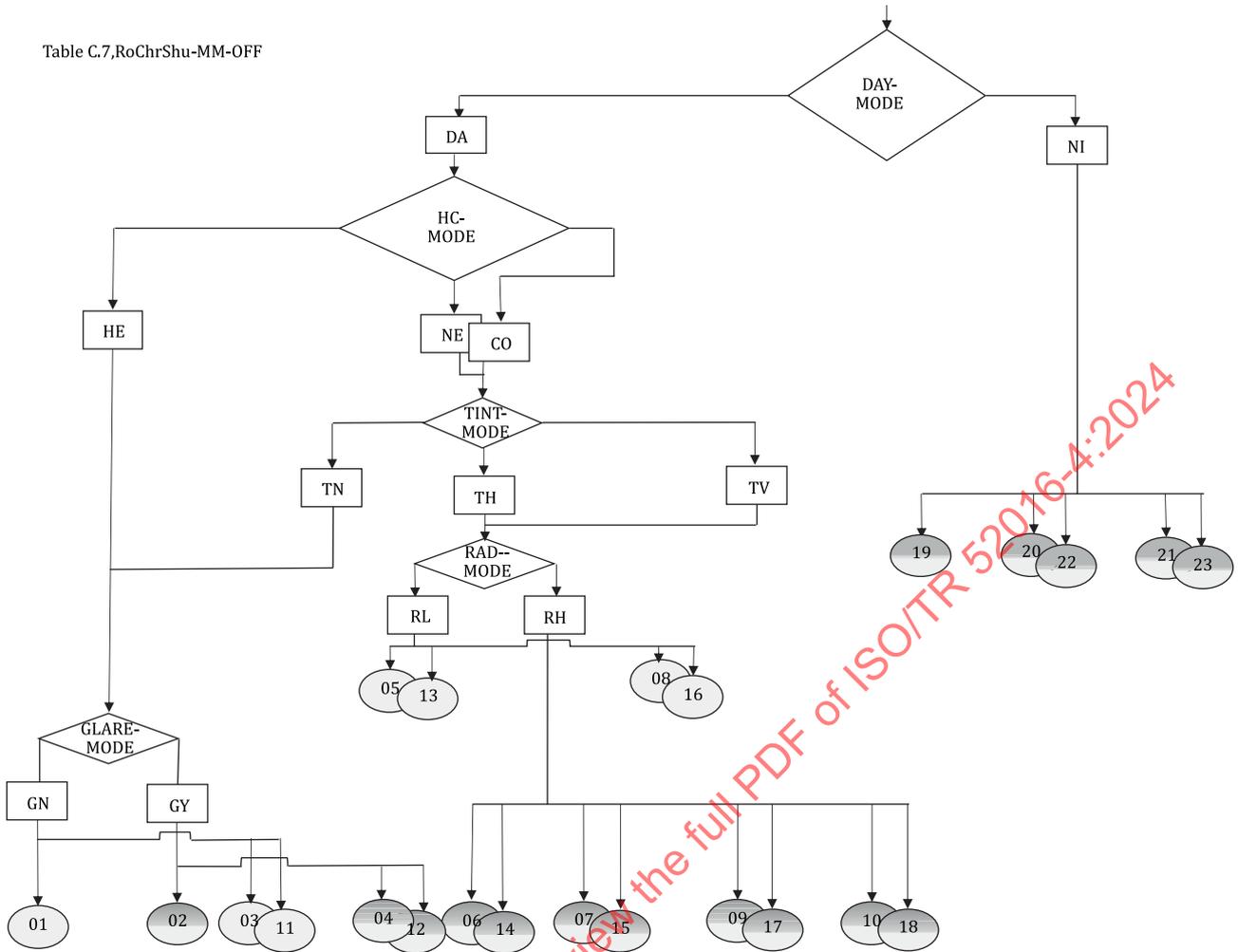
Table C.7,RoChrShu-MM-OFF

a) Manual control

Table C.7,RoChrShu-AUT-OFF
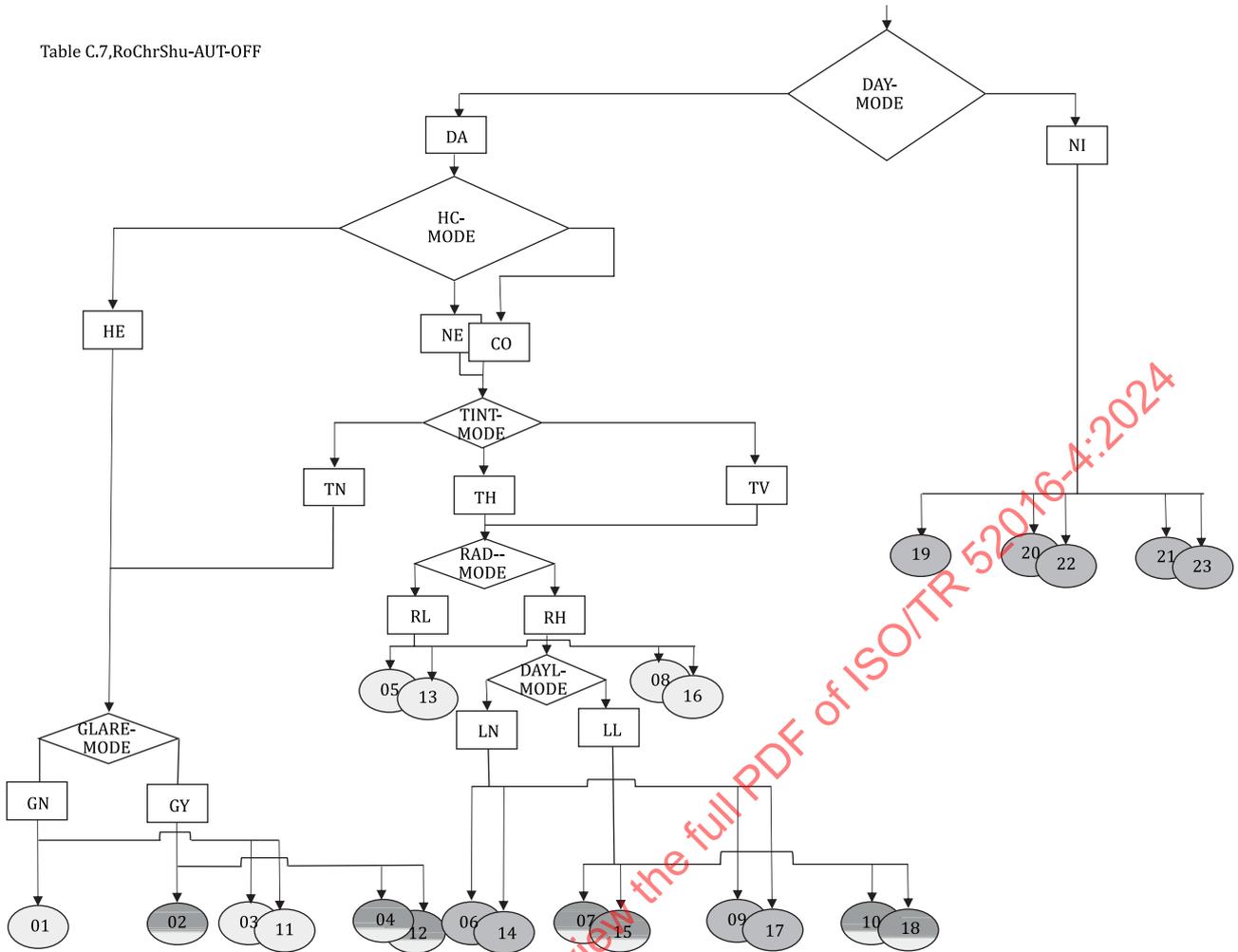
b) Automated control

