14 The Thermal Indoor Environment of Danish Detached Houses—Past, Present and Future

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Abstract

Danish detached houses have shown a new tendency in terms of the thermal indoor environment. On 13.4% of houses built after 2000, problems regarding overheating have been reported by the owners. In addition to this, we stand before climate changes resulting in rising temperatures, which will increase the problem of overheating in the indoor environment even further. Since 1979, the energy requirements of the Danish Building Regulations (BR) have been tightened regularly, causing increased focus on re-insulation and sealed constructions. But as we are now experiencing the consequences of the tightened requirements regarding problems of overheating in new and energy-retrofitted houses, it is urgent to assess the Danish Building Regulations' influence on the thermal environments of Danish houses. This paper investigates the consequences of rising outdoor temperatures on the indoor temperatures of Danish detached houses providing state-of-the-art on the subject. Through studies of the Danish Building Regulations, the paper examines how we ended up with overheated houses in the first place. Furthermore, it discusses the influence of the Danish 'Design Reference Year' (DRY 2013) on indoor temperatures in the future. Finally, the paper points towards different solutions, which could decrease the risk of indoor overheating and improve the thermal indoor environment.

Keywords

Thermal indoor environment · Indoor temperatures · Detached houses · Overheating · Danish building regulations · Design reference year · DRY 2013

14.1 Introduction

Research has recently revealed a shift in challenges regarding thermal comfort in Danish detached houses. A survey among Danish house owners carried out by the foundation Realdania shows that houses built before 2000 typically deal with problems of draught and cold, whereas houses built after 2000 are more inclined to deal with problems of overheating (Danskerne i det byggede miljø 2022, p. 73).

Likewise, overheating is a problem in energy-retrofitted houses. According to the Danish Energy Agency, overheating is a consequence in 22% of energy-retrofitted detached houses (Pedersen et al. 2015, p. 26). It is often seen in cases of re-insulation due to highly sealed, insulated facades with a lack of ventilation (Marsh et al. 2013). This gives rise to the question: how

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do we design and retrofit our houses in a way that does not only focus on energy consumption but also considers the indoor environment?

If the way we build today does not fit the current climate, we are in for a serious challenge with an expected temperature rise of approximately 3.4 °C within this century (*Temperature and climate change* no date; *Data i Klimaatlas* no date). Today we see a tendency to the demolition of older houses in favour of new builds simply because it can be more affordable to start from scratch rather than renovate an existing house. In 2016, around 1000 houses were replaced by new standard houses (Nørgaard no date). Houses from the 1960s and 1970s are at stake because they typically do not meet the current energy requirements and may be too cold in winter. However, in the future, the tendency could shift to the demolition of houses that are too hot in summer. Increased demolition and construction activity could fuel climate change and accelerate rising temperatures—a vicious circle.

This paper assesses the relationship between Danish Building Regulations and thermal indoor environmental challenges in Danish detached houses. Through studies of the Danish Building Regulations and the so-called Design Reference Year (DRY 2013), it is investigated how we ended up with houses that overheat.

Furthermore, the paper discusses the consequences of rising outdoor temperatures on indoor temperatures by providing a state-of-the-art based on a literature review of texts and papers that deal with climate change and its influence on indoor environmental conditions. The literature review is combined with the preliminary results from an ongoing research project concerning the thermal indoor environment of Danish detached houses taking place at Aarhus School of Architecture.

14.1.1 Where Did We Go Wrong? Danish Building Regulations of the Past 60 Years

To understand how we in Denmark went from houses that are too cold to houses that are too hot, we could for one, look at the Danish Building Regulations of the past 60 years.

The first national Building Regulations were launched in 1961 and held modest requirements for a minimum amount of 50 mm of thermal insulation in the outer walls and roof. Furthermore, windows should have two layers of glass with a gap of at least 12 mm (Ventzel Riis et al. 2021, p. 35). Until the 1960s, the building legislation did not focus on energy use or the indoor environment but solely dealt with matters of craftsmanship, building construction and materials (Ventzel Riis et al. 2021, p. 35).

