Architecture, Structures and Construction (2022) 2:23–37
https://doi.org/10.1007/s44150-022-00036-x

ORIGINAL PAPER

Daylight conditions in housing–Its role and priority in Danish building regulations

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Received: 2 December 2021 / Accepted: 8 March 2022 / Published online: 19 March 2022

Abstract

In a Danish context, the Building Regulation is the legislation for our built environment. Therefore, the focus of this survey is to investigate how Danish legislation treats questions on daylight in relation to the build environment. Furthermore, it looks at whether the specific ways of looking at daylight influence the general understanding of light and the processing of daylight design in the built environment. When acknowledging both its multifaceted character and the impact daylight has, as well as the inherent implications regulation can have on the practices that apply to them, the question remains as to how Danish building regulations treat questions of daylight in relation to the built environment. Furthermore, what is the implication of understanding these ways of looking at daylight? This survey is a profound study of 14 Danish building regulations, from the first historical regulations in 1856 up to the latest regulation of 2018. To investigate the role of daylight and its priority in Danish building regulations, daylight is defined through three theoretical topics: *vision, energy,* and *health*. This survey focuses on daylight in relation to private housing. Reviewing the 14 Danish Building Regulations illustrates how the understanding of daylight in relation to the built environment has changed. The different requirements on daylight design varies through time and reflects the political agenda of each specific historical period. This underlines how daylight is subject to changing agendas; however, it is rarely an agenda on its own.

Keywords Daylight design · Building regulation · Philosophy of technology · Housing · Legislation

Introduction

Daylight is an important part of our built environment as it has a significant impact on our surroundings and on us. Daylight generates our visual environment, our ability to feel comfortable and to stay healthy. In addition, light can foster particular feelings and atmospheres in an environment. Daylight is, therefore, multifaceted and cannot be understood in just one way but must be seen in relation to many diverse aspects of our building culture and everyday life.

In a Danish context, Building Regulations are the legislation for our built environment and have an impact on how actors in the building sector design, plan and construct buildings and our homes.

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The first construction provisions in Denmark were issued in Copenhagen following the great fire of 1728 with requirements for construction methods and materials. After yet another fire in 1795, requirements concerning the dimensions of exterior walls and beams were added. Furthermore, conditions influencing the access of daylight were included in the provisions, defining that the maximum height of the roof depended on the width of the road. In 1889 the first specification on unhindered access of daylight to interior spaces were included in the regulations, even though some builders found it very difficult to meet [1, 2].

Since then, building regulations in Denmark have played a central role in securing the safety and wellbeing of both residents and building users, as well as the interests and concerns of wider society. In the first provisions, the focus was on hindering the spread of fires in buildings and to the surrounding city and securing reasonable daylight conditions in the interiors facing the street. However, concerns and understandings of the resident's safety and wellbeing, as well as the interests of society have evolved and varied over the more than 200 years since the first regulations [3].

To acknowledge the multifaceted nature of daylight and its impact on us, it is relevant to consider how Danish building regulations have regulated and represented daylight. Furthermore, do the regulations emphasise specific approaches to light, and do these approaches differ over the 200 years of regulation?

This paper will try to shed light on these questions by way of a review of the requirements on daylight and the requirements that affect the access of daylight from the first provisions from the late eighteenth century to the building regulations of today (Fig. 1).

Fig. 1 Interaction between daylight, window opening and space. Photo: Nanet Mathiasen

Background

In a Danish context, the Building Regulation as the governing rule for the whole country was not compiled until 1961. Before that, there were many laws and regulations that differed from region to region and city to city. Copenhagen, the Danish capital, adopted its first unified building law in 1856, though there had been requirements dating back to the sixteenth century concerning the built environment in the city [1]. However, in reviewing the various historical building regulations, one learns that it was not until 2008 that daylight had its own chapter in the Danish Building Regulation and that was only in the overall context of indoor climate. Issues concerning daylight have historically not been treated as a separate subject in the Building Regulation. Hence, it creates the backdrop of this review, focusing on how and where daylight is included in Danish regulations.

The overarching legislation for construction in Denmark is the Building Act. The law is the framework that describes the purpose of legislation concerning construction and buildings. The Danish Housing and Planning Agency (Bolig og Planstyrelsen) outlines the intention of the law by stating "*The law must, among other things, ensure that buildings are constructed, arranged and used in such a way that they offer satisfactory security in terms of fire, safety and health*" [4].

The legal requirements of the Building Act are detailed in the Building Regulations (BR). The objective of the Building Regulations is to "*specify the requirements of the Building Act and contain the more detailed requirements that all construction work must meet. This means that the requirements described in the Building Act and the Building Regulation ensure that buildings are constructed, arranged and used in such a way that they offer satisfactory security in terms of fire and safety and health.*" [5] The two laws are closely linked; the Building Act is phrased in general terms and the law is not often changed. Whereas the Building Regulations are dynamic legislation that are adjusted more often and adapted to current political objectives. It is the Building Regulation that architectural studios, the construction industry and technical consultants refer to and aim to meet.

Architecture and design processes are often considered and described independently, not taking framework conditions such as tools, regulations and other societal constraints into account. Whereas it is commonplace to include building materials, technology and the physical context as well as philosophical viewpoints together in design when analysing architecture [6, 7] organization, tools or contemporary regulation of construction are seldom included. Nevertheless, voices exist that draw attention to how such framework conditions influence creativity and innovation, the changing responsibilities of the architect and the fluctuation of the boundaries between professionals within the building sector [8–11].

Within Science and Technology studies (STS) there is an understanding of technology as shaped in an interplay of social and material/technological possibilities, practices and considerations. And vice versa that technology plays a shaping role for both scientific and professional practices in a complex interplay [12].