Figure C.7 — Diagram for ISO 52016-3:2023, Table C.7

Table C.8, Ven-MM-OFF
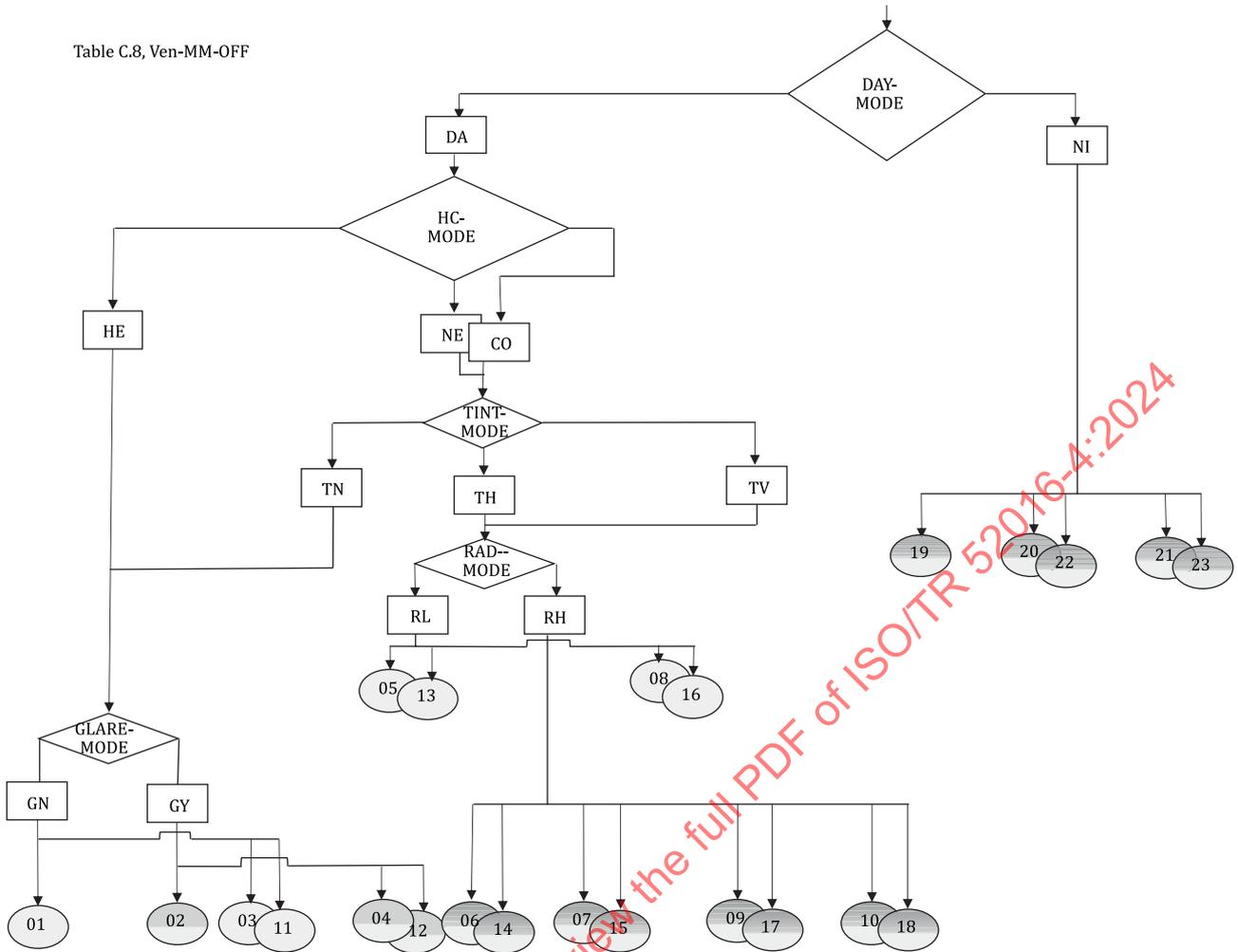
a) Manual control

Table C.8, Ven-AUT-OFF
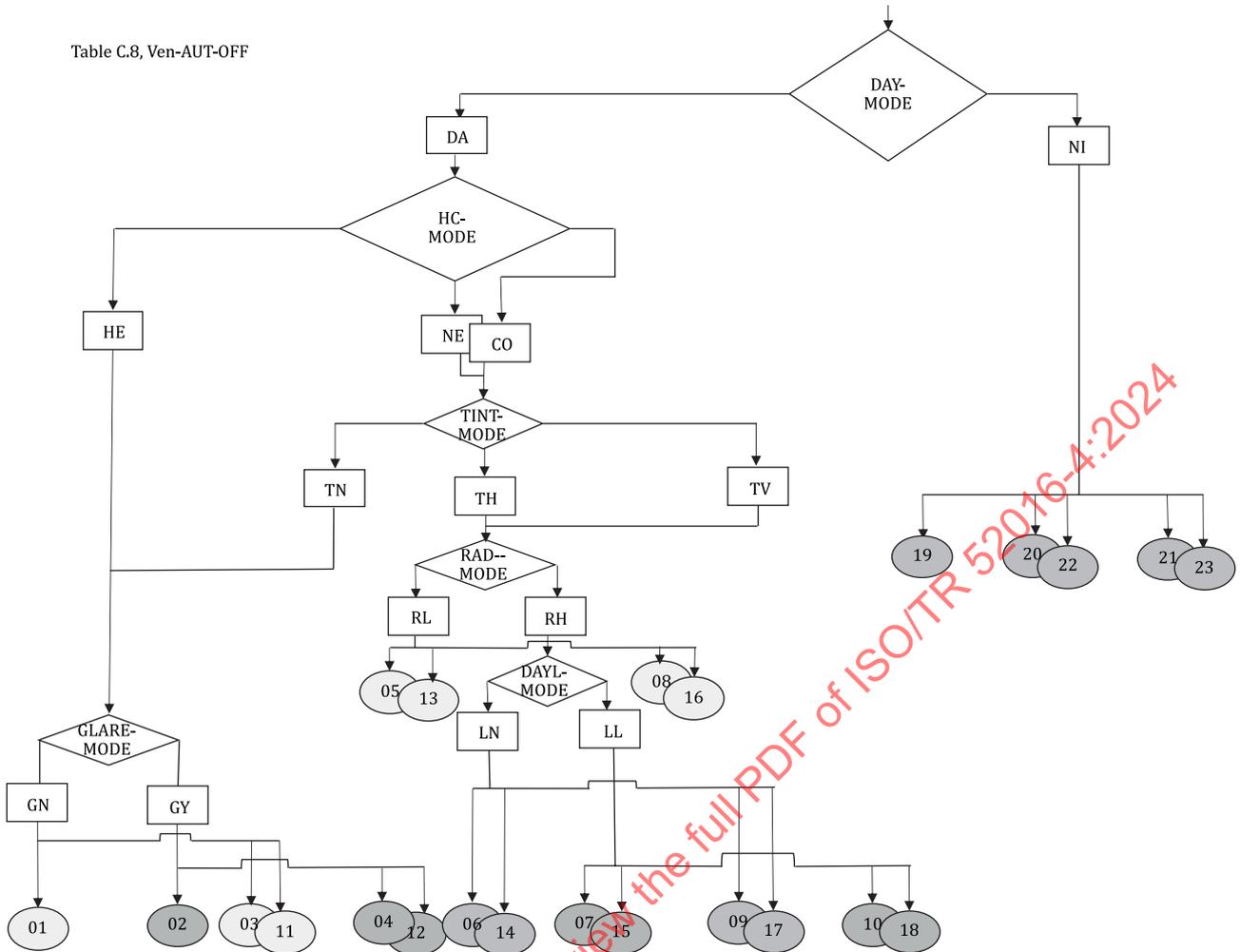
b) Automated control

Figure C.8 — Diagram for ISO 52016-3:2023, Table C.8

C.4   Aggregated flow diagrams

The same flow diagrams as in C.3, but further simplified, by aggregating the identical states resulting from a specific path. See Figure C.9 to Figure C.15.

Table C.2,ExRoChr-MM-RES
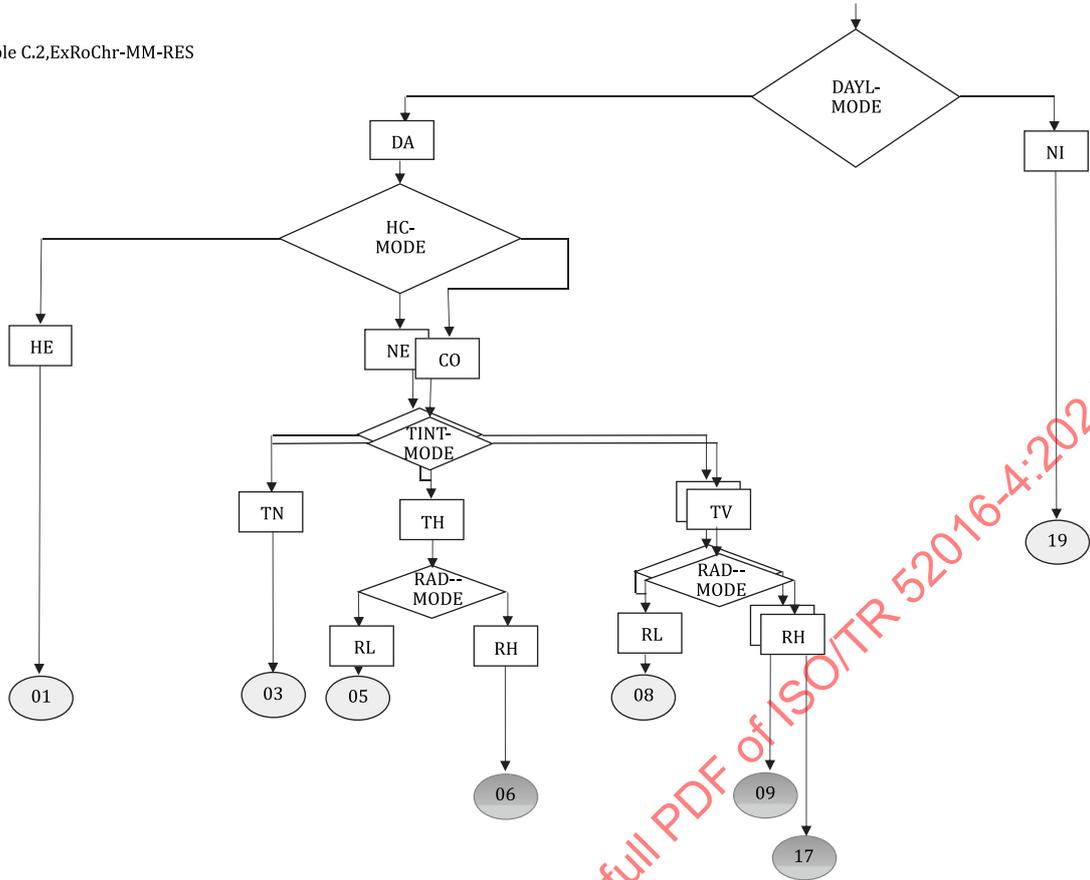
a) Manual control