The majority of the Danish building stock does not live up to current standards of energy use, simply because it was built before energy requirements were implemented in the Danish Building Regulations (Ventzel Riis et al. 2021, p. 35). In 1979 (BR77) the requirements for thermal insulation were tightened as a result of the oil crisis, which caused increasing energy prices and, with it, an economic motivation for thermal insulation. At the same time, a limit was introduced to the percentage of glass in the facade to a max. of 15% of the building's floor area (Ventzel Riis et al. 2021, p. 36).

This shift most likely had an impact on the thermal environment in Danish houses built after that time. This can be observed in a survey made by Realdania, in which 7132 house owners were asked about their indoor environment. 24.9% of owners of houses built between 1930 and 1959 reported problems regarding cold and draught, whereas only 14.6% of owners of houses built between 1980 and 1999 reported these problems (Fig. 14.1) (Danskerne i det byggede miljø 2022, p. 73).

The 10 percentage point drop between 1959 and 1980 shows that problems with cold and draught evidently have decreased significantly during these 20 years, which could be explained by the emerging focus on thermal insulation and smaller windows in the 1970s and 1980s.

It should be noted that the results of the survey depict the situation in the houses today and not at the time when the houses were built. Furthermore, it should be added that the Realdania survey neither reveals information on the

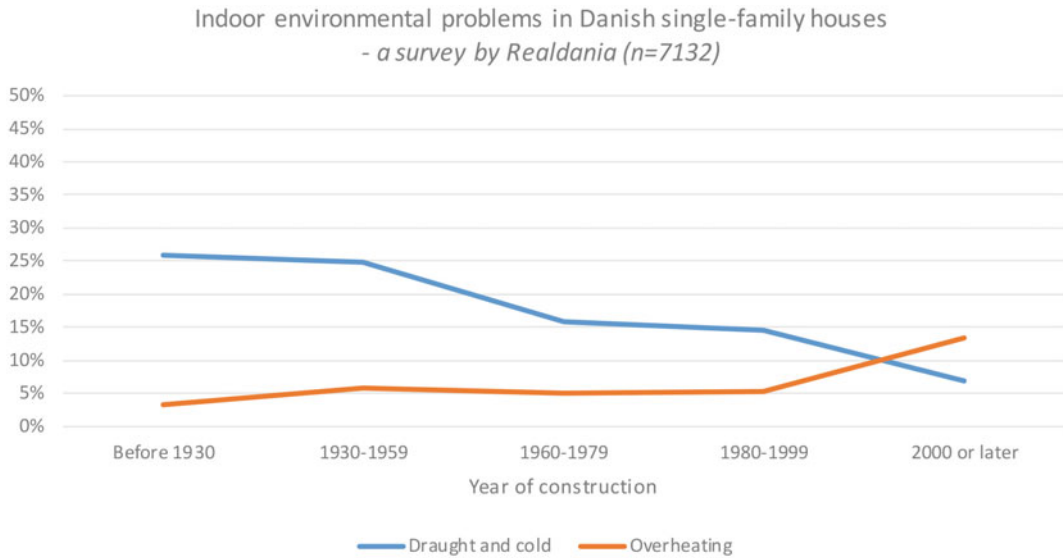

Fig. 14.1 Percentage of Danish houses with problems of either draught and cold or overheating based on the Realdania survey. (Danskerne i det byggede miljø 2022, p. 73)

condition of the houses nor the age of the owners, both of which have an enormous impact on responses in a survey about the indoor environments, which will be discussed further in this paper.

14.1.2 From One Indoor Environmental Challenge to Another

A lack of insulation requirements in the Danish Building Regulations could be one of the explanations why houses in Denmark built up until the 1970s are remarkably colder than houses built in the years hereafter. Even though many of the houses have been retrofitted since then, the current situation still reflects this picture (Danskerne i det byggede miljø 2022). The cold houses can partly be explained by a lack of thermal insulation, but also parameters such as airtightness and the quality of the construction are important factors when it comes to the thermal indoor environment. Houses built 100 years ago are likely to be less airtight and leaking facades and windows create a natural airflow through the house, also known as infiltration. Moreover, constructions of poor quality enable the transfer of heated indoor air to the outside (Lovell 2010).

