Biased Building Regulations For Windows?

Hacksen Kampmann, Thomas

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APPROACHES AND METHODS

IN ARCHITECTURAL RESEARCH

Editors: Anne Elisabeth Toft, Magnus Rönn and Morgan Andersson

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Anne Elisabeth Toft, Magnus Rönn and Morgan Andersson

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Jonas Vetlesen

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FOREWORD

Anne Elisabeth Toft and Magnus Rönn

The Nordic Association of Architectural Research (NAF/NAAR) is an independent and not-for-profit association of architectural researchers from universities and schools of architecture in the Nordic countries.

The present book, published by NAF/NAAR, is the proceedings publication from the association's 2019 symposium which was titled *Approaches and Methods in Architectural Research.*

The symposium was organized by NAF/NAAR in collaboration with researchers from the Department of Architecture and Civil Engineering at Chalmers University of Technology in Sweden, which also hosted the event on 13–14 June 2019.

The Department of Architecture and Civil Engineering at Chalmers University enthusiastically engages in research that queries architecture as a so-called 'making discipline' and 'material practice'. It has developed a keen interest in and knowledge about architectural research that specifically applies design- and practice-based methods such as projective research, often combined in transdisciplinary modes with methods adapted from scientific disciplines, the social sciences, the humanities, and the fine arts.

Focusing its discussions on a research interest shared by NAF/NAAR and its Swedish peers, the 2019 NAF/NAAR symposium pursued the current development of approaches and methods in architectural research.

During the symposium, twenty-four international researchers presented papers. All eleven articles in this publication—except those by the invited keynote speakers Isabelle Doucet, Professor of Theory and History of Architecture at Chalmers University of Technology, and Karl Kropf, Senior Lecturer in Urban Design and Historic Conservation at Oxford Brookes University and Director of Built Form Resource, an urban design, landscape,

BIASED BUILDING REGULATIONS FOR WINDOWS?

Thomas H. Kampmann

ABSTRACT

This article discusses the conditions under which windows are constructed in Denmark and offers general definitions concerning energy loss through windows. A brief introduction to the problems with regulating energy loss by means of windows in the Building Regulations BR2018 is offered as well, along with comments on future regulations.

Until recently, the Danish Building Regulations were difficult to understand from the perspective of energy performance for windows. Since a substantial part of the heat loss from buildings occurs through windows, this has a huge environmental impact.

The regulations are perceived as discriminatory, especially when it comes to secondary glazing and/or multi-frame windows, which are the solutions that are used most widely in historic buildings. Wooden windows are a simple way to store CO_2 in the construction for many years and are easy to maintain and/or improve without replacement. In additional, they can efficiently combine heat savings, noise insulation, low environmental impact, aesthetics, and historical preservation.[1]

The study was conducted by thoroughly reviewing all of the requirements concerning energy loss through windows and takes various typical Danish window types into consideration. Since no similar studies on this topic from the other Nordic countries are known, the current building regulations in each country will thus be examined briefly in the same way.

The article also includes an overview with a discussion of whether any of the Nordic countries have more applicable regulations, or whether the picture is the same across the region.

KEYWORDS

Multi-frame windows, building regulations, energy loss, protected buildings

BACKGROUND

As part of the Master's programme in Cultural Heritage, Transformation and Restoration (KTR) at the Royal Danish Academy, I have previously examined the Danish Building Regulations, BR2015,[2] and the proposal for BR2018[3] and responded to them in the anthology *Robust*.[4] This was done because the BR2010[5] was already highly problematic when it came to small and/or multi-frame windows. The response was provided since the proposal for BR2015,[6] and later for BR2018,[7] was being based on the rules of BR2010, apart from a simple lowering of the limits for energy loss, and there was a risk that the problems would be even bigger in the final version.

With this study, the aim was to give building consultants and authorities, manufacturers and students a tool for understanding the pitfalls as well as the rather complex field of energy consumption in connection with small and/or multi-frame windows, as seen in the BR2015[8] and BR2018[9] within and/or for the specific field of energy consumption.

Traditional windows are usually designed with several frames and sometimes even with glazing bars, but the problems concerning multi-frame windows are the same for new windows if they are divided into multiple units. The hope is that this article will also help develop and/or rethink the design of windows in future buildings. It is therefore necessary to undertake a careful examination of the final edition of BR2018.[10] Finally, the article provides a brief, comparative overview of how building regulations in Finland, Norway, and Sweden deal with the same problems.

INTRODUCTION

Denmark's energy supply was based mainly on imported oil until the energy crisis in the 1970s. At that time, Denmark had hardly any oil or natural gas production and neither hydro- nor nuclear power. The energy crisis therefore emphasized the urgent need for energy savings in order to achieve a high level of energy security. Since approximately 40 per cent of all energy consumption in Denmark occurs in buildings and about one third of the energy consumed in buildings is lost through windows, this is a topic of great importance for the overall energy equation.

Until the BR1995,[11] all windows were treated equally with the very simple rule that the U-value, thermal transmittance, for the entire Window being used should be lower than 1.8 kWh/m^2. In subsequent building regulations, however, the rules became much more complex, with the addition of a distinction between new windows with sealed units and windows with secondary glazing, whereby the latter, which are mostly used in traditional housing, have been treated more harshly than insulating glass unit (IG-unit) windows. The reason for this may have been that many new windows used for replacing older windows in traditional buildings, which have more than one frame and possibly glazing bars, did not fulfil the previously simpler legal requirements.[12]

In the BR2010,[13] windows with IG-units are treated completely differently from traditional windows with secondary glazing. Such windows are rated in relation to the U-value of the whole window in its actual form, size, and number of panes used, whereas windows with IG-units are rated based on a combination of the U-value and supplemental energy from the sun during the heating season, so-called energy gain (E). Furthermore, all windows with IG-units are supposed to be specified based on the energy gain of a reference window, E_{ref}, as though they were designed with only one single-frame window with a standard size of 1.23 by 1.48 metres. This applies regardless of the actual size of the window in use, the number of frames, whether it has mullions, transoms, and glazing bars, and whether it has noise reduction or solar-coated panes. All these different parameters have a huge impact on the total energy performance, which makes it very hard, if not impossible, to select the most energy-efficient windows based on the rules of the BR2018.[14] This shows that new windows with energy panes are given preferential treatment.

Until 2008, a minimum U-value for windows was mentioned in the regulations. However, that requirement disappeared in the BR2010[15]—apart from windows inside houses that open towards rooms heated to more than 5 Kelvin below the temperature in the specific room concerned. It is hard to see the logic in having rules for internal windows but not for windows in external walls. Since the tendency for many new houses is to make them look similar to old houses, this problem will thus affect new houses as well.

DEFINITION OF THE PROBLEM

The following extracts from the Building Regulations (marked in grey) are all direct quotes (without correction of potential spelling mistakes or ambiguities). The purpose of this article is to investigate whether the BR2018[16] meets the targets described in Chapter 11: Energy consumption:

> 250. Buildings must be planned, established, converted and maintained in order to avoid unnecessary consumption of energy for heating, domestic hot water, cooling, ventilation and lighting with due respect of the use of the building and the scope of the building work.[17]

The examination addresses the specific field of the energy consumption of windows, with a special focus on multi-frame windows. This article only examines Chapter 11 of the BR2018, which deals with energy consumption based on the associated guidelines concerning windows with a focus on housing.[18] This article focuses on describing the preconditions for understanding the design of different types of Danish windows and how the design influences the energy consumption.

The argument presented is that the BR2018[19] does not provide equitable tools that can assist building consultants, authorities, manufacturers, and consumers in selecting the most energy-efficient solutions. The competition parameter thus impedes the propagation of energy-efficient windows in traditional buildings as well as in new buildings equipped with multi-frame windows. Whether there are different requirements for windows with secondary glazing compared with windows with IG-units has also been examined as part of this.