Building upon a Heideggerian understanding of technology the post-phenomenological tradition within STS argues that technology also has a profound influence on our understanding and experiences of the field where the technology is applied and thereby how we work within this field [13].

The German philosopher Martin Heidegger claims that tools are non-neutral. A tool or technique shows us properties/qualities of the surrounding world or of the thing that we are working on. It is never neutral in the way it lets us perceive the world [14]. By that is meant that the use of a particular tool or technology always contains an implicit understanding of what they are used to perform and process. The users that apply a technology gain experience through its use, and in this process the technology amplifies some qualities of the issue/process or material that is worked on, while it reduces other qualities [15].

Drawing on this understanding of technology, we consider the building regulations as a regulating technology that are shaped by societal considerations, current practices, scientific knowledge, technological possibilities at any time. And furthermore, as a regulating technology that has inherent understandings of the field it regulates, has a structuring impact on the practices applying it by for instance asking for specific documentation Accordingly, building regulations are both a mirror of technology, scientific knowledge and societal considerations at any time. And the regulations have an impact on more than our cities and buildings they also influence by whom and how our buildings and cities are designed.

As stated in the introduction, acknowledging both the multifaceted character and impact light has, as well as the inherent implications regulation can have on the practices that apply to them, the question remains as to how the Danish Building Regulations treat the questions of daylight in relation to the built environment. Furthermore, what is the implication of understanding these ways of looking at daylight?

Theories on light

In order to discuss daylight, the term needs to be defined. However, the challenge when defining daylight is that light is not a tangible physical object like other building materials

[16]. The dimensions of a construction can be calculated and defined precisely. A material's maximum capacity, durability, surface characteristics etc. can be described and accounted for in relation to architectural design. Daylight is more complex. It is radiation; a spherical element without well-defined boundaries. Furthermore, daylight is often considered as an inherent part of building culture [17], an inevitable part that no one questions and may therefore be why building regulations have been hesitant to include it as an autonomous topic.

The body of scientific literature within the field of daylight is substantial, underlining that the topic of light can be understood from various angels and tends to expand further in even more directions. To grasp this large and complex topic, this project has chosen a specific approach where the overall theoretical framework is the understanding of light drawn from physics that understands it as part of the electromagnetic spectrum. From this basis, three overall themes of importance in relation to light and building regulation have been pinpointed, namely aspects of light as *vision*, *energy* and *health*.

Vision

In physics, light is described as part of the electromagnetic spectrum to which the human visual system responds. Within the wavelength range of 380 to 780 nm [18], the photoreceptors of the human eye absorb energy and thereby initiate the process of seeing. This part of the spectrum is what we call light.

Being able to see makes us capable of understanding our surroundings and conducting our everyday life [19]. Our knowledge on vison has developed through the centuries and has captured the attention of researchers since Antiquity [20]. The eye and the act of seeing has often been a focus research, particularly in the last 75 years. These investigations have resulted in a general understanding of the eye as an optical instrument focusing on the organisation of the visual environment and optimising visibility in order to support visual performance. [21, 22]. Visual performance is related to the structure of the retina (rods and cones), foveal and peripheral vision in relation to light properties such as intensity, colour of light, colour rendering and the effect these properties have on glare (disability and discomfort) and contrast (adaptation).

Energy

The sun is the source of daylight. When a ray of sunlight reaches the atmosphere, it scatters out across the sky. Most of the solar radiation (spectral irradiance) lies within the wavelength of 300–3000 nm. The solar radiation is reduced from the top of the atmosphere and until it reaches the surface of the Earth (sea level). It consists of ultraviolet light (UV) below 380 nm, visible light 380–780 nm and infrared light (IR) 780–2800 nm respectively. The allocation of the three types of light at the surface of the Earth are: UV light 4%, IR light 44% and visible light 52% [19]. This means that the most intense light lies within the visual field, the least in the ultraviolet field and second most in the infrared field, which are not visible but are perceived as heat.

The sun is approximately 150 million kilometres away from the Earth, which means that the rays from the sun can be considered as parallel to Earth, and since the Earth is a sphere, the altitude of the sun differs from latitude to latitude. These different altitudes of the sun are also part of climate definitions [23]. Solar radiation that reaches the surface of Earth is divided into two components: direct solar radiation from the sun, and diffuse radiation from the sky. The total of both components that reach the surface of Earth are called global radiation [24]. The global radiation that reaches the surface of the Earth (sea level) varies in intensity according to the latitude and the character of the sky. This means that the solar energy reaching Earth differs according to latitude and climate conditions.

When daylight in buildings is described, not only do both direct and diffuse solar radiation need to be considered, but also the reflected light from the surroundings, which means three components are included. The rays of light travel in straight lines directly from the solar disk. If something obstructs the rays of light, they are stopped. Rays of light cannot bend but they can be reflected from surfaces. The character of the surface material defines the way the rays of light are reflected. A matt surface reflects the rays of light evenly in all directions, whereas a glossy surface reflects the rays of light at the same angle as of incidence. How much of the light that penetrates the buildings depends on the character of the surroundings in relation to the apertures. The actual energy consumption is related to how balanced the daylight intake is, whether it allows too much or too little light to enter the space. The interior distribution of light is related to the window opening, its position, size and form (building geometry). This stresses the importance of the character of the surroundings when distributing light, in terms of obstructing elements (e.g. building structure), the design of the apertures and surface character.

Health

Humans have evolved beneath the sun's rays and exposure to daylight is required to stay healthy.

Nevertheless, this exposure to daylight must be balanced. Our bodies need exposure to daylight in order to produce vitamin D, but overexposure of the skin can lead to developing skin cancer. Seasonal affective disorder (SAD) is also related to exposure to light. This illness can occur if the intensities are too weak, like during wintertime at high latitudes far away from equator.