The oil crisis in the 1970s demanded controlled building envelopes to optimize the energy for heating the building stock, which simultaneously resulted in a warmer indoor environment in general. Since 1979 the energy requirements of the Danish Building Regulations have been tightened regularly causing increased demands for thermal insulation and sealed constructions. This means that even houses built after the energy crisis in the 1970s can be far from today's standards in terms of energy use.

In 1995, the requirements for window sizes were changed from the previous maximum of 15% of the floor area to 22% (Ventzel Riis et al. 2021, p. 36). The enlarged allowed window sizes combined with the increasing focus on sealed and insulated facades have likely caused an increase in indoor temperatures of Danish detached houses.

When looking at the aforementioned Realdania survey we see that 14.6% of houses built between 1980 and 1999 experience problems in terms of cold and draught, whereas only 6.9% of houses built after 2000 show these problems. On the other hand, for houses built after 2000, another problem seems to be at stake as the survey shows that 13.4% of these houses have problems with temperatures that are too high. As this is only a problem in 5.2% of the houses built between 1980 and 1999, there is an indication that the requirements introduced in the Building Regulations during the 1990s have had an impact on the indoor environment. From a comparison of the development in the Building Regulations and the indoor environmental challenges of Danish detached houses, it seems that the thermal conditions have shifted from problems of cold and draught to problems related to overheating, which partially relates to the changed requirements of the Building Regulations.

14.1.3 Indoor Overheating and Health Effects

The Danish Meteorological Institute predicts the future weather in Denmark to become "warmer, wetter and wilder" (*Vejret i Danmark bliver varmere, vådere og vildere* no date). For example, they foresee an increase in summer nights with temperatures above 20 °C as well as more and longer heatwaves defined as three coherent days with temperatures above 28 °C (*Vejret i Danmark bliver varmere, vådere og vildere* no date).

More frequent heatwaves can create health risks in the future as a clear connection between higher outdoor temperatures and mortality has been detected (Vardoulakis et al. 2015). In 2003 the most severe heatwave since 1500 occurred and was estimated to cause 70.000 excess deaths in Europe. If emissions continue unaffected, heat waves as intense as the European one in 2003 are expected every other year by the 2040s (Vardoulakis et al. 2015).

Though a connection between high outdoor temperatures and excess deaths has been observed, this link cannot be directly transferred to indoor temperatures. Indoor temperatures depend on the construction type, the indoor climate devices and the residents of each dwelling and can vary significantly from the outdoor temperature. Thus, conclusions on the health effects brought on by indoor temperatures are harder to determine (Vardoulakis et al. 2015). However, additional research indicates that indoor overheating can cause dehydration, heart problems and increased mortality—particularly among elderly people and other vulnerable populations (Ortiz et al. 2020).

As for Danish detached houses, the majority of which are only ventilated naturally (Videncenter for Energibesparelser i Bygninger 2017), frequent heatwaves with temperatures above 28 °C will most likely result in difficulties meeting the requirements of the Danish Building Regulations in terms of indoor overheating. They set a yearly maximum of 25 hours above 28°C in housing (*BR18* no date), and since the number of heatwaves is expected to rise from 2 to 9 days per year in Denmark (*Vejret i Danmark bliver varmere, vådere og vildere* no date), keeping down the indoor temperatures by ventilating with outdoor air only could become a challenge (Petersen et al. 2014).

When looking at the dwelling not only as a shelter from cold but also from warm weather, higher indoor temperatures as a result of elevated outdoor temperatures can cause problems for Danish residents. Escaping a heatwave can become harder in the future if indoor temperatures are affected by outdoor temperatures, which will be the case for many Danish detached houses not equipped with air-conditioning or mechanical ventilation with integrated cooling.