The study was conducted—to the greatest extent possible—by collecting data from window manufacturers and then comparing these data for various typical window designs with the BR2018.[20]

REVIEW OF RELEVANT WINDOW TERMS[21]

Design of windows

Traditional Danish windows are often designed with more than one frame. This often makes it necessary to divide the casement with a mullion if two separate frames are needed, and perhaps a transom in the case of four frames. Various combinations of this are also possible. Mullions and transoms are thus part of the casement and/or window jamb. If a window has more than one frame, it is referred to as a multi-frame window in this article. If the glass should be divided within the frame, this is done with glazing bars.

Windows with secondary glazing or storm windows

Traditional windows were normally fitted with only one layer of glass. To insulate against energy loss and noise, windows were subsequently given a secondary glazing in Denmark, at least since the start of the 1700s. While Danish windows nearly always open outwards, secondary glazing opens inwards. This hence necessitates removing potted plants or other items from the windowsill in order to open the window. Around 1900, linked frames became widespread. Here, the second pane is attached to the frame and opens along with it—with no need for potted plants et cetera to be removed.

When describing the construction of a window, the number of panes is specified through counting them from the outside. Thus, a window with only one layer of glass is called '1', while secondary glazing is referred to as '1 + 1'. Secondary glazing was traditionally made with ordinary glass but is now primarily made with energy panes. Energy panes consist of one layer of glass fitted with a hard energy-saving coating. The coating limits long-wave radiation between the two layers and thus reduces heat loss by close to 50 per cent. The hard coating is stronger than the glass, which means that the pane can be treated as normal glass.

To improve insulation, secondary glazing can be produced as a sealed unit with, for instance, two layers of glass. This is referred to as '1 + 2'. One of the

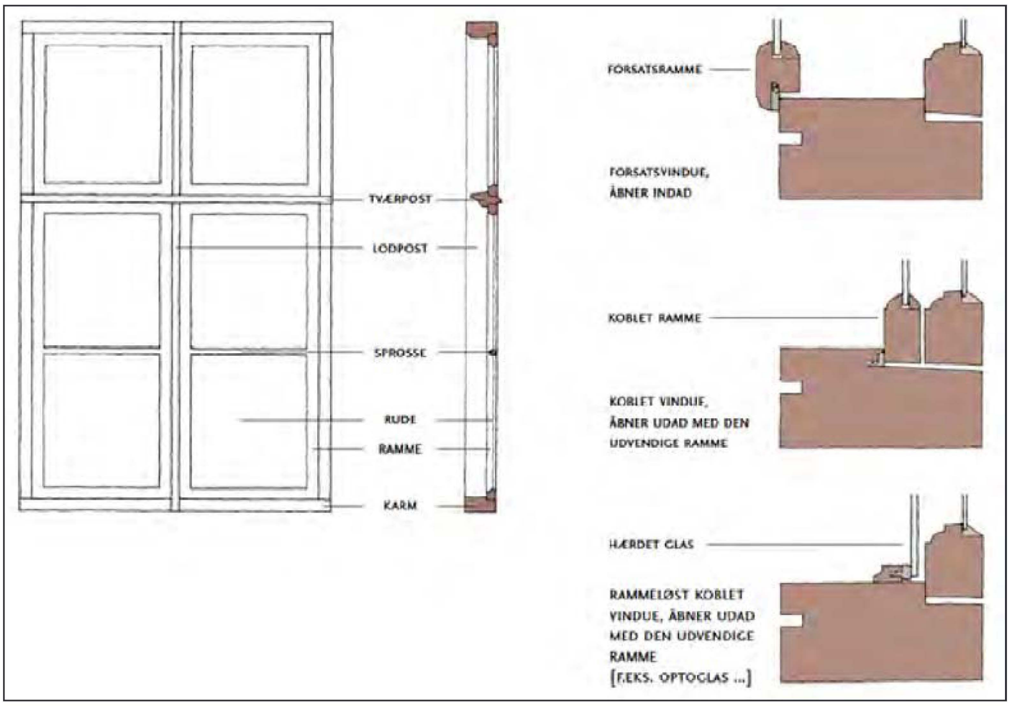


Figure 1. Design of a traditional Danish window. Source: Thomas Kampmann.

drawbacks of a window with secondary glazing is the difficulty of cleaning the individual surfaces as well as the fact that two frames have to be opened in order to let in fresh air. On the other hand, it is possible to clean all the surfaces, as opposed to the case of sealed units, in which the whole unit has

Figure 2. Typical Danish window with secondary glazing. Source: Thomas Kampmann.

to be replaced if the seal is broken. In addition, secondary glazing windows provide by far the best soundproofing, especially if there is an optimum amount of space between the two panes.[22]

Sealed-Unit Windows

Today, almost all windows have sealed units, in which two or three panes are joined together with a spacer. This is referred to as '2' or '3'. If one or more of the glass surfaces has an energy-saving coating, they are called insulating glass units (IG-units). While one benefit of a sealed unit is that there is no need to clean the surfaces facing the cavity, on the other hand, if the seal is broken and the insulating gas evaporates, the unit cannot be fixed, and has to be replaced entirely. Another benefit of IG-units is that because it is not possible to touch both sides of the layers it is thus possible to apply a very sensitive coating, a so-called soft coating, which is very effective. This construction, however, does not provide optimum soundproofing, since one of the most important parameters for soundproofing is the distance between the layers, which is not very large here.

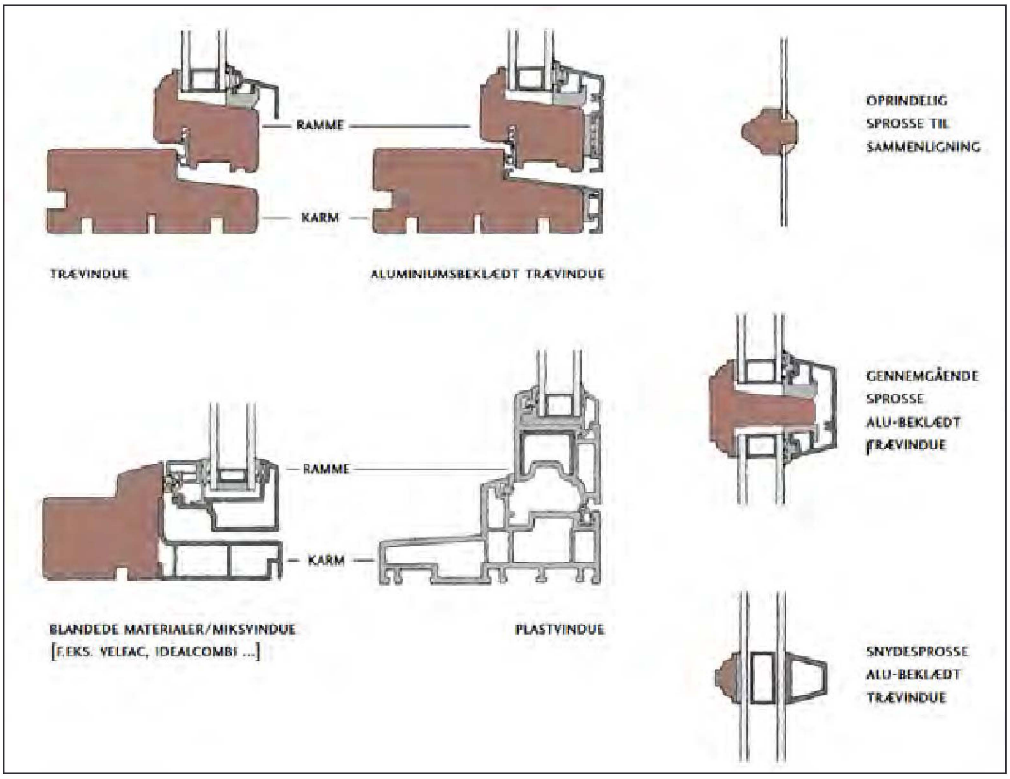


Figure 3. Details of typical Danish sealed-unit windows. Source: Thomas Kampmann.