Apart from the physiological effect of light, light also supports psychophysiological effects. Within the last 20 years, it has become well-know that light not only generates visual effects but also non-visual effects. In 2002, a new type of the retinal ganglion cell (RGC) was discovered [25]. This new cell, called intrinsically photosensitive retinal ganglion cell (ipRGC), has nothing to do with vision but relates to our well-being through, for example, the regulation of hormones that regulate our circadian rhythm. This new knowledge on how light affects our well-being has received a lot of attention and the artificial lighting industry has developed various lighting systems that support non-visual effects. However, there are still discussions over what the optimal support of non-visual effects is [23]. Although the discovery of the new cells is still very recent and research on the topic is ongoing, research agrees that the relation between natural light and the natural cycles are key to understanding the connection between light and human well-being.

Finally, it is not only the tangible interaction between the rays of light and our body that influences our health, as stated above. Also, the feeling of wellbeing in a daylit space is important [26]. When a window opening lets in direct sunlight, creating a pattern of slowly moving sparkling light, it can be visually stimulating [27] and making room for contemplation. It connects the interior with the exterior reminding the inhabitants of time and place. Furthermore having a view is important for our health and wellbeing and not any view. In a survey of people's ability to recover after surgery it was illustrated how patients that were in a hospital ward with a view to greenery recovered faster compared to those who only saw a brick wall [28].

So, both the physiological and psychophysiological effects of light depend on regular exposure to daylight. In the built environment, this requires building design that allows for the 24 h-cycle of light which offers both light and darkness. A building allowing for a well-lit environment needs to take this into account, especially at higher latitudes where light is a restrained resource during wintertime.

Defining light in relation to aspects of vision, energy and health

Vision, energy and health are all properties of light that need to be understood so that light can be used as best as possible in order to support different aspects. A brief summary of aspects of light to be aware of when investigating the built environment in relation to the three topics would be: 1) Vision—is there enough light and does it meet visual demands (intensity, spectral distribution, colour rendering)? Quantities and properties that can be defined and measured by well know units. 2) Energy—does light lead to overheating which requires cooling or is there too little light that requires the use of artificial lighting? The question of the size, shape and position of the windows are of importance in relation to the built environment and energy consumption. 3) Health—is there access to light so people will have the opportunity to be exposed to sufficient light supporting production of vitamin D, supporting hormone production and thereby support people's circadian rhythm?

The definition of light through science in relation to electromagnetic radiation and the three topics of interest in relation to the specification above are measured with well-defined quantities and units. However, apart from quantitative aspects of light there are qualitative aspects linked to perception and sensation. Perception of light in spaces such as shadow patterns, the directionality of light, adaptation and contrast is not defined through quantifiable terms, and is therefore often excluded when light is defined, even though these elements enhance space and form and are thereby fundamental for vision. Likewise, the intangible atmosphere of a space is of importance. Often the very first impression people have when entering a room is also how they chose to describe the room later. That immediate impression and atmosphere of a space is related to the qualitative aspects of light, which are not easy to define. Nevertheless, the intangible and atmospheric elements of architecture are of importance and often concern architects and those inhabiting a space.

Method

This review of the regulation of daylight in Danish housing is based on a study of 14 Danish building regulations. This survey focuses on light in relation to the built environment and takes it point of departure in definition of light in physics as radiation described through the electromagnetic spectrum. In the previous chapter, we described daylight in relation to three topics: vision, energy and health.

The Building Regulations have provisions for daylight in relation to various building types. This review focuses on daylight in dwellings. The focus is solely on the Building Regulations in Denmark. This approach is reflected in both text and diagrams.

There are extensive guidelines for electrical lighting in both Danish and European standards. However, these standards are *not* included in the review. Nor does the review include guidelines from the Danish Building Research Institute (Statens Byggeforskningsinstitut/SBi), as they are not law. This entails that there are some aspects of the regulation that are left out, as they are not considered as part of the scope of this review.

The review of the historical Danish Building Regulations starts in 1856 and ends with the latest regulation of 2018. In

1856, the capital of Copenhagen had its first comprehensive building law. This regulation is important since Copenhagen is the largest city and the city with the highest level of regulation. Furthermore, the Copenhagen Building Law became a model for the laws of other cities in the rest of the country. That is why the four Copenhagen building laws are included in this review representing building regulations before the national Building Regulations from 1961.

Daylight is not treated on its own in the Building Regulation until 2008. This means that of the 14 regulations reviewed only 4 has a specific section on daylight. Therefore, the review includes elements of the Regulations that have an impact on daylight conditions, though they do not necessarily mention light. The themes of the selected requirement are the site/building geometry (plot ratio, building height and distance to other buildings or plot boundaries) – as that affects the possible access of daylight; requirements for windows or light (the character of light that penetrates the window and how much light the inhabitants are exposed to related to health issues); and energy demand/heat loss as it concerns the window area (Fig. 2).