Although it cannot be stated directly how indoor overheating affects the residents' health, rising outdoor temperatures and future heatwaves will undoubtedly affect indoor temperatures with a high risk of overheating houses, which could potentially lead to some of the health risks mentioned above. Improvements in the thermal indoor environment of detached houses could thus lead to a decrease in incidents of overheating, which might contribute directly or indirectly to sustainable development goal 3.4 "By 2030, reduce by one-third premature mortality from non-communicable diseases through prevention and treatment and promote mental health and well-being" (Martin no date).

14.1.4 Overheating of Danish Houses

Being a Nordic country, one might think that Denmark was outside the risk zone of overheated houses, but paradoxically, even Danish dwellings experience overheating. The Realdania survey showed that this problem appears in 13.4% of houses built after 2000 (Danskerne i det byggede miljø 2022, p. 73). It is, however, important to remember that the investigation by Realdania is based on a survey in which house owners responded to a questionnaire about their indoor environment. This means that the results of the survey are somewhat subjective and do not necessarily match the actual number of houses experiencing overheating if measures were compared to the requirements of the building regulations.

The current Danish Building Regulations (BR18) define overheating in housing as the number of hours the temperature exceeds, respectively, 27 °C and 28 °C. Under the circumstances that the dwelling can be vented, the indoor temperature is allowed to exceed 27 °C up to 100 hours per year and 28 °C up to 25 hours per year (*BR18* no date). The limit has been increased since the former Building Regulations (BR15), which had a limit of, respectively, 100 and 25 hours exceeding 26 °C and 27 °C.

A change of the allowed temperatures was suggested in an analysis of the requirements for the thermal environment in BR15 for the Danish Energy Agency, as the requirements were difficult to meet in dwellings ventilated naturally (Petersen et al. 2014, p. 9).

The thermal indoor environment for new buildings is calculated from the so-called 'Design Reference Year' (DRY 2013), which is based on weather data for the years 2001–2010 (*BR18* no date). As DRY 2013 has outside temperatures of 28 hours above 26 °C and 11 h above 27 °C, the analysis concludes that it would cause difficulties not to exceed these temperatures in dwellings ventilated by outside air (Petersen et al. 2014, p. 9). Consequently, the allowed limit to maximum indoor temperatures has been raised in the current building regulation (BR18). It can seem strange that the temperatures defining overheating in the Building Regulations are changed as a consequence of difficulties meeting the requirements. Though, if new houses were to stay below the allowed maximum temperatures they would require mechanical cooling or air-conditioning, as natural ventilation would not be sufficient to cool down the houses in the warmest periods. However, as we are experiencing rising temperatures it is not a sustainable solution to continually raise the limit values of allowed indoor temperatures.

14.1.5 Climate Change and Thermal Indoor Environment

One should bear in mind that the DRY 2013 is based on 12 years old weather data and as we are in the midst of climate changes, which will probably cause a severe temperature rise, we are facing even higher temperatures in the future.

Comparing the temperatures of DRY 2013 to the temperatures of the past ten years (2013–2022), it becomes clear that the data used for DRY 2013 is not up to date. The average temperature of DRY 2013 is 8 °C, whereas the average temperature of today (the mean temperature of the years 2013–2022) is 9.3 °C (*Vejrarkiv* no date).

That is a temperature difference of + 1.3 °C in 12 years alone. In comparison, the average temperature in Denmark has increased by 1.5 °C since the 1870s (*Temperature and climate change* no date; *Data i Klimaatlas* no date). In other words, the temperature difference between the DRY 2013 data and the current temperatures is almost as big as the temperature rise of the past 150 years.

The Design Reference Year is constructed from more years meaning that months of representative average temperatures are taken from the period 2001–2010 and gathered into one year. The Design Reference Year has been constructed from the following months (Fig. 14.2).

In DRY 2013 months of extreme weather have been excepted as the reference year functions as a standard value that can be used for simulations of future buildings, e.g. However, it might not be a bad idea to integrate weather

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Year	2009	2009	2006	2010	2006	2005	2009	2009	2009	2008	2010	2009

Fig. 14.2 Design reference year (DRY 2013) is constructed from months chosen from the period 2001–2010 as shown in the figure above. (*Danish Design Reference Year—PDF Free Download* no date)

extremes into the calculations of future design reference years as the climate change will cause more extreme weather (*Temperature and climate change* no date; *Data i Klimaatlas* no date).