Glazing bars in windows with IG-units can be constructed in two ways. Either with through-going glazing bars, which are very clumsy (due to the thick IG-units) and highly ineffective in terms of insulation, or with so-called fake glazing bars where the glass actually extends over the entire pane with several profiles glued or clipped to the glass. While fake glazing bars are much more energy-efficient, they nonetheless still pose problems. Naturally, they are much less visible than through-going glazing bars, especially when viewed perpendicularly to the window, but when viewed at an angle, the fake construction is obvious. Another problem with fake glazing bars is that they can easily fall off.

Since many new buildings are well insulated, there is often a problem with overheating. In order to reduce this problem, many windows with IG-units are given a solar-control coating in order to reduce the risk of overheating. But as this is a permanent construction, it also prevents energy gain from the sun when needed in the cold season, which makes this solution problematic in climates with a heating season.

ENERGY LOSS THROUGH WINDOWS

The U-value, thermal transmittance, is the rate of heat transfer through a structure per temperature difference across the structure. It indicates the energy loss resulting from a building component and is measured in $W/m^2/K$. For windows, the U-value (U_{window} or U_w) is divided into:

1. Energy loss through panes (the upper arrow), which depends on the surface area of the panes (U_{glass});
2. Energy loss through casement, mullion, transom, and glazing bars (the lower arrow), which depends on the area casement, mullion, transom, and glazing bars;
3. Energy loss through the edges of the pane (only for IG-units, since windows with secondary glazing have no spacer) (the middle arrow), which depends on the length of the edges of the panes (Ψ, the Greek letter psi) and is thus relatively much bigger for a multi-frame window than for a large, approximately square window.

As the U-value of the IG-units of today is different and often lower than the U-value of the casement, mullion, transom, and glazing bars, the ratio between the different 'arrows' changes dramatically depending on the design of the window. Hence, a circular window with no glazing bars will have the highest share of energy-efficient panes and the relatively shortest edges around the panes. This share is somewhat lower for nearly square or rectangular windows and much lower for windows with mullions, transoms, and glazing bars. The share of the surface area of the panes will typically decrease from 75 per cent to 48 per cent in comparison with a single-frame window, and 1.23 by 1.48 metres compared with a window of similar size but with four frames and twenty panes. While it is quite simple to request the relevant U-values (from glass manufacturers), it is rather more complicated to calculate the U-value of the casement, mullion, transom, and glazing bars.

ENERGY GAIN THROUGH WINDOWS

When the sun shines, a certain percentage of the energy from the sun will pass through the window. The amount of energy that passes through the casement, mullion, transom, and glazing bars is negligible and is therefore omitted in the calculation of the total energy balance. The energy gained through the panes is referred to as the g-value, which denotes the percentage of solar energy that hits the panes during an average reference year and is

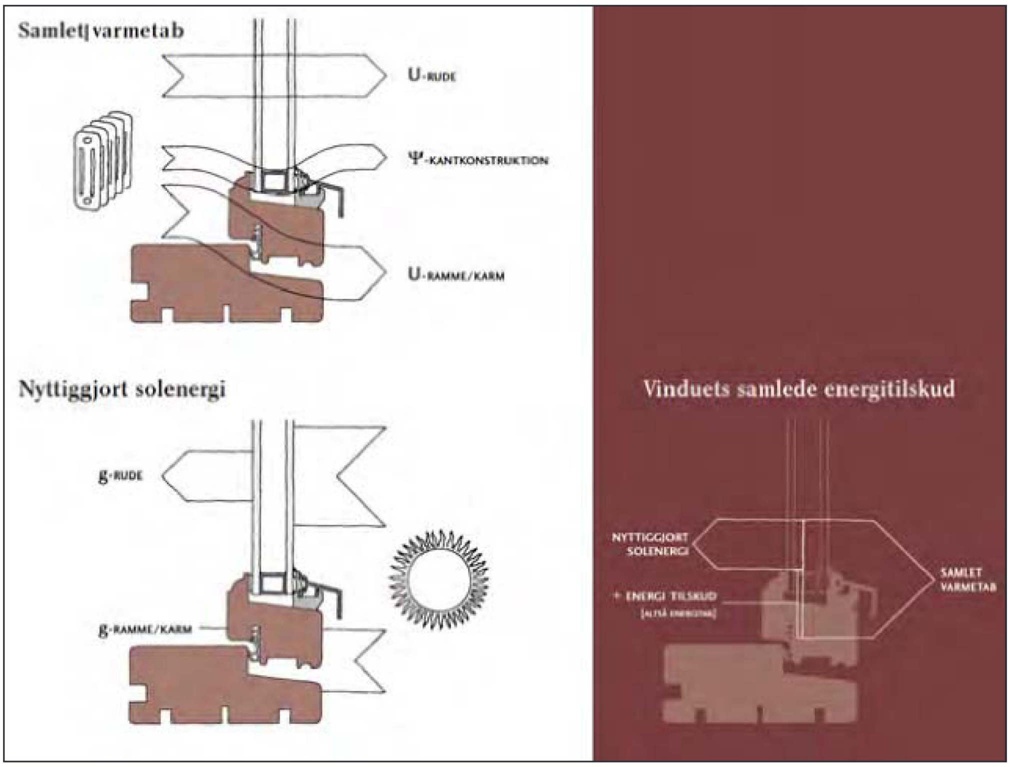


Figure 4. Energy loss and gain through windows. Source: Thomas Kampmann.

radiated into the interior, g_{glass}. The g_{window} is obtained by multiplying the g_{glass} by the ratio of the surface area of the panes to that of window as a whole.

TOTAL ENERGY BALANCE THROUGH WINDOWS

The total energy balance of a window is obtained by calculating the energy gained through the window during the heating season minus the energy lost through the window in the same heating season, and is referred to as E_{window}. As the energy gained through a window varies a lot depending on the orientation of the window, it is normally specified as a weighted average of the distribution of the surface areas of windows facing south. The unit is in kWh/m^2/year, and it is thus quite easy to calculate the yearly energy loss by simply multiplying the energy balance by the total sum of the surface area of the windows. The annual expenses are calculated by multiplying the total energy loss by the relevant energy price.

Since the total energy balance depends very much on the design of the window, the Danish Energy Agency has chosen to use a reference window consisting of only one frame, E_{ref} with a size of 1.23 by 1.48 metres. The official definition of the reference window follows below. Since the energy balance is highly dependent on the design of the window, E_{ref} cannot be used in calculating the energy loss, as will be explained in this article. A definition of the energy balance will follow as part of the explanation of the BR2018.[23]

ENERGY LOSS AS DEFINED IN BR2018

As Guideline 11, 1.6 of the BR2018[24] is still not available in English, the definition from BR2015[25] Appendix 6.2 (unpaginated) is shown instead, since they are much the same (calculation of energy gain through windows):

> For facade windows, see EN 14351 – 1 Windows and external pedestrian doorsets without resistance to fire and/or smoke leakage characteristics, the window manufacturer calculates the energy gain as:
> $E_{ref} = I \times g_w - G \times U_w = 196.4 \times g_w - 90.36 \times U_w$
> where:
> I: Sunlight corrected for the variation of g value with angle of entry
> g_w: Total solar energy transmittance of the window. G: Kilo degree hours in the heating season based on an indoor temperature of 20°C.U_w: Thermal transmission coefficient of the window

The solar heat gain I and the number of degree hours G during the heating season are determined on the basis of the reference year DRY (before the revision in 2014). The solar heat gain through windows depends on the orientation of the windows, and therefore a single-family house with the following distribution of windows is used as a point of reference:

North: 26%
South: 41%
East/west: 33%

The calculation uses a single-light opening reference window 1.23 m x 1.48 m. The energy gain E_{ref} is an appropriate expression to use in comparisons of the efficiency of different windows during the heating season. A separate assessment may need to be made with regard to nuisance due to solar heat gain and any overheating in summer.

Even though E_{ref} is based on exploitation of solar heat gain through windows in a single-family house, E_{ref} is also used to compare windows for replacement in buildings other than dwellings. This does not apply to holiday homes as, according to the provisions of the Planning Act, they are only used for a short time during the heating season.