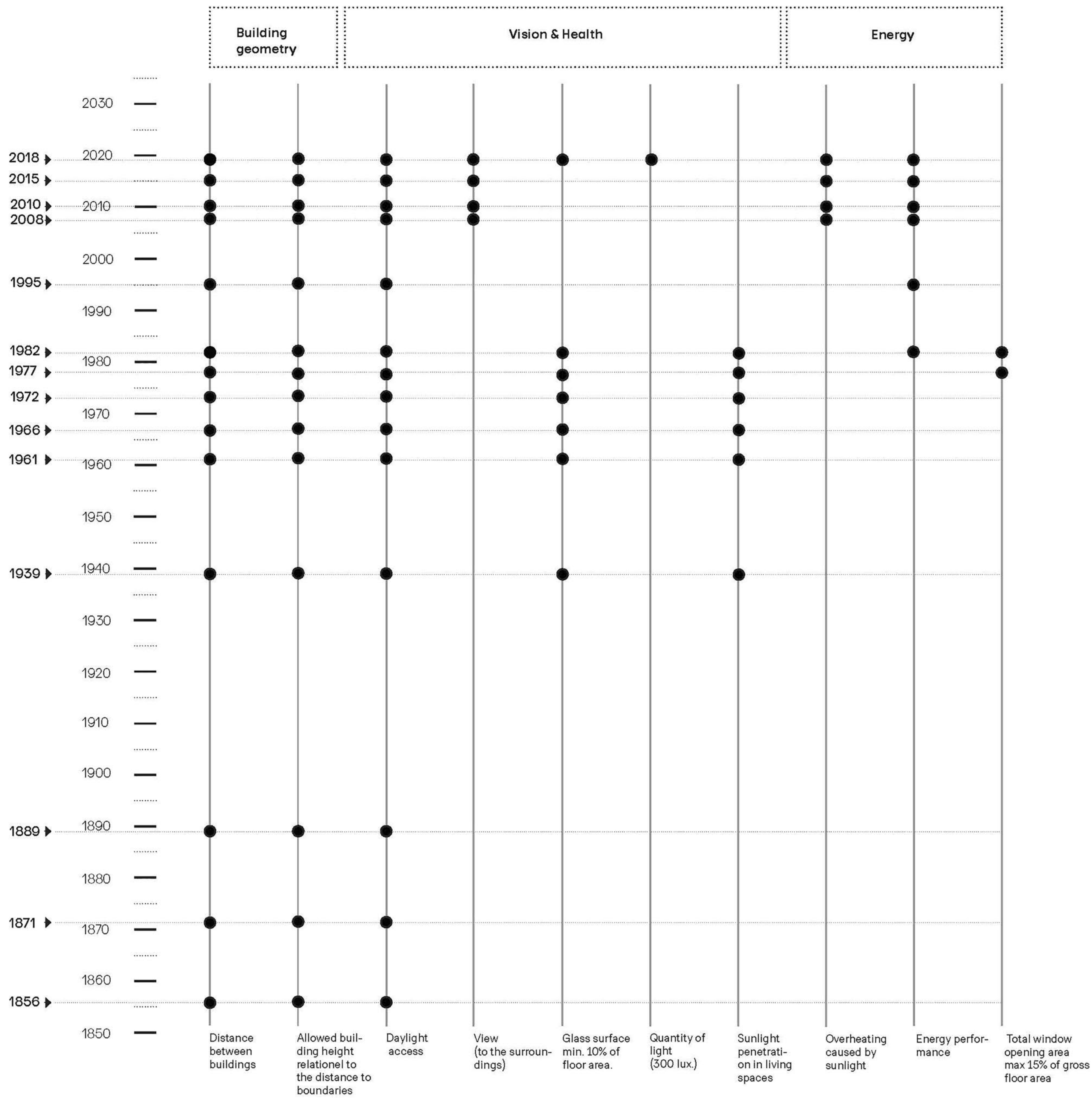

Fig. 2 Summary of the survey of the 14 Danish historical Building Regulations

Review of daylight in Danish building regulations

The first construction provisions in Denmark were issued in Copenhagen following the great fire of 1728 with requirements for construction methods and materials. After a big fire in 1795, dimensions for exterior walls and beams were added. Furthermore, daylight conditions were included with provisions defining that the maximum height to the roof depended on the width of the road. On a road with an 18 cubit width, you could build a house with 18 cubits to the roof. If the road was broader, you could build a somewhat higher building [29].

It was in 1856 that the first comprehensive building law was written, regulating the city of Copenhagen. In that law, the former provisions were compiled together and thus the rules were much easier to find. Regarding daylight, this law continued the requirements from the former provisions linking the height of the building to the width of the road, however, increasing the allowed height of building to the width of the road by a fourth of the width [30, 31].

A minimum of a fourth of the area of the site's open space and minimum distances of 3 cubits (less than 2 m) between buildings in yards (1856 § 65). There were no requirements for the size of the windows, only limits for how much of the width of the façade that the windows could constitute, namely two thirds of the width of the façade – probably to secure structural stability (§ 12). The law demanded adequate daylight access and ventilation to living quarters, basements and roofs used for residential purposes, without specifying what was adequate (§ 69 §70).

The next building law from 1871 kept the former regulations regarding daylight conditions, only adjusting the minimum open space, requiring a third of the area of the site to be open space when the site was outside the old city walls and a fourth of the area if the site was within the old city walls. The demands regarding living quarters in basements were slightly tightened only allowing residential use of basement if the road was more than 20 cubits and the ceiling of the basement was at least 2 cubits over the level of the road. The law continued the requirement for adequate light.

In the law of 1889, the required distance between buildings was the same as in the previous law, but awareness of health was growing, and the distance between buildings and the width of the yards was raised from 3 to 4 cubits. In front of rooms, workshops and kitchens, the distance to another building was to be 3 cubits plus a fourth of the building height. Additionally, sufficient light was required, though the law does not define how much that is.

The restrictions regarding living quarters in basements were tightened, only allowing them to be used for housing if the ceiling is 2½ cubits above the level of the road and windows open out to open air.

The replacement of the law of 1889 came in 1939 with a new law for the city of Copenhagen featuring a much more explicit focus on providing buildings that ensured health and wellbeing. This focus is displayed in a new concept introduced with the law: the plot ratio defining that the size of the building is dependent on the ratio between the total floor area of the building and the size of the site. In connection with this, the law stated that the utilization of a plot must ensure a patch of open ground providing "*satisfactory Lighting Conditions, Fire Protection, and Access Conditions*" [32]. These requirements also applied to the planting.