The indoor environment of buildings built at the moment is thus calculated from weather data, which neither matches the climatic conditions today nor reflects the climate change and temperature rise we are facing in the future. The consequence could be houses that get warmer in reality than expected from the calculations, which means that the residents will experience a significantly higher amount of hours of overheating than expected. In other words, a gap between the calculated and observed indoor environment is likely to occur not only in houses that are being built now but also in houses that are to be built in the years to come.

14.1.6 The Gap Between Measured and Perceived Indoor Environment

Besides a gap between the calculated and the observed indoor environment, it can be argued that a gap between the *measured* and *perceived* indoor environment is also evident and plays a role in recognizing cases of overheating.

The scientific paper by K. J. Lomas et al. '*Dwelling and household characteristics' influence on reported and measured summertime overheating: A glimpse of a mild climate in the 2050's*' concludes that questionnaires concerning the indoor environment on one hand "are a useful tool for identifying thermal discomfort or the prevalence of overheating", but on the other hand, they are likely to underestimate the general prevalence of overheating in homes (Lomas et al. 2021, p. 11). The paper explains further, how older people are less inclined to report overheating than younger people, and therefore questionnaires answered by people older than 75 can be misleading when compared to the measured thermal indoor environment.

As the measured and the perceived thermal indoor environment can be two very different things, both can be correct even if they do not match each other. The perceived thermal indoor environment or thermal comfort is completely dependent on the person perceiving it. The same measured temperature can be too warm for one person and too cold for another. The perception of temperatures is closely related to age, gender, physics, clothing and activity level, but also the heat sensitivity of a person and the previously experienced temperature play an important role in the perception of a given temperature (Lomas et al. 2021, p. 4).

When the prevalence of overheating reported by people older than 75 can be misleading it has to do with the fact that people over 75 generally tend to have a higher comfort temperature than younger people due to their lower metabolic rates. Thus, they simply feel comfortable with high indoor temperatures, which could otherwise be classified as 'overheating' (Lomas et al. 2021, p. 11). Based on the questionnaires and monitored indoor climatic conditions, the article states that the monitored overheating was far higher than reported by the residents. In cases with residents older than 75, overheating was monitored in one-third of the dwellings, while the reported prevalence was only 8% (Lomas et al. 2021, p. 10).

This suggests that high age and heat sensitivity are closely linked to each other and that the residents' age is of great influence on the responses given in a questionnaire. If these conclusions are compared to the aforementioned Realdania survey, showing that 13.4% of houses built after 2000 suffer from overheating, it leads to the speculation of how the age factor comes into play here. As the survey is not backed by monitoring of the indoor environment, the responses of the residents stand alone and given that some of the houses built after 2000 have residents over 75 of age, the number of houses experiencing overheating could potentially be even higher than the stated 13.4%.

14.1.7 Renovation or Demolition

In Denmark, houses with low energy efficiency tend to be replaced by new houses with a higher level of energy efficiency, (Nørgaard no date) but according to the Realdania survey, more than every eighth of these houses suffer from overheating. Hence, in the future, it is very likely that we will experience fewer problems related to cold and draught but instead will have an increase in overheating-related problems in Danish houses.

During this century, the average annual temperature in Denmark is expected to rise by 3.4 °C (with an uncertainty range from 2.9 to 4.3 °C) from 8.4 °C (the average temperature over the years 1981–2010) (*Temperature and climate change* no date; *Data i Klimaatlas* no date) (Fig. 14.3).

With rising temperatures due to climate changes, it is most likely a question of time before overheating of Danish houses becomes a severe problem. As heating a house is known to be easier than cooling a house (Heschong 1979, p. 15), the houses built today could become targets for demolition in the future.