New windows can lead to problems with overtemperature on sunny days, so an assessment should be made in many cases of the potential need for solar screening.[26]

The problem is that the calculations should be based on a so-called reference window with a fixed standard pane and not on the actual window used in each case. This is probably due to the fact that the energy performance changes to a great extent depending on the number of panes and glazing bars, the type of glass, and the use of special noise-reduction or solar-control glass (Appendix 1). Furthermore, the rules only apply to windows designed with IG-units, whereas the rules are completely different for windows with secondary glazing.

DIFFICULT TO OBTAIN DATA FOR WINDOWS

As part of this examination, preparing an updated survey of the energy consumption of typical Danish windows in various typical variants was planned. Unfortunately, it has not been possible to find a single manufacturer of

IG-unit windows that includes an energy calculator on their website, even though this was quite common just a few years ago. All the manufacturers should also be able to produce the values when they deliver windows.

All the manufacturers contacted mention that they are prepared to present the relevant data if requested. The Danish producers 'Velfac' and 'Rationel' were so kind as to send data from their window database when requested, whereas 'Idealcombi' could only refer to a local carpenter when asked for information.

A third Danish manufacturer, Bøjsø, Døre og Vinduer, provides the following information on the energy calculation for their windows on their homepage (translated by the author):

> When you receive offers and/or order confirmation from Bøjsø, we also specify the precise energy statistics for the specific window or door, which also includes a comprehensive calculation of the entire specification of average U-value. We can also send an energy fact sheet with the total energy calculation.[27]

It has only been possible to find a single website with an energy calculator, namely that of a manufacturer of secondary glazing.[28] All the data collected for g- and U-values as well as the total energy balance for a representative selection of typical window types is shown in Appendix 1. It has thus only been possible to update the energy survey with limited data, meaning that the energy diagrams shown are based on data that is somewhat obsolete. The data collected does nevertheless show that manufacturers of energy-saving windows now make windows with much better energy performance than in the past.[29]

INFERENCES FROM THE DATA COLLECTED

As Appendix 1 shows, traditional wooden windows provided with secondary glazing (green background colour in column A) have almost the same energy performance regardless of the window design. This is relatively poor for E_{ref} with only one frame in comparison with windows with IG-units, but much better for divided windows with mullion, transom, and glazing bars—as well as for noise-reducing panes. The main reason why the energy performance is somewhat worse with glazing bars is that the shadows cast by the glazing bars have a negative effect on the g-value. On the other hand, IG-unit windows have very good energy performance for E_{ref} and with a three-layer

IG-unit, they have an A-grade positive energy balance ($E_{ref} > 0$). However, for windows with two casements or more, the energy performance is poorer than for windows with secondary glazing.

If one takes the example of a traditional window with four frames and one glazing bar (column I), the recently introduced A-grade triple-pane 'Velfac Classic (3)' (row 16) has a 84 per cent greater energy loss than traditional windows (1+2) with secondary glazing with double coating (row 5) (energy gain ÷37.8 kWh/m^2/year compared with ÷20.5 kWh/m^2/year). For windows with two layers of glass, the C-grade 'Velfac Classic' double-pane window (2) (row 14) has an energy gain of ÷54.5 kWh/m^2/year and therefore only a 5.6 kWh/m^2/year better energy gain than traditional secondary glazing with one hard-coated energy-saving pane (row 7), with an energy gain of ÷60.1 kWh/m^2/year (1+1).

EXAMINATION OF THE BR2018, CHAPTER 11: ENERGY CONSUMPTION

Note that the guidelines for the BR2018[30] are still not complete—and not yet available in English translation. Chapter 11 deals with energy consumption in buildings and hence also energy consumption through windows. Windows, along with external doors, roof lights, skylight domes, glazed external walls, glazed roofs, and hatches facing the outside are often treated differently than the rest of the building envelope. This is presumably because these are 'weak' spots that are much thinner than walls and roofs and develop extensive thermal bridges. There is also an extra challenge associated with building parts that contain glass, namely how they gain energy from the sun, which will result in extra energy in the heating season and can cause overheating in the summer.

> 250. Buildings must be planned, established, converted and maintained in order to avoid unnecessary consumption of energy for heating, domestic hot water, cooling, ventilation and lighting with due respect of the use of the building and the scope of the building work.[31]

This first provision is very easy to understand and has a clear purpose; not least because there is a general understanding of global heating as a serious challenge that calls for a reduction of energy consumption and a securing of energy supplies. The more we reduce consumption, the lower the demand for energy will be.

251. Buildings must be planned, established, converted and maintained to ensure that the energy demand does not exceed the energy framework, which includes the total demand of the building for energy supply for heating, ventilation, cooling, domestic hot water and lighting. Energy supply from various energy sources must be added using the energy factors stated in ss. 252 and 253. Evidence must be provided based on the instructions of the Danish Building Research Institute 213 Energy demand in buildings.

(2) For additions, changes in use, conversions, temporary movable pavilions and holiday homes, the provisions of ss. 267-292 can be applied as an alternative to the energy framework.

251. states that the energy demand for a building should not exceed the calculated energy framework. Again, this is a clear and logical requirement, and it seems obvious that one should use the actual energy data from the windows in use and not data from a reference window. Therefore, you need to know the exact energy performance of the actual window to make a correct energy performance framework for a building. This speaks in favour of the manufacturer having to make the calculations as well as disclose the data when providing quotes and/or receiving orders.[32]

The problem is that the rules for windows are rather confusing. The energy performance framework should be calculated for the entire building, and in 11, 1.4 [5] it is specifically mentioned that the calculation must take into account all thermal bridges (not only for windows). If the transmission loss is calculated without thermal bridges, it will normally be 50–70 per cent higher when compared with calculations in which the thermal bridges are included. These rather clear rules indicate that it is important to calculate as accurately as possible so as to get the right results in order to design buildings with energy demands that are as low as possible. On the other hand, paragraph 258 states that calculations should be made based on a reference window. However, as we have seen, windows perform very differently depending on their size, shape, design, and number of panes.

255. Buildings and building parts, including windows and doors, must be planned and established to ensure that heat loss is not increased to a significant degree as a result of: Moisture in structures. Unintended air flow though entrances in e.g. shops, offices and hotels.

2) Unintended air flow though building parts, e.g. heat insulation exposed to wind effects.
3) Thermal bridges.

256. For energy calculations, the following preconditions apply to the calculations:
1) In calculation of transmission areas, transmission loss and heat loss frameworks, DS 418 Calculation of heat loss from buildings must be applied.
2) The energy effect of thermal bridges must be included in the form of documentation of U values for each building part.[33]

Please note that the thermal bridges in, for instance, windows should be included in the calculations of heat loss is mentioned in particular. However, when a reference window is used, most of the calculations do not take this element into account, as seen in provision 258. Windows are mentioned specifically, presumably because there are major problems with thermal bridges in windows. The general minimum requirements for building envelops state that:

257. Each building part must be insulated to ensure that the heat loss coefficients do not exceed the values stated in Appendix 2, Table 1.
(. . .)
(2) Subsection 1 does not apply to ss. 267-270 and ss. 274-282.
(. . .)
Tables for Chapter 11 – Energy consumption
Table 1 – General minimum requirements for building envelopes
For gates and hatches opening to the outside or to unheated rooms and glass walls and windows adjacent to rooms heated to a temperature creating a temperature difference between the rooms of 5 °C or more:
U value [W/sq. metre K] 1.80.[34]

As becomes clear, there are no minimum requirements for windows in Table 1, except for windows inside buildings that are adjacent to rooms heated to such an extent that a temperature difference between the rooms of 5 °C or more results. See paragraph 268 below. This is exactly the same wording as in the BR2015,[35] and it is hard to see this rule having any practical application. The rules regarding the U-value for windows have been replaced with minimum requirements for the energy performance for a reference window. The general minimum requirements for windows, glass outer wall, skylights, and glass roofs state that:

258. Windows, glass outer walls, skylights and glass roofs must be in accordance with the following requirements for energy performance:
For windows and glass outer walls, the energy balance for the reference window may not be lower than -17.0 kWh/sq. metre per year. The energy balance is calculated as $E_{ref} = 196.4 \times g_w - 90.36 \times U_w$.
(. . .)
Sound glass and other functional glass may be used if the reference windows fulfils the energy balance requirement. However, glass with a lower solar heat transmittance (g value) may be used if energy savings related to the solution can be proven.
(2) The reference dimensions for windows, glass outer walls, skylights and glass roofs is 1.23 metres x 1.48 metres.[36]

Using soundproofed glass will generally result in a poorer U-value for IG-unit windows if the distance between the layers is reduced to less than 14 millimetres as a result of a thicker inner pane. This is often the case if the manufacturer's normal window has an interspace of around 16 millimetres, which is the optimal distance for minimizing the U-value. Likewise, using solar-coated glass will result in a dramatically poorer g-value and thus a significantly poorer energy balance for the actual window.