Table C.2,ExRoChr-AUT-RES
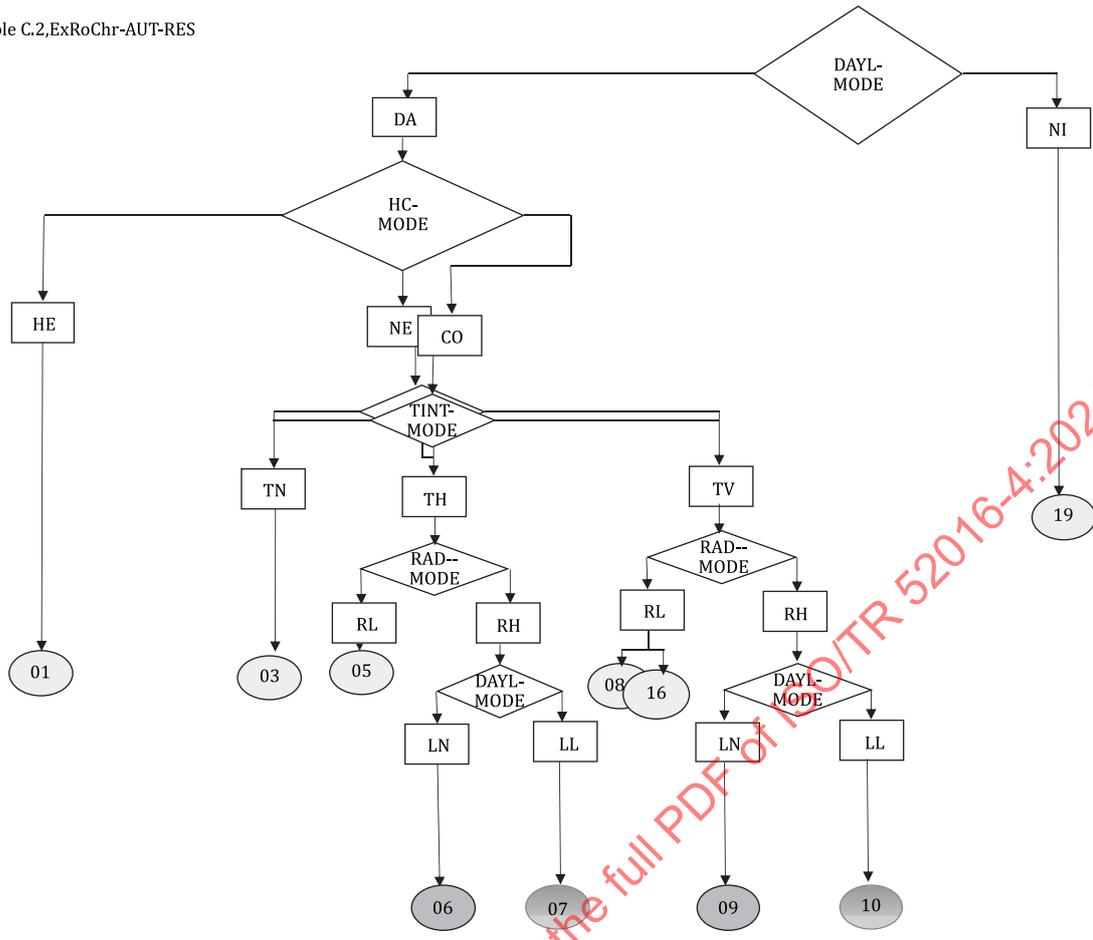
b) Automated control

Figure C.9 — Aggregated diagram for ISO 52016-3:2023, Table C.2
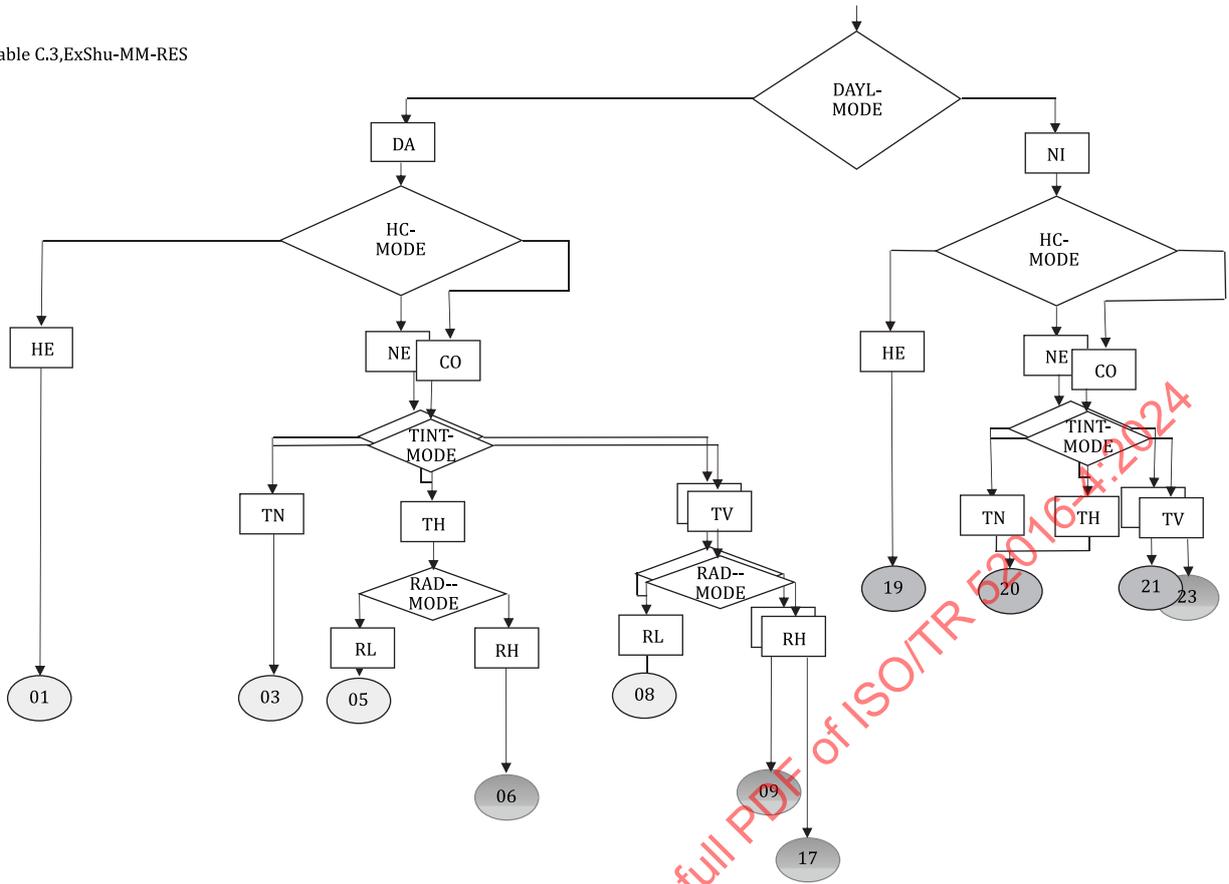
Table C.3,ExShu-MM-RES