Requirements for the distance between buildings and a ratio between the height and the width of the road and between the buildings on the site continued, differing across the various areas of the city. The law featured a new item, which linked the requirements for ratios of height and width and distances between buildings to daylight conditions besides fire protection and access conditions.

Furthermore, the law required a light opening area (lysningssareal) corresponding to a minimum of 10% of the floor area of the room and 7% in case of roof lights. It had to be ensured that at least one habitable room (preferably the largest) had access to sunlight and windows on two sides to ensure the possibility of ventilation. This law is the first that explicitly regulated lighting conditions.

In 1961 [33], the first national Building Regulation came into force with detailed prescriptions expanding on the general provision in the national Building Act from 1960. Both the Building Act and Building Regulations governed only the country and market towns, whereas the city of Copenhagen and Frederiksberg had laws of their own until the 1970s.

The heights of and distances between buildings were still regulated in the Building Act, though now for the entire country (Byggelov for købstæderne og landet, 1960), with a maximum plot ratio of 50% in cities and 20% single family houses (§ 33). The regulations over height and distance depended on where the building was located (§ 34). In cities with a maximum plot ratio of 80% or more, the maximum height of the building could be 0.8 of the width of the road to the opposite building, and 3 m + 0.8 of the distance to the boundary of the site. The maximum road width was 20 m. If it was outside older urban areas, the maximum height was 0.4 of the road width to the opposite building, 3 m + 0.5 of the distance to boundaries of the site and 0.4 of the distance to other buildings on the plot.

The requirement of a lighting area of at least 10% of the floor area of the room in living areas continued. In case of poor lighting conditions, an increased lighting area could be required. If skylights were used, the prescribed lighting area was reduced to 7%. 10% lighting area also applied to basements. In ancillary rooms such as bath/WC, an opening with 0.6 m^2 frame lighting area was required (BR61 Sect. 4.1.1, subsection 7). At least one room in every residential apartment – preferably the largest – ought to receive a reasonable extent of sunlight (BR 61 4.1.4., subsection 2).

The Building Regulation from 1966 [34] recommended sunlight in outdoor living areas. The degree of utilization and the distance rules were still regulated in paragraphs 33 and 34 of the Building Act, which also applied in 1961, with the possibility of exceptions only if ancillary rooms such as stairs and bathrooms facing boundaries and living spaces receive light from other sides.

When building on the same plot, the distance between additional buildings, garages, sheds, etc. was reduced to 1 m, however, there had to be 2.5 m next to windows to the living room, kitchen and bedrooms. Regarding living spaces, the requirements for the minimum lighting area from 1939 and 1961 continued (BR 61 4.1.1., subsection 7). Likewise, the demand for sunlight in at least one room in a residential apartment remained (BR 66 4.1.4., subsection 2).

The BR 72 regulations [35] maintained the distance rules, however, somewhat differentiated depending on the plot ratio. The regulation required that no part of a building exceed a height 0.4 of the distance to the opposite site of the road. In older urban areas with predominantly enclosed buildings, no part of a building must have a height that exceeds:

a. on plots with a plot ratio of 0.80 or more: 0.8 of the distance to the opposite side of the road.
b. on plots with a plot ratio less than 0.80: 0.6 of the distance to the opposite side of the road.

However, the distance to boundaries increased outside older urban areas.

Outside older urban areas with predominantly enclosed buildings it was required that the height of no part of a building exceeded: a. For single-family houses with up to 2 stories (including semi-detached houses, terraced houses, chain houses, group houses and the like), 4 times the distance to neighbouring boundary,

In older urban areas with predominantly enclosed buildings, the height of no part of a building exceeded: 3 m + 0.8 of the distance to the neighbouring boundary on plot ratio is 0.80 or more. On plots for which the general maximum plot ratio was less than 0.80: 3 m + 0.65 the distance to the neighbouring boundary. (BR 72, Sect. 3).

The distance rules of 2.5 m between buildings on the same plot continued and applied for garages, sheds, etc.

The percentage rules for the lighting area of 10% of the floor area (7% for skylights) continued together with the requirement that rental housing "*must be oriented in such a way that it receives sunlight to a reasonable extent*" (BR 72, Sect. 4.1.4., subsection 1a).

In the regulations from 1977 [36], the rules from the previous regulation regarding building height in relation to the distance to boundaries were maintained. The requirement for distances was lowered if it was not in front of a living space, kitchen or workspace. The same applied to exterior walls, which had windows for living rooms, kitchens or workrooms, if the rooms had satisfactory light access through other windows.

The distance rules were increased. On plots where the maximum building percentage was set at less than 90, no part of a building could have a height exceeding 0.6 × the distance to the opposite road line.

Where the maximum building percentage was set at 90 or more, no part of a building could have a height exceeding 0.8 × the distance to the opposite road line.

The rule of glazed area of 10% of the rooms floor area (7% for skylights) remained, and it was required that residential apartments receive a reasonable amount of sunlight (4.3.2., subsection 3) (4.3.3., subsection 2). The big change came in 1979 with an addition to the regulations on thermal insulation following the energy crisis, which introduced an upper limit for the allowed window area in a building. The total window opening area with the frames, including skylights, glass walls and glass sections in doors to the open air, could not exceed 15% of the building's gross floor area (BR77 – addition 79, Sect. 8.1., subsection 9).

In the regulations from 1982 [37], the focus on energy and reduction of heat loss in all parts of the building, including windows and doors, was further increased. The provision limiting the total window opening area to 15% of the building's gross floor area continued (Sect. 8., subsection 10). In addition, a new section was added: Building components that limit spaces that are assumed to be heated to at least 10 °C or at least 18 °C could be designed in such a way that the transmission coefficient k expressed in W/m^2 °C did not exceed 2,90 W (8. subsection 8).