The energy gain E_{ref} is an appropriate expression to use in comparisons of the efficiency of different windows during the heating season. A separate assessment may need to be made with regard to nuisance due to solar heat gain and any overheating in summer.[37]

As shown in Appendix 1, there can be a huge difference between the energy data for two given windows, which again confirms the objection that using a reference window does not give a true picture of the energy-related conditions of different types of windows. The energy frameworks for residential units, halls of residences, hotels et cetera state that:

259. For residential units, halls of residence, hotels, etc. the total energy supply demand of the building for heating, ventilation, cooling and domestic hot water per sq. metre heated floor area may not exceed 30.0 kWh/sq. metre per year plus 1,000 kWh per year divided by the heated floor area.
(…)

> 267. In case of changes in use of a building or parts of a building which results in a significant increase in energy consumption, the energy demands may be observed by using the energy framework in ss. 259-266 or by following the requirements for U values in s. 268.[38]

And there are no rules for windows except the general rules of 259–66 or 268.

> 268. Building parts adjacent to heated rooms must be established with heat loss coefficients corresponding to the temperature to which the rooms are heated stated in Appendix 2, Table 2. Windows, glass outer walls, glass roofs and skylights must fulfill the requirements stated in ss. 257 and 258.[39]

Concerning windows, paragraph 268 only refers to ss. 257 and 258, which state that the calculation should made based on the deceptive reference window, and not based on the specific energy framework of the windows in question.

> 269. In case of changes in use of a building or parts of a building, structural circumstances may result in failure to fully observe s. 268. In that case, the missing capacity must be replaced by other energy solutions which compensate for this failure.

> 270. Structural changes must be in accordance with the requirements in s. 268. Changes which result in an increase in energy consumption may be carried out provided equivalent compensating energy savings are carried out.[40]

There are no rules for windows in the regulation Table 2—Minimum requirements for the building envelope in the case of changes in use. The energy requirements for additions (ss. 271–73) state that:

> 271. Additions must be planned and established in a way which ensures that the energy demand does not exceed the energy framework on calculation. If the energy framework is used for additions, the energy framework only applies to the addition. The size of the energy framework for the addition is calculated based on the area of the entire building. Alternatively, the requirements may be observed by observing the U values stipulated in s. 268 or the heat loss framework stipulated

in s. 272. It is a condition of the use of the U values in s. 268 that the total area of outer doors and windows, including skylights, dome lights, glass outer walls and glass roofs does not exceed 22 per cent of the total heated floor area.

272. The heat loss framework may be applied to additions if the heat loss of the addition does not exceed the heat loss which would have occurred if the U value requirements in s. 268 had been complied with.

(2) In this context, the heat loss framework only includes the addition. However, 50 per cent of the previous heat loss through the part of the facade on the existing building which is covered by the addition may be included in the heat loss framework.

273. Windows in the addition may be included in the heat loss framework as the actual windows or windows with a U value of 1.2 W/sq. metre K. The actual windows must be used in the calculation of the real conditions.[41]

How the last sentence in 273 should be understood is unclear. But, apparently, energy data for the actual windows should be used so as to calculate the real conditions. When asked directly, the Ministry of Transport, Building and Housing referred me to the Copenhagen municipality, which was asked as well but was unsure of what exactly was meant and could not provide a proper answer. The energy requirements in connection with conversions and the replacement of building parts are presented in ss. 274–79 and the corresponding table:

274. In conversions, energy savings must be carried out to the extent that they are financially viable and do not involve a risk of moisture damage. The energy demands in conversions may either be observed by fulfilling the requirements for all building parts affected in s. 279 or by observing the renovation classes for existing buildings in ss. 280-282. The renovation classes constitute an energy framework for existing buildings.

275. Conversions for which the annual savings times useful life divided by investment exceeds 1,33 are considered financially viable. If conversions are not financially viable, the lack of financial viability must be proven. If a conversion is not financially viable, it should be determined if a smaller conversion would be viable.

(2) In structures with room for insulation, e.g. sloping roofs with rafters, examinations must first be carried out to determine if insulation of the cavities are financially viable and then if reinsulation according to the requirements in s. 279 is financially viable.

276. Changes to buildings which involve an increase in energy consumption may be carried out if corresponding compensating energy savings are carried out.

277. If building parts or installations are replaced, the provisions in s. 279 and the installation parts must be maintained irrespective of their financial viability.

278. Churches and additions which form part of a listed ancient monument are exempt from the provisions of ss. 274-282.
(2) Listed buildings are exempt from the provisions of ss. 274-282 if observing the energy requirements in ss. 274-282 would be contrary to the architectural, cultural, historical or environmental values of the listed building.
(3) Buildings worthy of preservation which are included in a local preservation planning regulation or a registered preservation declaration or buildings appointed in the municipal plan as being worthy of preservation under s. 19(1) of the Danish Act on Listed Buildings are also exempt from the provisions in ss. 274-282 if observation of the requirement would be contrary to the plan or appointment in question.

279. Conversion or other changes to the building must be in accordance with the requirements for U values and linear thermal transmittance stated in Appendix 2, Table A. Windows, glass outer walls, glass roofs and skylights must fulfill the requirements stated in ss. 257 and 258.[42]

Paragraphs 274–82 address conversions and replacements of building parts and thus also the renovation or replacement of windows. The table above shows that a renovated secondary window should have a minimum U-value of 1.65. This is very sensible, as it can be achieved very simply by mounting a secondary glazing window with one layer of energy-saving glass. The problem arises when one reads the definition for a renovated secondary window. As the guideline from 2018 is still not available in English translation, what follows here is the definition from the BR2015:[44]

> Renovated secondary windows are windows which are dismantled, renovated and reinstalled in another building. In this context, the removal of windows for work which is comparable to regular maintenance, for example painting, puttying and repair is not a renovated window if the windows are reinstalled in the same building.
>
> No requirements are specified for the energy performance of secondary window frames which are fitted on existing, permanent windows.[45]

This definition of a renovated window is rather unusual, and this author is not aware of any actual examples such renovation. It would mean that there is a window opening in another building into which the renovated windows would fit exactly—which is considered somewhat unlikely. Presumably, they could only be installed in a brand-new building—which would have to follow the rules for the reference window. In that case, it would be more appropriate to call these recycled windows.

The provisions continue by specifically mentioning that there are no requirements for renovated secondary windows if they remain in a building. This is quite strange, since one of the most common and cost-effective ways to reduce energy consumption is to install energy glass in the secondary frame—a procedure that is even allowed in protected buildings. The energy consumption will thus be halved.

If one were to insert an energy pane with two coatings, the total energy consumption would fall to one sixth compared with the use of ordinary glass

Table 1. Building elements and U-values (Table 3 in Appendix 2 to the regulations)43

Building element	**U-value [W/m²K]**
(. . .)	*(. . .)*
doors/gates	*1.80*
hatches, new secondary windows and skylight domes	*1.40*
renovated secondary windows	*1.65*
(. . .)	*(. . .)*

in the secondary frames. Furthermore, it is clear that secondary windows will only be rated based on their U-value and the sun gain through the windows. Since a window with secondary glazing will gain even more energy from the sun than an IG-unit window, this seems discriminatory, since it shows that the requirements for windows designed as a window with secondary glazing are only supposed to apply to the U-value of the actual window size. There is no explanation for the difference and the, in this respect, incomprehensible discrimination in comparison with IG-unit glass windows.