a) Manual control

Table C.3,ExShu-AUT-RES
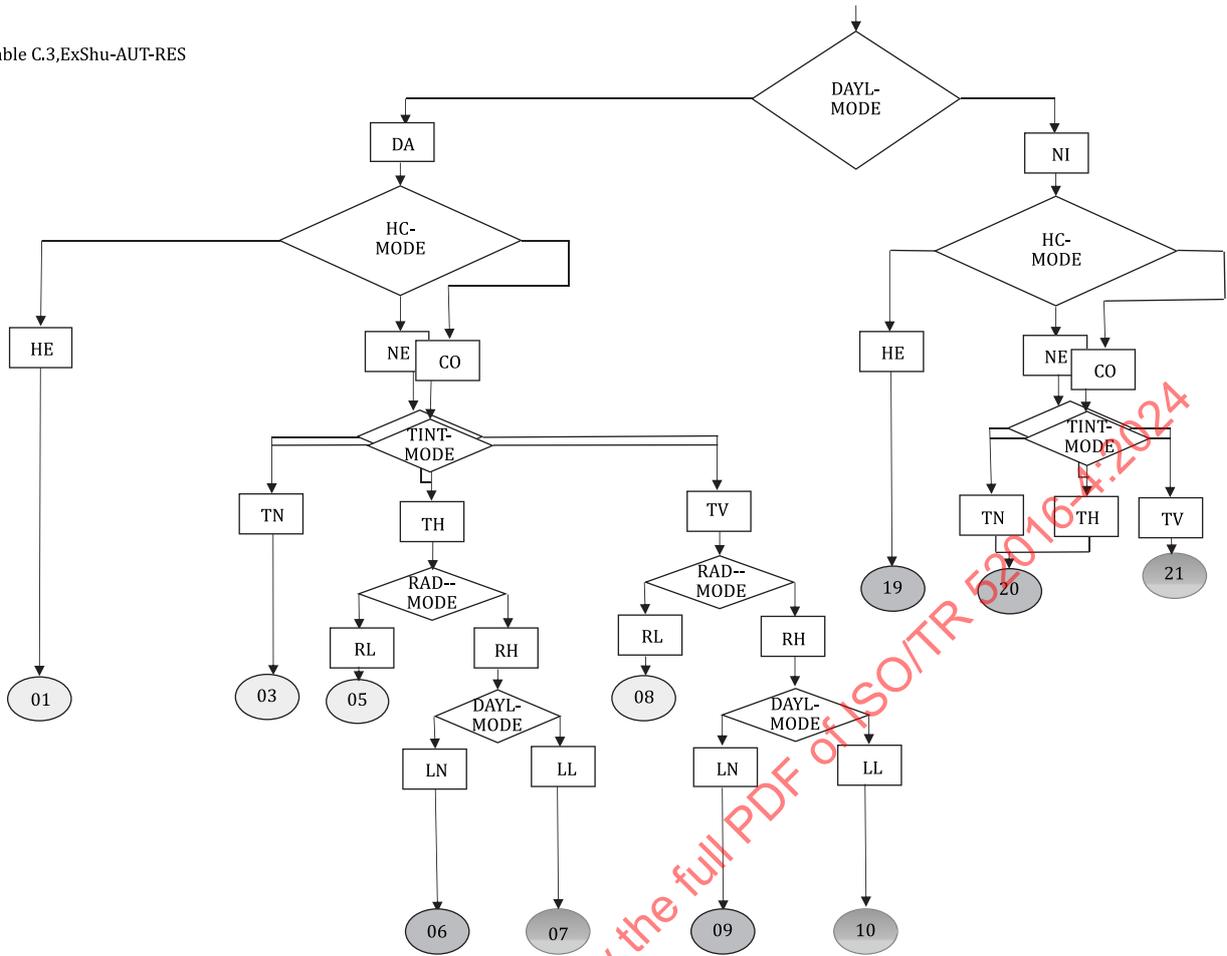
b) Automated control

Figure C.10 — Aggregated diagram for ISO 52016-3:2023, Table C.3
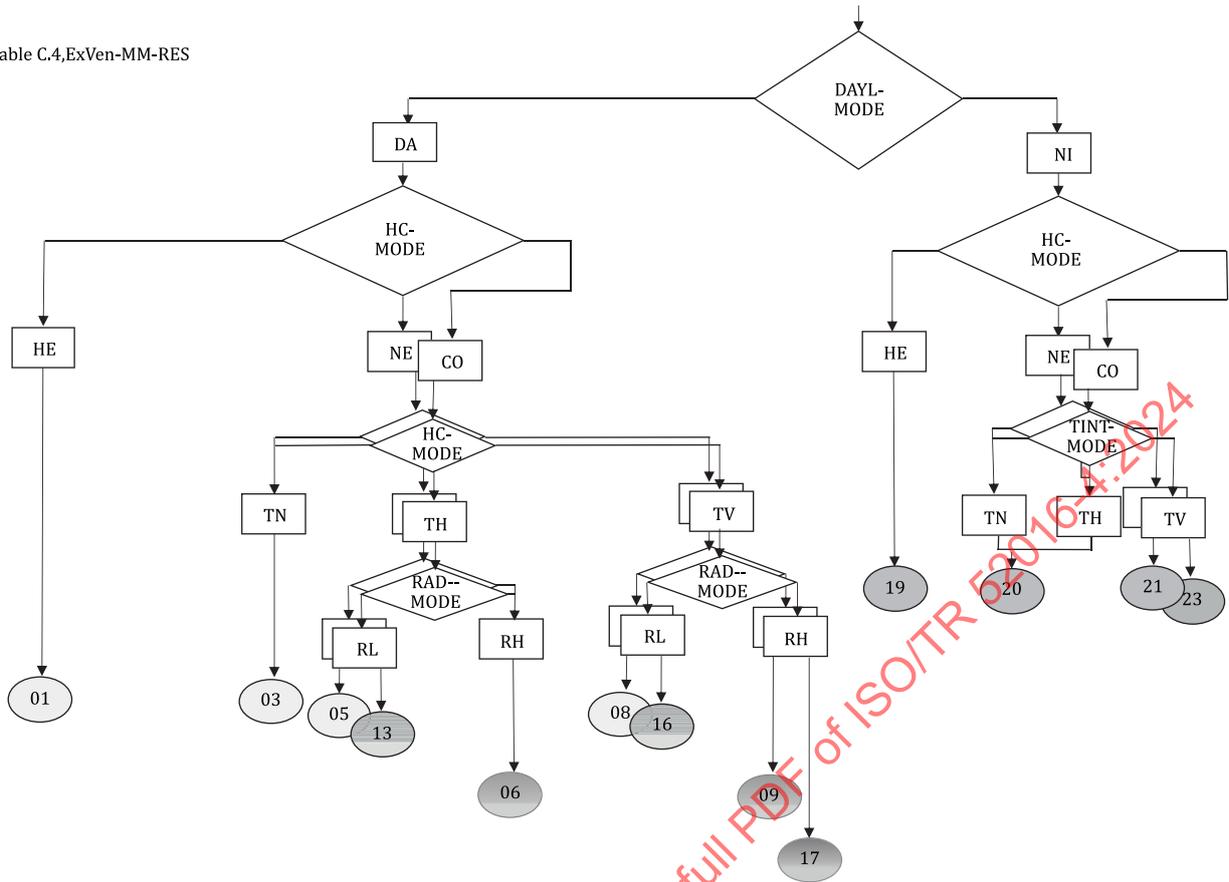
Table C.4,ExVen-MM-RES

a) Manual control

Table C.4,ExVen-AUT-RES
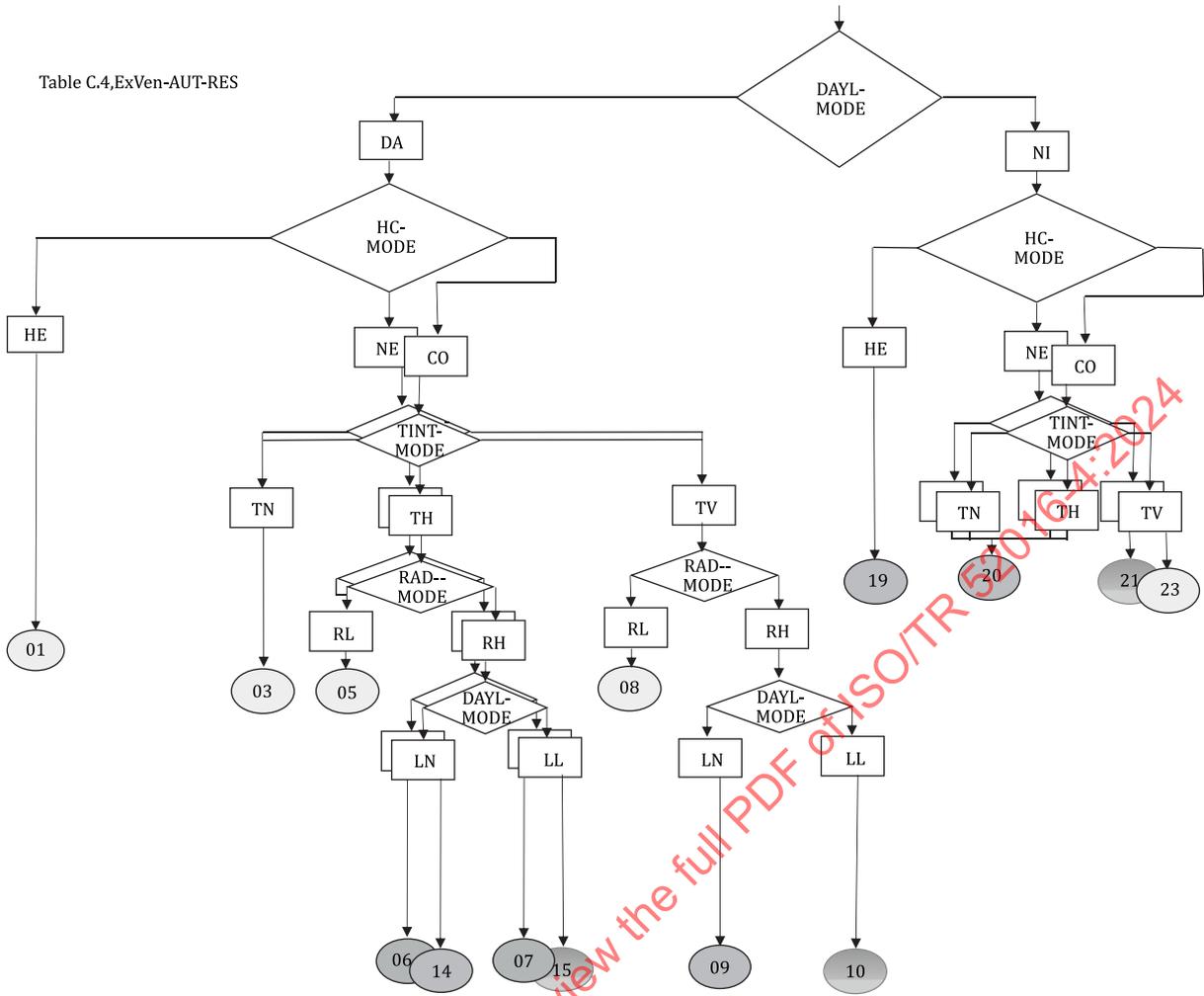
b) Automated control