The other provisions for distance between buildings and boundaries were not changed; the 10% rule for kitchens and living spaces, as well as the requirement for sunlight to a reasonable extent in residential apartments remained (4.3.3, subsection 2). However, a gradual change of daylight planning from a task with a focus on light and function towards a calculation task started here.

In the 1995 regulation [36], the distance rules were slightly loosened compared to the previous regulations.

On plots where the maximum building percentage was 60% or less, the minimum distance was 0.4 × the distance between buildings on the same plot. On plots where the maximum building percentage is greater than 60%, but less than 110: the minimum distance was 0.6 × the distance between buildings on the same plot. On plots where the maximum building percentage is more than 110%, the minimum distance was 0.8 × the distance between buildings on the same plot (Sect. 3.5., subsection 1).

The building had to be assessed with a total heat loss calculation—and windows were included as part of this total calculation. The maximum U value for windows and exterior doors, (including skylights, glass walls, gates and shutters) to the exterior was 1.80 (8.2., subsection 1) [38]. The prerequisite for the calculation of the building's total heat loss was that the total area of windows and exterior doors should not exceed 22% of the heated floor area of the building (8.2., subsection 5). It was required that the building's total energy supply demand for heating and ventilation per. m^2 heated floor area did not exceed 160 MJ/m^2 per year, plus 110 MJ/m^2 per year divided by the number of floors. The energy demand could not exceed 250 MJ/m^2 per year (8.4.2., subsection 1). Living rooms and kitchens as independent rooms should have a window (4.3.2. subsection 4).

In 2006, energy classes were introduced for single-family homes, and defined an *energy framework*—the maximum total energy supply demand for heating and ventilation of the house in different classes. From 2006 onwards, the requirements for the energy frameworks have been tightened every 5 years.

BR 2008 [39] maintains the height-limit for single-family homes as 1.4 × the distance to the boundary as well as the minimum distance of 2.5 m to boundary. For multi-story buildings, the height-limit is 8.5 m, otherwise the municipal council must decide on the height of the building. The plot ratio was set at a maximum of 60% for multi-storey buildings, 40% for fully or partially adjoining houses and 30% for single-family homes (2.7.2).

Access to daylight in living areas was required and the windows should be placed to avoid nuisances and should possibly be shielded from sunlight that may cause overheating. The instructions state that a window area of 10% (7% for skylights) of the floor area with a transmittance of 75% is sufficient and it should be possible to look out of it (6.5.1). The energy framework was tightened to 70 kWh/m^2 per year, plus 2200 kWh per year divided by the heated floor area (7.2.2).

With the BR10 [40], the requirements for distance to roads and boundaries as well as the building's maximum height and the requirements for daylight were unchanged (2.7.3. and 6.5.2., subsection 1).

The energy framework, the energy for heating, ventilation, cooling and domestic hot water per m^2 of heated floor area was tightened. For single-family homes, it was 52.5 kWh/m^2 per year, plus 1650 kWh per year divided by the heated floor area, and for low-energy houses it was 30 kWh/m^2 per year, plus 1000 kWh per year divided by the heated floor area (7.2.2).

With the BR15 [41] there is no change regarding requirements for the maximum height of buildings and distances to the plot boundaries (Sect. 2.2.3).

Regarding daylight in homes, the regulation stated that living spaces and communal areas should have satisfactory light without causing unnecessary heat load and one must be able to look out (3.3.1., subsection 6). The considerations regarding overheating from sunlight or other nuisances were unchanged. According to the guidelines (which are not requirements), living spaces are considered to be adequately lit if the daylight factor is 2% in half of the space.

The regulations tightened the energy framework further allowing a maximum of 30.0 kWh/m^2 per year, plus 1000 kWh per year divided by the heated floor area (7.2.2., subsection 1). The energy frame for the low energy class 'building class 2020' was 20.0 kWh/m^2. In order to fulfil the requirements in building class 2020, the energy contribution through windows should be no less than 0kWh/m^2, and 10 kWh/m2 for skylights (7.2.4.1., subsection 2). The glazed area for dwelling in this low energy class should be no less than 15% of the floor area of kitchens and living spaces, with a light transmittance higher than 0.75; for lower light transmittance the glazed area should increases accordingly (7.2.4.1., subsection 6).

With the BR18 [42], requirements regarding distances or height were not changed nor was the energy frame except for when it comes to windows and glass exterior walls. Building class 2020 requirements were applied to windows, which required that the energy contribution from windows must not be less than 0 kWh/m2 per year and for skylights and glass roofs, the energy contribution must not be less than 10 kWh/m^2 per year.

Living rooms and kitchens must be adequately lit (§379), and it has to be possible to look out to the surroundings (§378). The old rule of glazed area of 10% of the room's floor area returned, defining the glazed area as the free opening area minus the frame and lattice areas.

The geometry of the surroundings was included, as the calculation has to be corrected for shading surroundings, reduced light transmission etc. (Danish Transport, Building and Housing Agency's Guidelines on light and visibility). Alternatively, sufficient daylight is defined as 300 lx or more at no less than the half of the relevant floor area for at least half of daylight hours (Sect. 379, subsection 2). Shielding from sunlight in order to prevent overheating in the rooms and nuisances from direct solar radiation was still required (§381).

In 2020, a voluntary sustainability class was introduced, with the expectation that is will be included in the Building Regulations in 2023. The rule of 300 lx more at no less than the half of the relevant floor area for at least half of the daylight hours remained [48].