If one takes into account that the energy loss through windows with secondary glazing will change relatively little if one compares the reference window with windows with many frames and panes, this is even more remarkable. New secondary windows are defined as new 1 + 2 windows, which means that the outer part of the window has one layer of glass, whereas the pane in the secondary glazing should be given an energy-saving pane. Otherwise, it is not possible to achieve a U-value of less than 1.40.

As is shown in Appendix 1, this type of window actually has a U-value of slightly less than 1.40, but has an energy gain for the actual window that is worse than that of a 1 + 1 solution with only one energy-saving glass in the secondary glazing. The far most energy-efficient window with secondary glazing is achieved with a 1 + 2 solution with an energy pane with two coatings. This design is also actually even better than that of equivalent new three-layer energy-saving panes—except in the case of the reference window! Here it should be mentioned that some manufacturers have had problems with thermal breakage when using energy panes with two coatings.

RESULTS OF THE EXAMINATION OF THE FINNISH BUILDING LEGISLATION OF 2013/2017

The Finnish building legislation for new buildings is from 2017 and for buildings undergoing renovation or alternations from 2013.[46] For windows, there are only requirements for the U-value: this should generally be less than 1.00 $W/m^2/K$. There are, however exceptions for:

> buildings to the extent to which they are protected, and where observing the provisions would change the protected parts in a way that cannot be considered acceptable;
> Additionally, here is a simple rule:
> If old windows and external doors are repaired, the thermal resistance

> must be improved where possible.
> If the windows are repaired, achieving the original or better level would be sufficient, but there would not be actual obligation to improve.[47]

If this law were adhered to according to its intention, this would suggest a very simple and energy-efficient way to preserve original windows. There are no requirements for energy gain from the sun, the g-value, but the energy amassed through the windows is often mentioned as a huge problem. The general advice is to acquire new windows with a low g-value in order to prevent overheating in the summer. This is astonishing advice in light of the quite cold climate of Finland. In Denmark, overheating is not a problem in older houses with a relatively small share of windows and solid brick walls, which balance the temperature. It must be recalled that a low g-value will apply throughout the whole year—also during the heating season. It should also be noted that there are no examples of windows with low g-value in Appendix 1—even though they have a very low energy performance.

NORWEGIAN BUILDING LEGISLATION OF 2017

The currently valid Norwegian building legislation is from 2017 and quite simple and clear with regard to the requirements for the insulation quality of windows.[48] There are only requirements for the U-value: this should generally be less than 0.80 and, at minimum, less than 1.2 W/m^2 K. There are no requirements for energy gain from the sun, the so-called the g-value. As Appendix 1 shows, it is impossible for common Danish windows to achieve a U-value as low as 0.80, apart from windows with only one frame and with a three-layer IG-unit. This, however, limits architectural freedom. But there are some exceptions for buildings with outer walls made of logs. For protected and conservation-worthy buildings, the following rule applies:

> In the case of projects where compliance with the requirements in this chapter is incompatible with the preservation of monuments of cultural and/or antiquarian value, the requirements apply insofar as they are appropriate.[49]

SWEDISH BUILDING LEGISLATION OF 2011/2018

The Swedish building legislation came into force in 2011, with various amendments until 2019.[50] The law deals with the overall energy framework, and states that energy gain from the sun through windows, the g-value, should be taken into account (translated by the author):

Section 3: When calculating a building's energy use, the building's design, location and orientation are taken into account, including outdoor climate and passive solar radiation.

If the building does not meet the requirements for the primary energy figure after changes have been made, the following U-values shall be striven for in changes to the building envelope. (BFS 2017:5).

U_{window} 1.2 W/m^2, K.[51]

It appears that one is free to choose between various window solutions as long as the total energy framework is adhered to. If not, the maximum U-value must be 1.2 W/m^2 K. Though there are no specific requirements for energy gain from the sun, i.e. the g-value of the windows, energy gain is used in the overall energy framework—just as in Denmark. There is also a comprehensive description of the conditions of buildings worthy of preservation, 1:2213 Particularly valuable buildings:

A building can be such a particularly valuable building referred to in Chapter 8, Section 13, PBA, either because it has such values itself or because it is an essential part of a particularly valuable built environment. What is stated here about buildings also apply for areas of built environment.

A building can be particularly valuable if it clarifies earlier societal conditions. Examples of this are

- buildings that represent an earlier common building category or structure that has now become rare.
- buildings that illustrate earlier dwelling conditions, social and economic conditions, working conditions, different groups' living conditions, urban building ideals or architectural ideals and values and thought patterns, and buildings that have represented functions or activities important to the local community.

A building can also be particularly valuable if it clarifies the societal progress. Examples of this are

- buildings that e.g. illustrate the emergence of social movements, the breakthrough of mass car ownership, immigration or emigration,
- buildings that have served as role models or in other ways been acclaimed in its time, and
- buildings that are characterized by a strong architectural idea.

A building can also be particularly valuable if it in itself is a source of knowledge about older materials and construction techniques.

A building can be particularly valuable from an artistic point of view if it shows special aesthetic qualities or has a high level of ambition regarding architectural design or in construction and material choice or in artistic design and decoration.

The concept particularly valuable means that the building particularly well shall illustrate a certain condition or in its context have few counterparts that can illustrate the same condition.

Buildings from the time before the built environment expansion of the 1920s, that have its main character preserved, currently represents such a limited part of the building stock that most of them can be assumed to fulfill some of the criteria for particularly valuable building. (BFS 2016:6).

General recommendation
Windows: Windows are often of great importance for how the building is perceived and its cultural values. Reasons for deviation from the requirement for maximum U-value could be if the windows are manufactured specifically to meet the building's aesthetic or cultural values. Original windows should only be replaced using windows that in respect of materials, proportions, division and profiling are well suited to the character of the building. Windows may also have a highly significant cultural value to the extent that they should not be replaced unless there are exceptional reasons. Other measures to increase thermal resistance should be taken instead.[52]

If this law were adhered to based on its intention, this would suggest a very simple and energy-efficient way to preserve original windows, thus similar to the Finnish regulations. However, there is no mention of the very large energy-saving potential of energy-improving traditional windows.

RESULTS AND DISCUSSION

Denmark is the only Nordic country that makes direct reference to the total energy balance of a window in which both energy loss and energy gain from the sun are taken into account. In both Sweden and Denmark, it is necessary to calculate the total energy framework for an entire building, which, for windows, includes the total energy loss and energy gain from the actual windows in the actual building. The calculations therefore show the actual energy performance of the windows, but since energy loss and gain are calculated separately, it is rather complicated to compare the total energy balance for windows with an alternative scenario—for instance, windows with secondary glazing—and it is feared that this is rarely done in practice.

The Danish BR2018[53] can be helpful when selecting the most energy-efficient windows with IG-units whose geometry corresponds to the single light/one-frame reference windows. However, if the windows, for instance, have more than one frame, this does not apply. Furthermore, the information regarding windows in the BR2018[54] is quite illogical and hard to understand. The BR2018[55] should thus be modified as far as windows are concerned, not least since round half of the windows used in Denmark are multi-frame.[56] The regulations should also stop using E_{ref}, and all windows, including windows with secondary glazing, should be rated based on the energy balance of the actual window in the actual design.

Based on discussions in the other Nordic countries about overheating in the summer caused by windows, which therefore recommend windows with a low g-value, it seems important to consider these factors as well. Windows with a low g-value will save energy for cooling in the summer but, on the other hand, increase the consumption of energy in the winter. Of course, unlike Denmark, the rest of the Nordic countries also have to take into account their large geographical range, which extends over several different climate zones.