Figure C.11 — Aggregated diagram for ISO 52016-3:2023, Table C.4
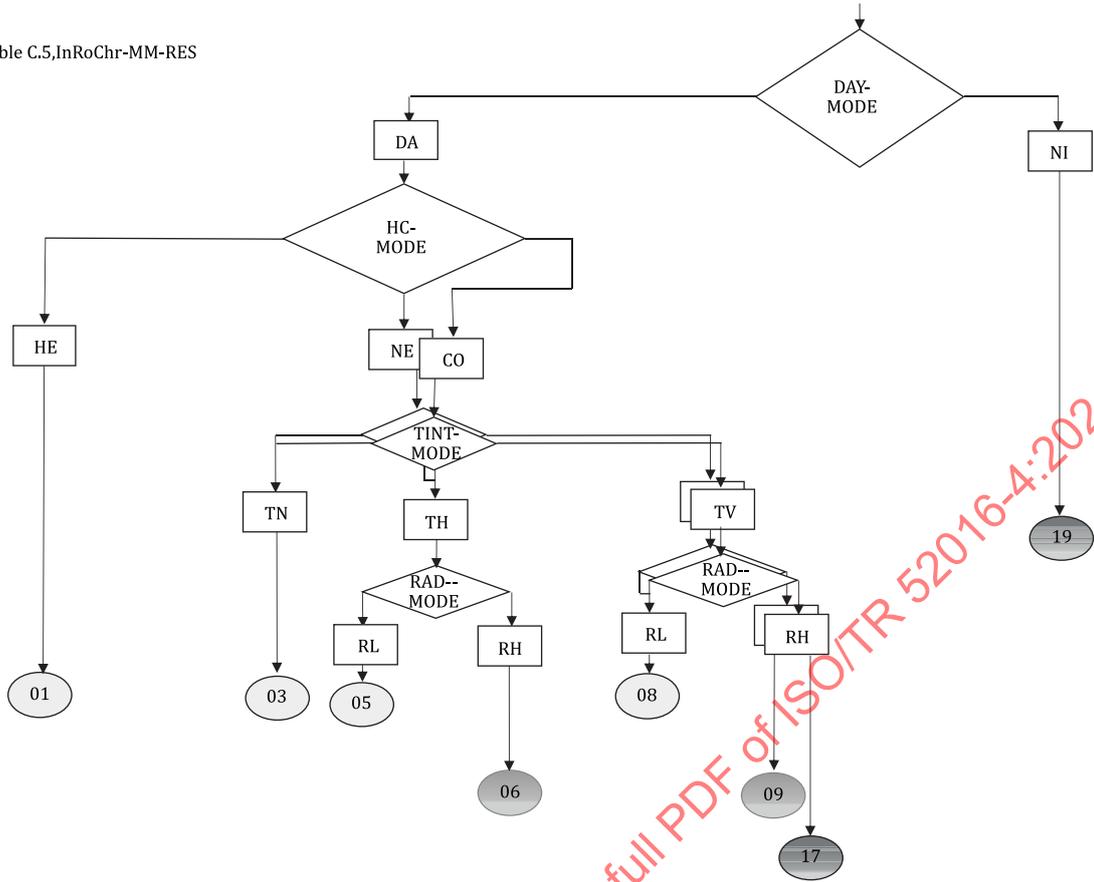
Table C.5,InRoChr-MM-RES

a) Manual control

Table C.5,InRoChr-AUT-RES
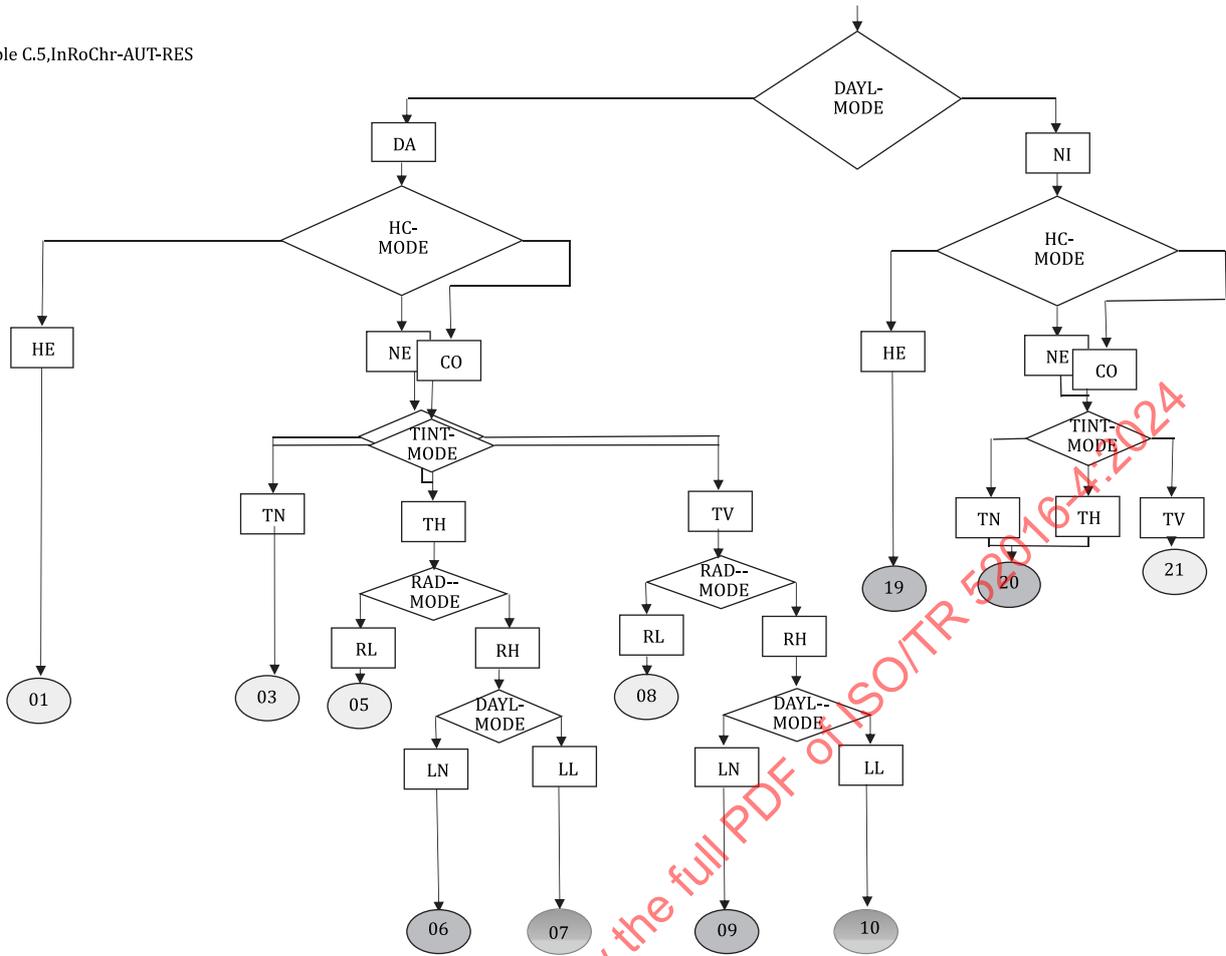
b) Automated control