As the percentage of new buildings in Denmark each year adds up to 1%, it only constitutes a small part of the total building stock (Bech-Danielsen et al. 2018, p. 14). Around 70–80% of existing buildings are expected to still stand in the year 2050 ('Bygherreforeningen bidrager til regeringens klimahandlingsplan' 2020). In addition, a report by the Danish engineering company Rambøll published in 2020 shows that it is more advantageous to renovate than to demolish and build new—both in terms of economics and environmental impact (Sørensen and Mattson 2020, p. 6). Thus, demolition and new builds are hardly the most efficient way to reduce emissions

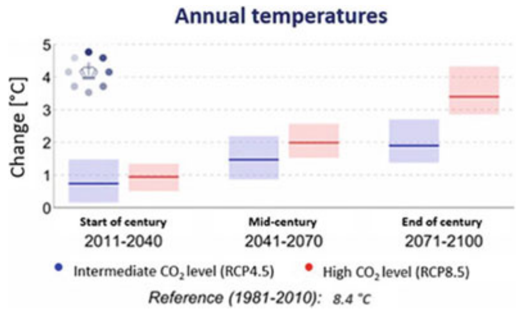

Fig. 14.3 Denmark's expected temperature rise during this century for two different scenarios (RCP4.5 and RCP8.5). (*Temperature and climate change* no date)

and solve the climate crisis. Instead, we should look for solutions for the retrofit of houses which have high energy use and with it a large potential for energy saving.

As the first actual energy requirements were implemented in the Danish building regulations in 1979 (BR77), the majority of buildings built before 1980 do not meet these energy requirements (Dansk Byggeri 2019, p. 15). Housing built before 1980 accounts for 35% of the total building stock and especially the housing stock contains a large potential in terms of energy savings through retrofit. Detached houses from the 1960s and 1970s play an important role in this matter as they account for a great part of the total amount of detached houses in Denmark. Between the years 1960 and 1979, 450,000 new detached houses were built, which corresponds to the same amount built within the 100 years before that (Lind and Møller 1996, pp. 136–137). Today detached houses constitute around 40% of the total amount of single-family houses in Denmark and adds up to 1 million in total (Sode and Jensen 2018; *Typehuse fra 60'erne og 70'erne renoveres efter ny metode* no date). Therefore, it would be obvious to look towards detached houses from the period 1960–1979 as a target for retrofit.

14.1.8 Indoor Environmental Retrofit

For a building to be sustainable, it is not enough that it meets certain requirements for energy consumption, it should also be healthy and comfortable to live in. Thus, instead of speaking exclusively about energy retrofit, to a greater extent, we should operate with the term ‘indoor environmental retrofit’.

According to the Danish Energy Agency, overheating is a consequence in 22% of energy-retrofitted detached houses (Pedersen et al. 2015, p. 26). The problem is often seen in cases of re-insulation due to highly sealed, insulated facades with a lack of ventilation (Marsh et al. 2013).

However, recent research indicates that twentieth century Danish houses possess architectural features, which enable the regulation of the indoor environment. The regulation can even happen passively that is by means of non-electrical devices only (Lyhne 2021). Utilizing these passive architectural features as an integrated strategy could potentially serve as a solution to indoor environmental challenges (Kongebro 2012). Moreover, passive architectural solutions would simultaneously bring down the energy use spent on the regulation of the indoor environment. Therefore, the starting point for a sustainable renovation should be an analysis of the existing house including architectural features that impact the thermal conditions.

When renovating detached houses built between 1960 and 1979, one should be aware of their thermal advantages as well as thermal disadvantages. The houses from this period are characterized by relatively big windows, which are a primary reason for energy loss on one hand, and on the other, a source for optimal daylight conditions. Additionally, the big windows could cause overheating, but an overhanging roof, which is also typical for this house type prevents direct sunlight from entering the house in summer when the sun angle is at its highest.