Windows with secondary glazing have a similar energy performance to IG-unit windows for multi-frame windows. Since the majority of existing buildings have multi-frame windows, it seems far more important to make them as energy-efficient as possible, contrary to the practice in the past four decades, in which they have often been replaced with new windows. This might have a big impact on total energy consumption, and it is probably far more sustainable to improve the energy efficiency of existing windows in older building stock than to replace them with new ones.

CONCLUSION

None of the building regulations of the Nordic countries specifies the great potential of energy-optimizing original windows.

None of the Nordic building regulations requires a direct calculation of the energy loss and gain for the actual window in the actual design of windows.

The lack of energy calculators on manufactures' websites is a very big problem. In Denmark, window manufacturers are obligated to provide the actual energy data, but only if it is requested in connection with an offer. Since it is so cumbersome to find the most energy-efficient solution, it is feared that this does not happen in practice.

All companies should provide a publicly available energy calculator in order to receive an energy rating, so that it would be possible to find the right energy data before requesting an offer. There also needs to be an independent website, including for windows with secondary glazing, that addresses the sustainability (life-cycle analysis), maintenance, noise reduction, total economy, and energy performance of windows in typical designs and sizes.

If the Finnish rule 'If old windows and external doors are repaired, the thermal resistance must be improved where possible' were combined with reliable energy calculators to actually find the right energy data, the Nordic countries could most likely combine building conservation with massive energy savings.

NOTES

[1] Thomas Kampmann, *Heat loss through windows*, Centre for the Restoration of the Built Heritage, Raadvad, Copenhagen (*Vinduers Varmetab*, RAADVAD – Nordisk Center til Bevarelse af Håndværk) (Lyngby, 2002), https://www.bygningsbevaring.dk/uploads/files/vintab12slutrapport2.pdf; Thomas Kampmann, *Noise nuisance! How to achieve the best noise insulation of windows?*, Centre for the Restoration of the Built Heritage, Raadvad, Copenhagen (Støjgener! Hvordan opnås den bedste støjisolering af vinduer?', Center for Bygningsbevaring i Raadvad) (Lyngby, 2004), https://www.bygningsbevaring.dk/uploads/files/vinduers_lydisolation_GI_artikel_2.pdf; and Thomas Kampmann, *Total environmental impact of windows, Life cycle analysis of four window types – or how to costeffective and conveniently reduce CO2 emissions significantly!*, Centre for the Restoration of the Built Heritage, Raadvad, Copenhagen (Vinduers samlede miljøbelastning, Livscyklusanalyse af fire vinduestyper – eller hvordan man billigt og bekvemt begrænser CO_2 udslippet mærkbart!', Center for Bygningsbevaring i Raadvad) (Lyngby 2004), https://www.bygningsbevaring.dk/uploads/files/vinduers_livscyklusanalyse_GI_artikel_2.pdf (if not otherwise mentioned, all URLs accessed in May 2021 unless otherwise noted).

[2] Ministry of Transport, Building and Housing, *Danish Building Regulations 2015*.

[3] Ministry of Transport, Building and Housing, *Danish Building Regulations 2018*. (Trafik-, Bygge- og Boligstyrelsen, *Bygningsreglementet 2018*).

[4] Thomas Kampmann, 'Through the Looking-Glass: Why Current Building Code Employs Double Standards When Relating to Existing Windows', in *Robust, Reflections on Resilient Architecture*, edited by Albert Algreen-Petersen and Søren Bak-Andersen (Prague: GEKKO Publishing, 2017).

[5] *Guidance for the Danish Building Regulations 2010*. (*Anvisning om Bygningsreglement 2010*), https://sbi.dk/anvisninger/Pages/Anv230-Anvisning-om-Bygningsreglement-2010-udgave-4.aspx.

[6] Ministry of Transport, Building and Housing, *Danish Building Regulations 2015*.

[7] Ministry of Transport, Building and Housing, *Danish Building Regulations 2018* (Trafik-, Bygge- og Boligstyrelsen, *Bygningsreglementet 2018*).

[8] Ministry of Transport, Building and Housing, *Danish Building Regulations 2015*.

[9] Ministry of Transport, Building and Housing, *Danish Building Regulations 2018*.

[10] Ibid.

[11] Ministry of Transport, Building and Housing, *Danish Building Regulations 1995*, p. 88. (Trafik-, Bygge- og Boligstyrelsen, *Bygningsreglement 1995*, p. 88.)

[12] Thomas Kampmann, *Vinduers Varmetab*.

[13] *Guidance for the Danish Building Regulations 2010* (*Anvisning om Bygningsreglement 2010*).

[14] Ministry of Transport, Building and Housing, *Danish Building Regulations 2018* (Trafik-, Bygge- og Boligstyrelsen, *Bygningsreglementet 2018*).

[15] *Guidance for the Danish Building Regulations 2010* (*Anvisning om Bygningsreglement 2010*).

[16] Ministry of Transport, Building and Housing, *Danish Building Regulations 2018* (Trafik-, Bygge- og Boligstyrelsen, *Bygningsreglementet 2018*).

[17] Ibid., p. 54.

[18] Ibid.

[19] Ibid.

[20] Ibid.

[21] Thomas Kampmann, *Vinduers Varmetab*.

[22] Thomas Kampmann, 'Støjgener! Hvordan opnås den bedste støjisolering af vinduer?'.

[23] Ministry of Transport, Building and Housing, *Danish Building Regulations 2018*.

[24] Ibid.

[25] Ministry of Transport, Building and Housing, *Danish Building Regulations 2015*.

[26] Ibid., p. 117.

[27] See Bøjsø, 'TECHNICAL INFO: Energy' ('TEKNISK INFO: Energi'), https://boejsoe.dk/teknisk-info/energi/. The information on the homepage has been changed since 2017 or the passage cited has been deleted.

[28] Energiforsatsgruppen, Glazierguild [A *laug* (guild) is an old Danish term for an association of craftsmen in the same profession], Glarmesterlauget, Denmark, https://glarmesterlauget.dk/om-glarmesterlauget/energiforsatsgruppen (downloaded on 20 May 2017).

[29] Thomas Kampmann, *Vinduers Varmetab*.

[30] Ministry of Transport, Building and Housing, *Danish Building Regulations 2018*.

[31] Ibid., p. 54.

[32] Ibid.

[33] Ibid.

[34] Ibid.

[35] Ministry of Transport, Building and Housing, *Danish Building Regulations 2015*.

[36] Ministry of Transport, Building and Housing, *Danish Building Regulations 2018* (BR18), p. 55.

[37] Ministry of Transport, Building and Housing, *Danish Building Regulations 2015*, p. 117.

[38] Ministry of Transport, Building and Housing, *Danish Building Regulations 2018*, pp. 55–57.

[39] Ibid., p. 57.

[40] Ibid.

[41] Ibid.

[42] Ibid., p. 58.

[43] Ministry of Transport, Building and Housing, *Danish Building Regulations 2015*. See Table 3 in Appendix 2, p. 127.

[44] Ibid., p. 79.

[45] Ibid.

[46] *Ministry of the Environment Decree on Improving the Energy Performance of Buildings Undergoing Renovation or Alteration* (2013), and *Decree of the Ministry of the Environment on the Energy Performance of New Buildings* (2017).

[47] *Ministry of the Environment Degree on Improving the Energy Performance of Buildings Undergoing Renovation or Alternation, Explanatory Memorandum*, p. 35.

[48] *Regulations on Technical Requirements for Construction Works* (2017).

[49] Ibid. p. 58.

[50] 'Boverket's building regulations – mandatory provisions and general recommendations on determining the building's energy use during normal use and a normal year (Boverkets författningssamling, Boverkets föreskrifter och allmänna råd om fastställande av byggnadens energianvändning vid normalt brukande och ett normalår), BEN', in BFS 12 (2016), and 'Boverkets föreskrifter om ändring i verkets byggregler 6 (2011)—föreskrifter och allmänna råd', in BFS 4 (2018).

Boverket = National Board of Housing, Building and Planning

[51] Ibid. This is the paragraph in Swedish language: '3 § Vid beräkning av byggnadens energianvändning ska byggnadens utformning, placering och orientering beaktas, inklusive utomhusklimat och passiv solinstrålning.'