Analysis

In reviewing the historical regulations, it becomes clear that the first regulations were a reaction to the large fires in Copenhagen. These created the need for regulation of the built environment to reduce the spreading of fire. Therefore, the very first regulations were concerned with the building geometry defining the building height and the distance to the neighbouring buildings. These requirements had an impact on the aesthetics of the urban space, making the streets of Copenhagen look beautiful and well organised, and also secured daylight access to the interiors facing the streets. As the diagram shows the requirements for building heights and distances have been included ever since, with a tendency towards more distance between buildings and reduced heights.

The first nineteenth century regulations did not require much distance between the buildings on the plot challenging the daylight situation in the rooms facing the enclosed backyard. However, the 1871 and 1889 regulations required somewhat increased distances between buildings on the same plot, revealing an emerging awareness of health considerations. The adjustment came after comprehensive critique from medical doctors who were concerned about the health situation of the people living in the very dense areas of Copenhagen [43]. The combination of very dense housing areas and a cholera epidemic induced a rapid spread of infection and challenged the health situation of the inhabitants. That gave rise to an initiative by the Danish Medical Association, which conducted a building experiment taking special care of the density of the housing areas through an architectural design that focused on the height and distance of the housing blocs, the possibility to ventilate each apartment properly and space for green surroundings in the immediate areas. This building experiment from 1853 until 1871 became an inspiration for many future housing concepts in Copenhagen [44] (Figs. 3 and 4).

Today, there are still requirements for heights and distances on plots, something that has hardly changed since the 1960s. The main emphasis today is ensuring privacy by hindering the view inside as well as providing daylight access from the 1939 building law. Besides these requirements, the local district plans regulate the plot ratio, distances between buildings and the allowed building heights today.

Daylight and window design

The 1939 regulation is the first regulation with an emphasis on daylight. This regulation introduces this rule of thumb: that an opening area of at least 10% of the floor area (7% if it is a skylight) provide sufficient daylight. This rule was included in the Regulation for more than forty years. Considerations over light transmittance of the glazing of no less than 0.75 as well as the definition of a glazed area as opposed to an open area were first added in the most recent Regulations from 2018.

Glass technology plays an important role for the daylight design and the regulation of daylight access. From the earliest building regulation till the most recent glass has changed dramatically from only allowing small window openings to today making entire glass façades possible [45]. And with the possibilities of various energy coating of the glass, the

Fig. 3 Housing for the Danish Medical Association, 1871. Architect: Thorvald Bindesbøll. Photo: Louise Grønlund

Fig. 4 Housing for the Danish Medical Association, 1871. Architect: Thorvald Bindesbøll. Photo: Louise Grønlund

experiences of light through glass it is no longer a slight green coloring. The coating can decrease the light transmittance as well as alter the colour of light.

However, this rule was not in force between 1982 and 2018. Since the energy crisis in the early 1970s, daylight has been subordinated to the energy agenda. First in an addition from 1979 to BR77 focusing on heat loss and thus allowing a maximum opening area of 15% of the building's gross floor area. This requirement had an immense impact on daylight intake and can be seen directly in architectural design, revealing a huge difference in having a minimum daylight intake of 10% of the floor area to a maximum of 15% of the building's gross floor area [46, 47]. This implies a prioritization of which spaces could be well-lit and which could be less well-lit, for example allowing larger windows in kitchen and living room and smaller windows in bedrooms, storage rooms and bathrooms. Moreover, the impact of the regulation is evident in sizes of windows in the architectural design of that period (Figs. 5, 6 and 7).

By 1995, this rule was no longer included in the BR. Instead, the window and daylight access, still a part of the regulation of the energy demand, became a part of extensive calculation of energy supply and demand. In 2015, BR required a glazed area of 15% of the floor area of the central living spaces such as the kitchen or living room.

In 2018, the regulation reintroduced the rule of 10%, but included a guideline in order to make sure that daylight intake actually did have the possibility to enter the space on discussion. As an alternative to this rule, a new rule was introduced, inspired by European standards, where sufficient amounts of daylight can be documented by calculating the interior illuminance from daylight is 300 lx or more at least half of the relevant floor area for at least half of the daylight hours (BR18, §379, subsection 2). This documentation is calculated in simple simulation programs, all mainly in relation to engineering calculation strategies. This leaves the architect with very little impact on the actual daylight design. It also eliminates most of the qualitative approaches, where the architect traditionally is very influential. From BR 2008, a progressive view to the surroundings has been required. In earlier regulations, this was only required in workspaces.

As the review and Fig. 7 show, daylight and qualities stemming from daylight are a concern in the 1939 regulation. Here sunlight in the interior of residential housing is enhanced and described as a quality bringing the orientation of the building into focus. This continues in the Building

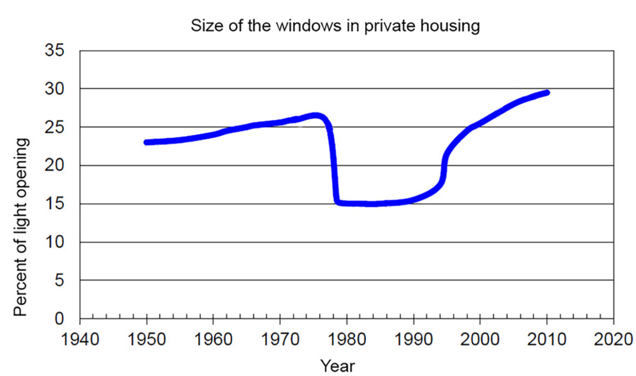

Fig. 5 Permitted size of windows according to the Danish Building Regulations. Source: Logadottir A et al. (2013) *Dagslys i boliger*. SBi-rapport 2013:32. Copenhagen: Statens Byggeforskningsinstitut, Aalborg Universitet

Regulations from 1961 until 1982. In the 1995 regulation, sunlight was not mentioned. When sunlight turns up again in 2008, it is with reservations for creating overheating. This indicates a shift in concern to light, where sunlight is no longer a positive spatial element that is important to include, but a possible nuisance that can create problems. This is further stressed in the Building Regulation from 2018, which lists the aspects of light you have to take into account when designing and constructing buildings: *daylight is best utilized as a light source, unnecessary energy consumption is avoided, unnecessary heat supply to the rooms is avoided, nuisance to direct solar radiation can be avoided, glare nuisance is minimized* (§377, subsection 2). Five statements where only the last relates to vision and the visual environment.