14.1.9 Research Methods

As part of an ongoing research project at Aarhus School of Architecture focusing on the indoor environmental conditions of Danish detached houses, case studies and semi-structured interviews have been carried out together with owners of nine houses that have undergone retrofits spanning from minor renovation works to complete house renovation projects (Rysz 2022). The houses are located in the mid and southern regions of Jutland and the owners are a mix of younger couples with children, senior couples and seniors living alone. In more cases, the respondees point towards architectural elements in their homes which influence the indoor temperatures and their thermal comfort.

Three of the cases show similar organization and orientation of functions: the living room and one or more bedrooms facing the garden to the west of the house (Fig. 14.4).

In one of the cases, a detached house from 1965, half of the house, the part containing the kitchen, eating area and living room, was renovated. In this case, it is not the newly renovated part but the non-renovated part of the house that experiences overheating in summer.

On the question of whether or not direct sunlight can be inconvenient during the day, the husband answers: “Yes, when I’m working from home. After four o’clock, especially in the sun during the summer months, I have to shut down. (…) It both gets too hot and it is bothering”.[1]

The problem of overheating in this case occurs in specific west-orientated rooms at certain times during the day. The fact that only the non-renovated part overheats indicates that other factors than energy-retrofit can lead to temperatures higher than desired and that in this case, the experienced overheating is closer related to the orientation of the room.

A respondee from one of the other cases told that she and her husband had the house built in 1968 and at that time they did not think much about the orientation of the house. “I actually don’t think we gave it much thought, because the architect turned the house the way he found best (…) I don’t really think we thought about that. To us, I think it was more a question of interior decoration and things like that”.[2]

[1] Translated from Danish into English by the author.
[2] Translated from Danish into English by the author.

Fig. 14.4 Three cases of detached houses from, respectively, 1965, 1968 and 1973. The three houses have a similar orientation of living rooms and bedrooms facing the garden to the west

The resident later told that the architect mentioned should be understood as a representative from a standard house company as no architect was involved in the building process of the house. As is the case for many detached houses in Denmark built in the 1960s and 1970s, the house in question here is a standard house, which can be defined as a house built from a set of drawings that have formed the basis for many houses in different locations. One of the consequences of the standard house, which is not designed for a specific plot, is that the orientation of the house can be more or less coincidental.

A third case, an architect-designed detached house from 1973, had a similar layout and orientation of functions with the living room and bedroom facing west, but here the residents did not experience problems in terms of overheating in summer. "Yes well, as for the thermal indoor environment, we are very happy with the big trees over there, they provide shading in summer. (…) The afternoon sun moves all the way around here, and in summer, when the sun is at its highest, the tree crowns ensure shading, and in winter, when the sun angle is a bit lower, they allow for daylight to enter. It actually works very well".[3]

The owners themselves enhance the tall trees in front of the living room and bedroom as a natural kind of sun shading and explain how they contribute to regulating their indoor temperatures. This case shows an example of how external objects can affect the indoor environment thermally. Besides the trees to the west, the house is equipped with an overhanging roof, which similarly serves as sun shading in summer when the sun angle is high. The house is designed with a displaced facade, which means that the size of the overhanging roof varies from room to room creating more or less shade inside. In this way, the roof has been used as a means to ensure larger eaves above the bedroom, and thus secure it from overheating in summer (Fig. 14.5).

From this research, it is not possible to conclude a relationship between the tendency of overheating and the level of retrofit that the houses have undergone. This is due to the number of houses and house owners included in the project as well as the format of the research. The semi-structured interview allows the interviewees to go in depth explaining the indoor environmental situation of their dwellings accompanied by their own experience of the thermal conditions, but the answers given will be strongly influenced by the thermal comfort criteria of each respondee and so the interviews do not form a solid base for general conclusions regarding indoor temperatures and overheating (Brinkmann and Tanggaard 2020).

The research project concerned collects data for measured temperatures and relative humidity in each case, which eventually will be paired with data from the interviews, but as the quantitative data is not accessible until the fall of 2023, this paper deals with the preliminary conclusions of the project, which for now, are based on the interviews alone.

[3] Translated from Danish into English by the author.