Figure C.12 — Aggregated diagram for ISO 52016-3:2023, Table C.5
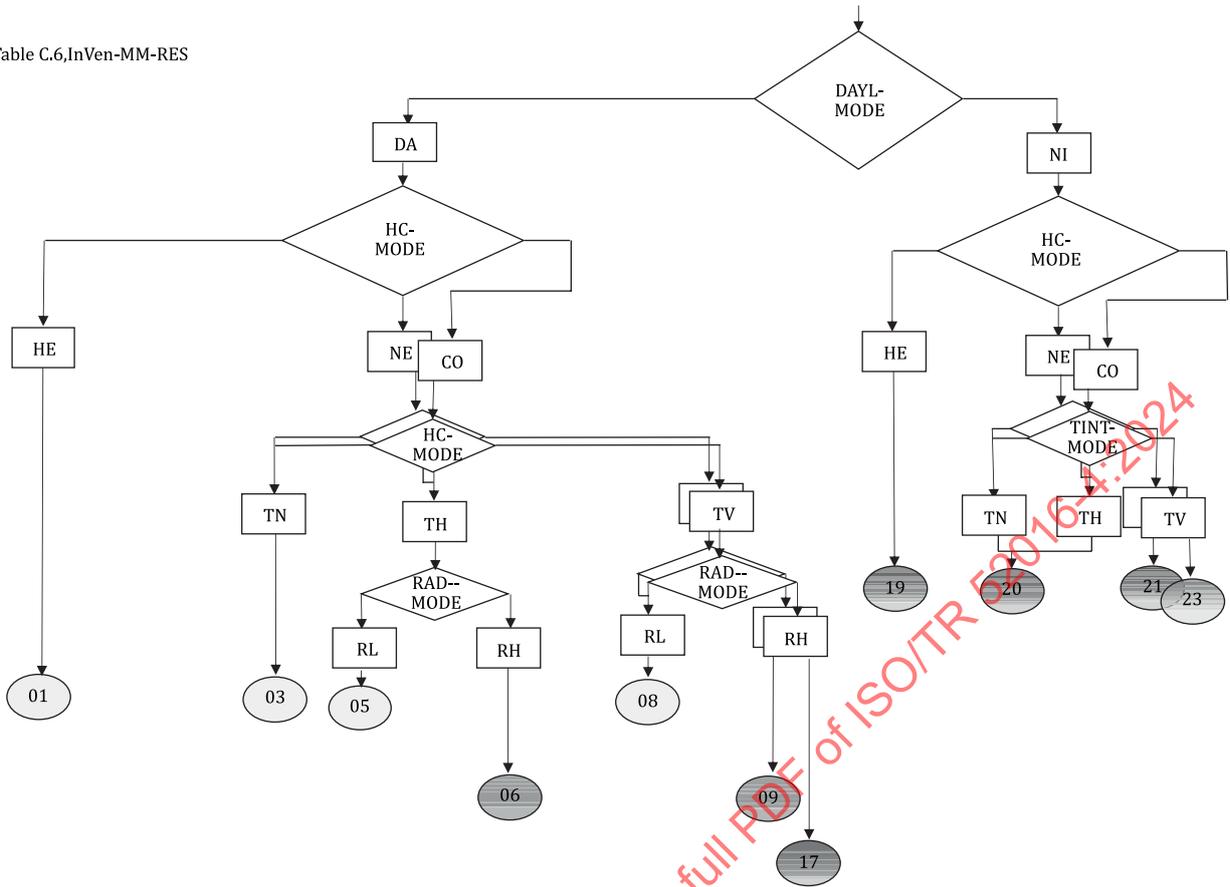
Table C.6,InVen-MM-RES

a) Manual control

Table C.6,InVen-AUT-RES
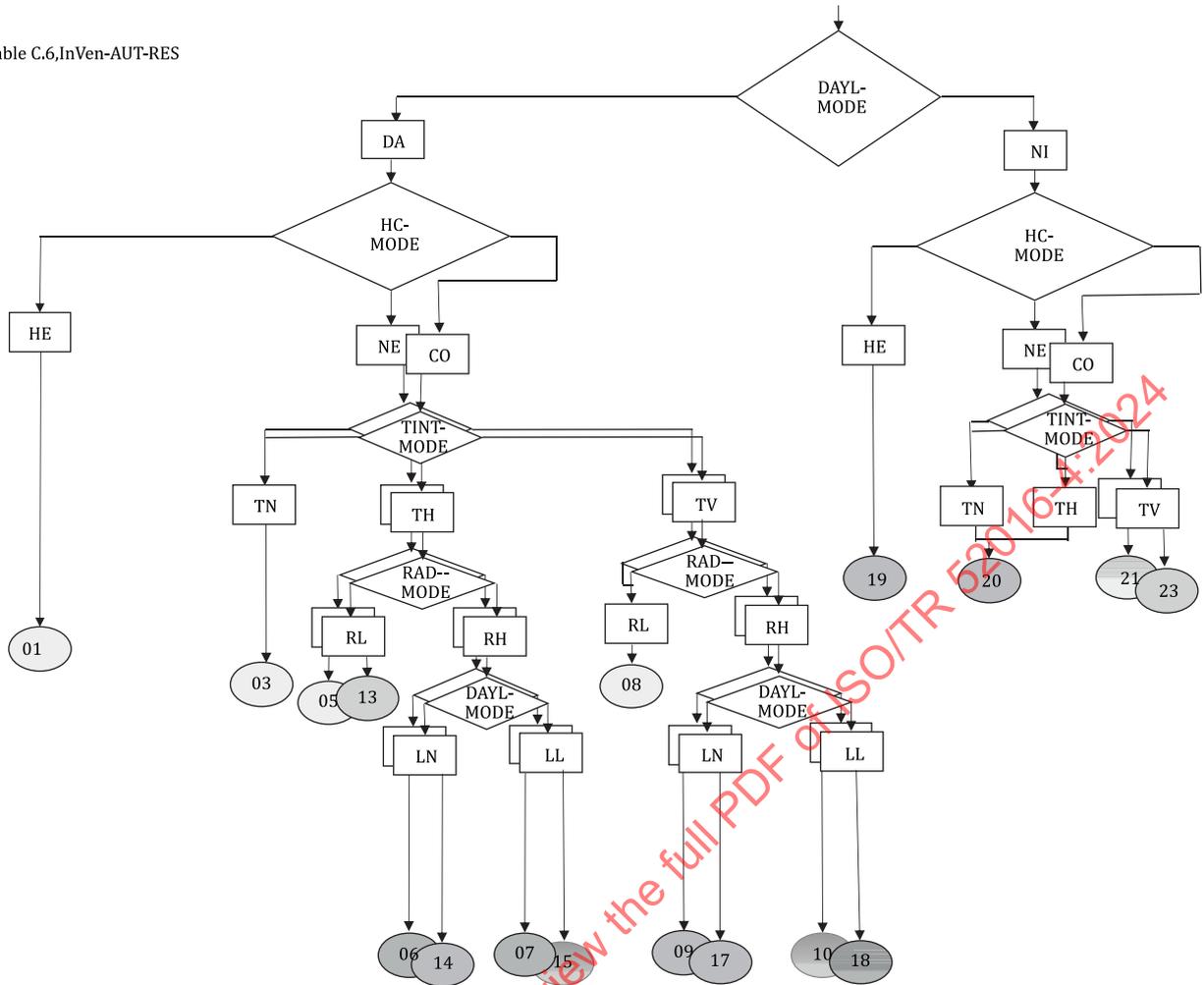
b) Automated control