Fig. 6 Social housing *The Blue Corner*, 1988. Architect: Vandkunsten, Copenhagen. Photo: Louise Grønlund

Discussion

The review of the Building Regulations over 175 years shows that they seldom treat daylight as a topic in on its own right. That does not mean that daylight has not been regulated, but is typically subordinate to other agendas, mainly fire safety, health and energy. Daylight, and for that matter other issues in regulations, are often driven as part of a political agenda reflecting the current problems or discussions in society, scientific knowledge such as medical knowledge on health and technological opportunities such as computation possibilities allowing complex calculations of light distribution and energy consumption. That is also illustrated at present, as the overall driver is the agenda of sustainability and reduction of energy consumption.

Fig. 7 Social housing *The Blue Corner*, 1988. Architect: Vandkunsten, Copenhagen. Photo: Louise Grønlund

Many elements of the early requirements continue in the latest regulations, but the emphasis on daylight qualities does not. Vision has not had a very prominent position in building regulation. The regulation from 1939 is the one that stresses qualities related to vision the most. It is worth noting that the purpose of light in our homes, namely our ability to see the space we occupy as well as the things we surround ourselves with, is not mentioned in any of the 14 regulations reviewed. It is only defined as quantity, either as opening area in relation to the space or as lux, whereas qualities such as shadow patterns, the directionality of light, adaptation and contrast are not included.

Health has been a theme in all the building acts though not very explicitly. In the former regional or local building acts such as the early building laws of Copenhagen, minimum distances between buildings on the site were required, allowing a minimum of daylight and air circulation in order to prevent the spread of illness. Health as linked to wellness is first seen in the 1939 regulation, where light and sunlight are emphasised as important elements in a dwelling. In the Danish Building Act after 1960 it is an explicit aim but have been rather vaguely treated in the Building Regulation at least when it comes to daylight. Within the latest 20 years new knowledge on the non-visual effects of light have emerged. That has led to an awareness of the crucial impact of daylight on human health and demands for healthy daylight solutions.

The introduction of heat loss and the energy framework as some of the most dominant requirements in the regulation mean that daylight qualities and the visual environment gradually play a reduced role in daylight design. It is evident that there was a need to lower energy consumption because of the oil crises of the 1970s, and sustainability the climate crisis of today are also circumstances to be dealt with. However, bringing the calculation to the fore implies that the architectural daylight design is now made in an excel sheet and in energy simulation programs.

Assuming building regulations are a regulating technology that is non-neutral implies that the way we have to work with daylight when complying the regulations influences the way we understand light and reduces the visibility of some of its properties due to these tools. In this case the visual qualities of light pivotal for the visual indoor climate and the spatial qualities that depends on shadow pattern, directionality of light, adaptation and contrast are the reduced. In addition, during this process the responsibility for daylight design changes hands from the architect to the engineer and leaves us with a rather unilateral approach where daylight impacts on the visual environment and the spatial are reduced. This leads to the question of how to include all the relations that daylight design affects in an intelligent way in relation to vision, health and energy in future daylight design.

Conclusion

Reviewing the 14 Danish Building Regulations illustrates how the understanding of daylight in relation to the built environment has changed. The different requirements on daylight design vary through time and reflect the political agenda of each specific historical period from fire protection to climate crisis. This emphasises how daylight is subject to changing agendas; however, it is rarely an agenda on its own.

The understanding of daylight and its role in the built environment varies over time. The first regulations that had an impact on daylight penetration in housing were the regulations defining the heights and the distance between housing. The regulation affected potential obstructions to daylight but were included in the regulation to minimize the spread of fire. Later the density of urban housing was also regulated in order to improve health. The knowledge on the impact of sunlight on health made the regulation pair daylight and health. Sunlight penetration, natural ventilation and view were important aspects that supported the intention of the building regulation to promote people's health. When the energy crisis hit Denmark, the rules regarding energy consumption were tightened. Since daylight apertures not only let light in, but also give rise to heat loss, rather severe restrictions were imposed. Subsequently, the building regulation has regulated daylight through considerations that are related to energy consumptions.

Designing daylight aperture as an integrated part of architecture has been one of the core elements of architectural design throughout history. Traditionally it has been a subject of interest concerning aesthetics, articulating distinctive atmosphere as well as supporting specific functions. With the focus on energy, daylight has become a subject for an engineering calculation, carried out in various simulation programs.

Defining light through physics, light is described as part of the electromagnetic spectrum with an effect on human vison, health and furthermore on aspects related to energy. By prioritising energy aspects, the focus on human vision and health is put aside. In addition, the window as an instrument to create a visual environment supporting both health and vision is not prioritised. The future daylight discussion will most likely continue in the field of energy, but by taking new steps into discussions on sustainability and climate changes new approaches could be useful. A closer look at human needs might take the discussion on daylight back to a broader understanding of daylight and reintroduce a holistic approach to designing with daylight.

Acknowledgements Engineer, senior researcher Kjeld Johnsen and student of architecture Vilhelm Carlström have kindly contributed to this article.

Declarations

Conflict of interest The authors declare that they have no conflicts of interest.

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