[52] Boverket's mandatory provisions and general recommendations on determining the building's energy use during normal use and a normal year (Boverkets föreskrifter och allmänna råd (2016:12) om fastställande av byggnadens energianvändning vid normalt brukande och ett normalår, BEN). Ibid., p. 3.

[53] Ministry of Transport, Building and Housing, *Danish Building Regulations 2018*, proposal.

[54] Ibid.

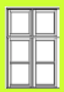
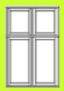
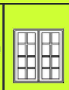
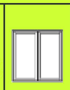
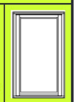
[55] Ibid.

[56] Thomas Kampmann, 'The Future 2015 Danish Building Regulations Concerning Energy Performance of Multi-Frame Windows', paper for the conference *7. Passivhus Norden: Sustainable Cities and Buildings*, Copenhagen, 20–21 August 2015.

[57] Energiforsatsgruppen, Glazierguild, Denmark.

APPENDIX 1

Diagram showing the energy loss (U-value), energy gain (g-value), and total energy balance of the entire window for typical Danish windows. The figures for sealed-unit windows and for 'Bøjsø' were obtained from the manufacturers. The numbers of windows with single-layer glass or secondary glazing come from the 'Energiforsatsgruppe', as association of manufacturers of windows with secondary glazing.[57] Source: Thomas Kampmann.

	A	C	D	E	G	H	I	K	L	M	O	P	Q	S	T	U	W	X	Y	AA	AB	AC	AF
1	Survey of typical Danish window sizes and divisions for a quick overview of energy conditions in relation to legislation and lowest heat loss																						
2	Windows, size 1.23 x 1.48 m or 1.18 x 1.18 m (CEN product standards)	Four frames many glazing bars 1.23 x 1.48 m			Four frames one glazing bar 1.23 x 1.48 m			Four frames without glazing bars 1.23 x 1.48 m			Two frames many glazing bars 1.18 x 1.18 m			Two frames two glazing bars 1.18 x 1.18 m			Two frames without glazing bars 1.18 x 1.18 m			One frame without glazing bars reference window 1.23 x 1.48 m			Energy labelling, the class is determined by the energy balance for a single-frame window E reference 1.23 x 1.48 m
3	U-value, for the entire window, g-value, energy gained from the sun Energy balance, for the whole window during one year	U W/m^2K	g %	Energy-balance $kWh/m^2/year$	U W/m^2K	g %	Energy-balance $kWh/m^2/year$	U W/m^2K	g %	Energy-balance $kWh/m^2/year$	U W/m^2K	g %	Energy-balance $kWh/m^2/year$	U W/m^2K	g %	Energy-balance $kWh/m^2/year$	U W/m^2K	g %	Energy-balance $kWh/m^2/year$	U W/m^2K	g %	Energy-balance $kWh/m^2/year$	
4	New 'Bøjsø' window, linked frames with IG-units (1+2)	1.38	0.3	-64.7	1.38	0.34	-58.4	1.38	0.34	-57,0	1.35	0.32	-59.4	1.35	0.35	-53.8	1.35	0.37	-50.2			3,0	Energy class A $0 \le E_{ref}$
5	Traditional / new window with secondary glazing provided with IG-units with double energy coating (1+2)	0.94	0.3	-25.6	0.94	0.33	-20.5	0.94	0.34	-18.2	0.97	0.32	-25.3	0.97	0.34	-20.7	0.97	0.36	-17.8	1.03	0.42	-9.8	
6	Traditional / new window with secondary glazing provided with IG-units (1+2)	1.42	0.29	-70.7	1.42	0.32	-65.6	1.42	0.33	-63.5	1.37	0.31	-63.5	1.37	0.33	-59,0	1.37	0.34	-56.2	1.25	0.42	-31,0	Energy class B $-17 \le E_{ref} < 0$
7	Traditional / new window with secondary glazing provided with one energy pane (1+1, 4-mm thick energy pane)	1.66	0.42	-67.2	1.66	0.46	-60.1	1.66	0.47	-57.7	1.68	0.44	-65.6	1.68	0.47	-59.3	1.68	0.49	-55.4	1.77	0.58	-45.6	
8	Traditional / new window with secondary glazing provided with one energy pane (1+1, 6-mm thick energy pane for 44 dB soundproofing)	1.64	0.41	-67,0	1.64	0.45	-60.1	1.64	0.46	-57.8	1.67	0.43	-65.9	1.67	0.46	-59.7	1.67	0.48	-55.8	1.77	0.57	-46.8	Energy class C $-33 \le E_{ref} < -17$
9	Traditional / new window with linked 'Optoglas®' provided with one energy pane (1+1)	1.74	0.42	-75.1	1.74	0.46	-68,0	1.74	0.47	-64.9	1.74	0.44	-70.7	1.74	0.47	-64.4	1.74	0.49	-60.5	1.73	0.58	-41.9	
10	New 'Bøjsø' window, linked frames with one energy pane (1+1)	1.73	0.39	-79.9	1.73	0.43	-71.9	1.73	0.44	-70.1	1.73	0.41	-76.5	1.73	0.44	-69.5	1.73	0.46	-64.9			-41,0	Energy class D $-55 \le E_{ref} < 33$
11	New 'Bøjsø' window, double glazing IG-units, energy glazing bar, with warm edge (U-value glass 1.1 W/m^2K) (2)	1.88	0.3	-110,0	1.65	0.36	-78.2	1.59	0.37	-70.5	1.88	0.31	-108.5	1.68	0.36	-80.7	1.55	0.4	-61.8			-32,0	
12	New 'Rationel Forma Basic' wooden window, double glazing IG-units, energy glazing bar, with warm edge (U-value glass 1.21 W/m^2K) (2)	1.54	0.34	-71.5	1.45	0.39	-53.3	1.43	0.40	-49.8										1.32		-13.2	Energy class E $-60 \le E_{ref} < 55$
13	New 'Rationel Forma Premium' wooden window, triple glazing IG-units, energy glazing bar, warm edge (U-value glass 0.53 W/m^2K), (3)	1.09	0.25	-48.1	0.99	0.29	-32.9	0.97	0.30	-30,0										0.78		6.5	
14	New 'Velfac classic' wood/alu window, double glazing IG-units, energy glazing bars, warm edge (U-value glass 1.21 W/m^2K) (2)	1.61	0.35	-76.7	1.46	0.39	-54.5	1.42	0.40	-49.5	1.62	0.38	-71.8	1.48	0.41	-53.4	1.39	0.43	-41.0	1.31	0.54	-12.3	Energy class F $E_{ref} < 60$
15	New 'Velfac classic' wood/alu window, double glazing soundproof IG-units, energy glazing bars, warm edge (2)																			1.29	0.53	-11.9	
16	New 'Velfac classic' wood/alu window, triple glazing IG-units, energy glazing bars, warm edge (U-value glass 0.53 W/m^2K) (3)	1.09	0.25	-48.5	1.04	0.29	-37.8	1.02	0.29	-34.9	1.06	0.28	-41.7	1,00	0.30	-32.1	0.97	0.31	-26.2	0.8	0.39	4.7	
17	New 'Velfac classic' wood/alu window, triple glazing soundproof IG-units, energy glazing bars, warm edge (3)																			0.84	0.39	1.1	
18	Traditional / new window with secondary glazing provided with ordinary glass (1+1) – used in Denmark since 1731	2.32	0.43	-124.9	2.32	0.47	-117.7	2.32	0.48	-116,0	2.36	0.45	-124.8	2.36	0.48	-118.4	2.36	0.5	-114.3	2.52	0.6	-110.3	
19	Traditional / new window without secondary glazing (1)	4.46	0.49	-307.3	4.46	0.53	-299.1	4.46	0.54	-299.1	4.58	0.51	-313.4	4.58	0.55	-306.2	4.58	0.57	-301.6	4.99	0.68	-318.6	

NAF 2019, Biased Building Regulations for Windows, APPENDIX 1, *Source: Thomas Kampmann*

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