Figure C.13 — Aggregated diagram for ISO 52016-3:2023, Table C.6
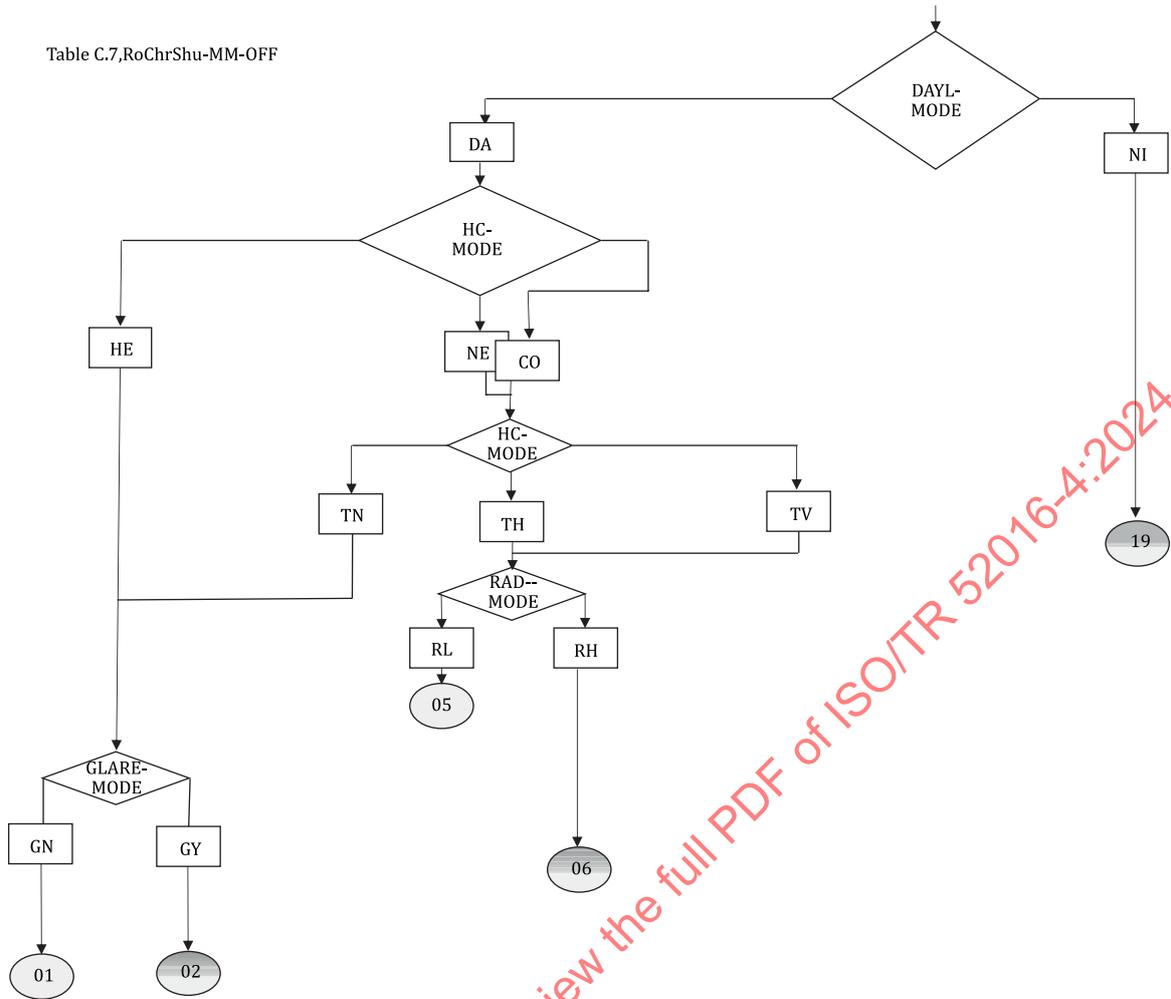
Table C.7,RoChrShu-MM-OFF
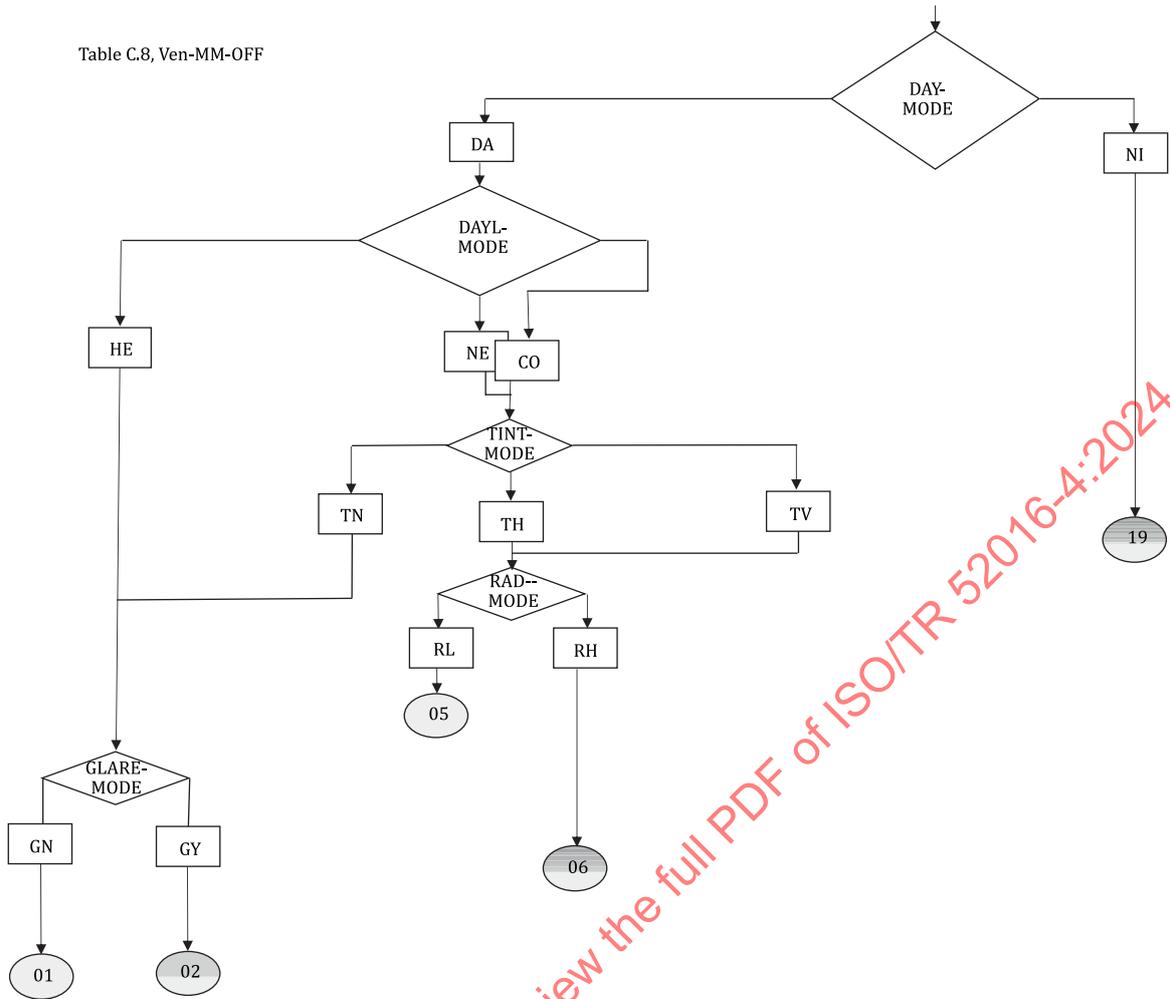

a) Manual control

Table C.7,RoChrShu-AUT-OFF
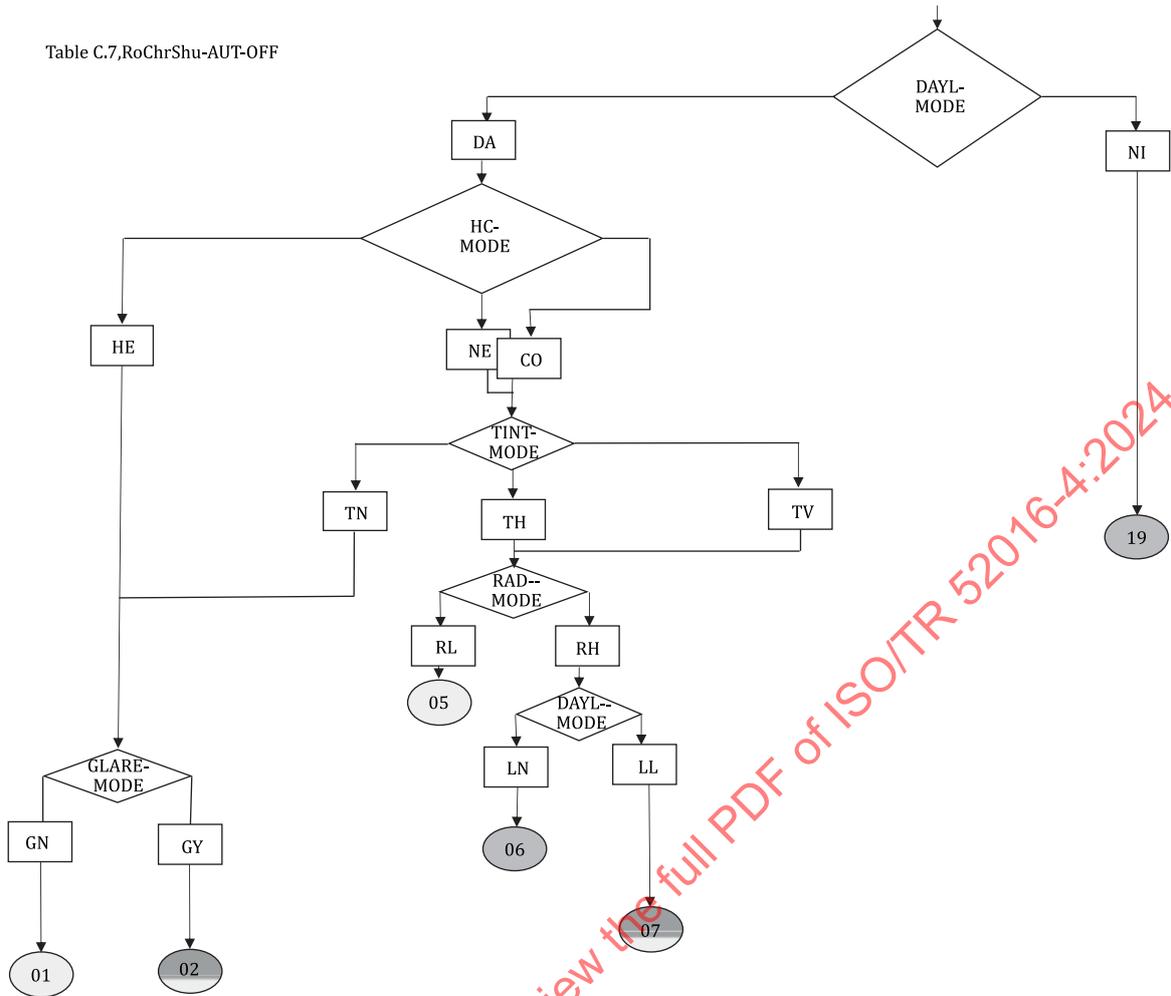
b) Automated control

Figure C.14 — Aggregated diagram for ISO 52016-3:2023, Table C.7

Table C.8, Ven-MM-OFF

a) Manual control

Table C.8, Ven-AUT-OFF
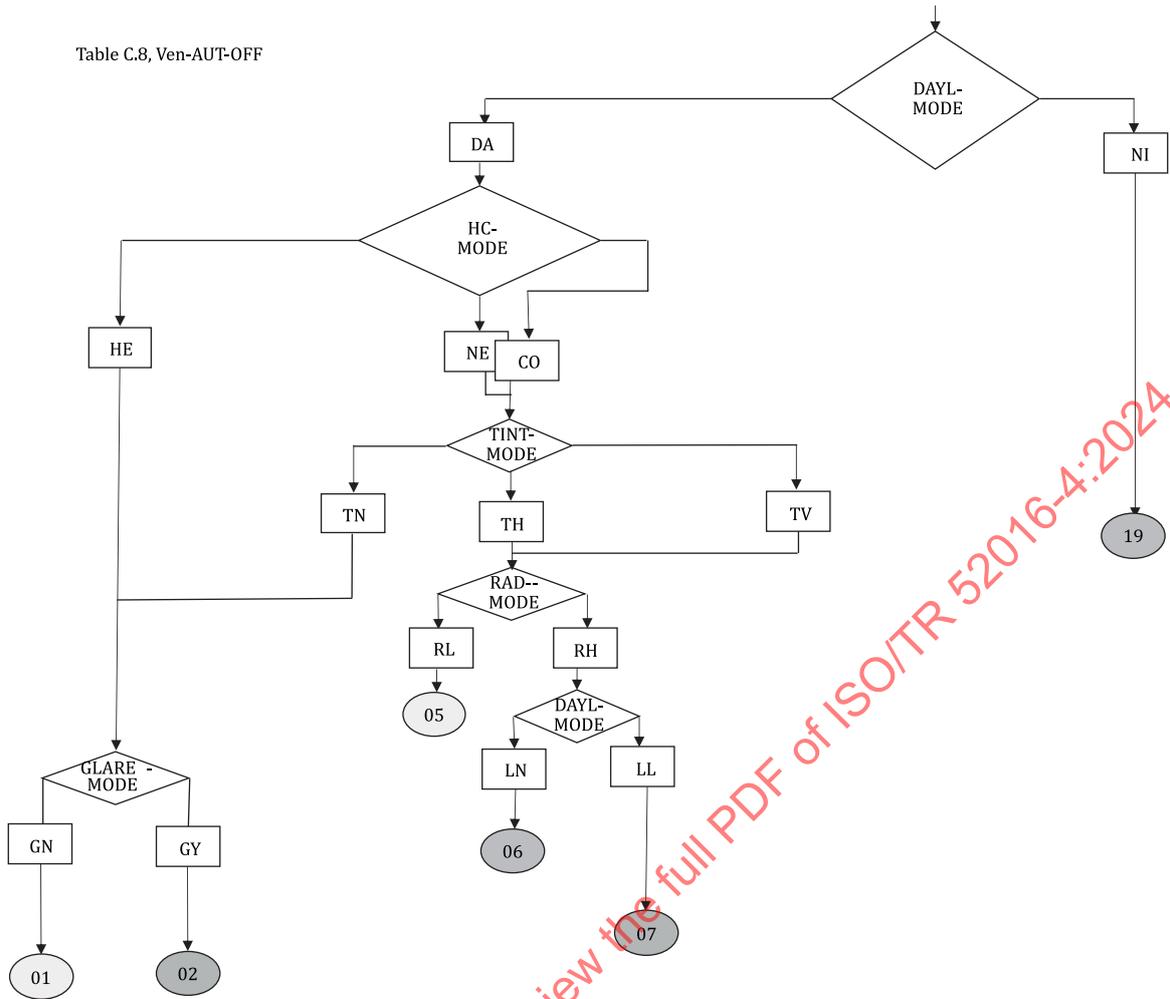
b) Automated control

Figure C.15 — Aggregated diagram for ISO 52016-3:2023, Table C.8

Annex D
(informative)

Basic study reference control strategies

D.1 General

This Annex contains background information and justification of the reference scenarios, as introduced in 6.8.7 and illustrated with the flow diagrams in Annex C. The study that has been used as the main basis for the reference control scenarios in ISO 52016-3 is described. Notes are used to point to details that have been dealt with slightly differently in ISO 52016-3, or details that, for the sake of simplicity of the calculation procedures to be demonstrated, have been dealt with differently in the spreadsheet calculations.

The study focuses on solar shading devices such as roller blinds and venetian blinds and also covers shutters. [24] In principle the findings are also applicable to chromogenic glazings. The effectiveness of the adaptive building envelope element to save energy while maintaining or improving thermal and visual comfort is in any case dependent on the physical properties and degrees of freedom of the product or assembly.

D.2 Background

Solar shading devices play a key role in the thermal performance of buildings and the comfort of their occupants. For several years, their thermal, solar and visual properties are well described in the various international standards (e.g. ISO 15099 and ISO 52022-3) and, for most of them, considered by most of the building design software.

However, the control strategies, i.e. the definition of how shading devices are operated, are very often either absent or very poor.

Therefore, the ES-SO initiated a study [24] with the goal of establishing conventional control strategies for most common shading devices and modes of operation, so that the overall solar shading performance can be optimized. These control strategies have also been developed as a basis for ISO 52016-3.

D.3 Methodology

D.3.1 General

The following methodology was used to develop the control strategies:

a)   definition of a draft control strategy on the basis of scientific bibliography and experts' experience;

b)   test of this draft control strategy with the IDA-ICE software developed by the EQUA company;

c)   analysis of the results and improvement of the draft control strategy;

d)   back to steps 2 and 3 until proper results have been obtained.

The main criteria used for the evaluation of the proposed control strategies were:

—   the energy consumption of the building (heating and cooling);

—   the comfort level of the occupants (degree hours above a defined internal temperature);

—   the daylight level on a horizontal plane positioned at a defined distance from the façade;

—   the number of movements of the shading device.

D.3.2   Variations considered

The following variations were considered when developing the control strategies:

— type of building: residential, office premises;

— type of solar shading devices: roller blinds, venetian blinds, shutters or equivalent;

— type of installation: external, internal;

— type of operation: manual, motorized, automated.

In order to evaluate the draft control strategies in various climatic conditions, three different locations were considered:

— Athens;

— Strasbourg;

— Helsinki.

In order to calculate the extreme cases corresponding to the lowest energy consumption for heating / cooling, the following variations were also considered:

— shading device always retracted: 0 % glazing coverage at all time;

— shading device always extended: 100 % glazing coverage at all time.

D.3.3   Definition of the appropriate control strategy

For a given type for building, solar shading device and type of installation, a control strategy was judged appropriate when:

— Changing the operation mode, an improvement of either the energy consumption or thermal comfort, or both, was observed.

— It was considered that an optimum usage of the shading was reached considering:

  — the balance between heating and cooling/thermal comfort;

  — the balance between energy consumption and visual comfort of the occupants;

  — both extreme cases: shading always retracted/extended;

  — the number of movements of the shading device was consistent with the expert's experience.

D.4   Control strategies

D.4.1   General

The control strategies use parameters intended to reproduce the way people (manual or motorized) or a logic (automated) would operate the shading devices. These parameters are:

— either external (e.g. external temperature, external illuminance on the façade); or

— internal (e.g. operative temperature, daylight level on a desk).

The use of either a parameter or the threshold values considered, or both, differs depending on the different criteria presented further on (e.g. type of space, type of shading, type of command). The subclauses D.4.2 to D.4.5 present general assumptions and references considered for each variation and parameter. More detailed information is provided in the ES-SO report [24].