Fig. 14.5 Big trees and the overhanging roof of the detached house from 1973 provide sun shading in summer. The displaced facade creates an enlarged overhang above the bedroom preventing it from overheating

14.2 Discussion

As we already experience problems of overheating in Danish detached houses, the increase in outside temperatures as a result of climate changes will undoubtedly worsen this situation. Additionally, our current building regulation is based on weather data, which is neither up-to-date nor reflects the future climate with its foreseen temperatures. As the weather data behind the Design Reference Year (DRY 2013) is 12 years old, it creates a baseline for the calculation of the indoor environment of future houses that is too low compared to today's outdoor temperatures.

The average temperature at the end of this century is expected to be around 11.8 °C (*Temperature and climate change* no date; *Data i Klimaatlas* no date). In comparison, the average temperature of DRY 2013 is 8 °C. That is a temperature difference of + 3.8 °C, which corresponds to nearly 50%.

Research within the field of indoor environmental health calls attention to potential health risks of indoor overheating, such as dehydration, heart problems and increased mortality (Ortiz, Itard and Bluyssen 2020). As the majority of Danish houses are ventilated naturally (Videncenter for Energibesparelser i Bygninger 2017), a significant rise in outside temperatures will most likely affect the indoor temperatures, too. Furthermore, the future Danish weather is likely to entail frequent heatwaves, which will probably bring the indoor temperatures above the maximum values outlined by the Building Regulations and lead to difficulties in meeting their requirements.

Imagining that houses built in Denmark today will last for at least 80 years, they should thus be suited for temperatures remarkably higher than the temperatures we build for today (DRY 2013). However, the houses built today will not be able to manage such temperatures, as they already experience challenges in terms of overheating as it is. The Realdania survey shows that 13.4% of houses built after 2000 tend to overheat (Danskerne i det byggede miljø 2022). The worst-case scenario could be a need for demolishing these houses before the end of the century due to overheating. As demolition and new builds will cause increased energy consumption and carbon dioxide emissions, such a situation will only enhance the climate crisis.

A report by the Danish engineering company Rambøll shows that it is more advantageous to renovate than to demolish and build new—both in terms of economics and environmental impact (Sørensen and Mattson 2020, p. 6). Therefore, it would be beneficial to look for possibilities for the renovation of the existing housing stock in Denmark.

It is important to notice that overheating is also seen in cases of energy-retrofit, however, a case study carried out by the author shows cases of houses experiencing overheating in parts that have not been renovated. This finding indicates that just the orientation of the rooms influences the indoor temperatures significantly and that rooms oriented to the west are likely to overheat —a finding supported by other research studies

(Kolarik et al. 2019). Furthermore, the case study points towards existing architectural elements as contributors to the regulation of indoor temperatures. Hence, when renovating houses from the 1960s and 1970s it is of utmost importance that not only the energy efficiency but also the thermal indoor environment of the house is taken into consideration. This can be done through interviews with the residents and mappings of architectural elements that influence the thermal indoor environment and can prevent overheating. However, these means must be taken into consideration before the retrofit takes place for them to become tools in facilitating an optimal indoor environment from the beginning, rather than mending a poor indoor environment as a result of energy retrofit.

14.3 Conclusions

The research paper intended to investigate the consequences of rising outdoor temperatures on the indoor environments in Danish detached houses. Studies of the Danish Building Regulations and Design Reference Year (DRY 2013) combined with a literature review have shown that the foreseen temperature rise due to climate change can cause severe challenges regarding the indoor environments of Danish detached houses.

The research addresses an urgent need for an update on today's Danish Building Regulations as the Danish Design Reference Year (DRY 2013), is constructed from weather data, which does not match the temperatures we see today. DRY 2013 is used as a baseline for calculations of the indoor environment for new builds, but relying on temperatures significantly lower than the ones of today can consequently lead to higher indoor temperatures than calculated. This could be the case for the houses built after 2000 that suffer from overheating, but it could also be the case for future houses.

New houses have the benefit that the functions of the house can be orientated optimally in terms of the sun's path, which in itself can minimize overheating, but that is not the case for existing houses. For existing houses standing before renovation or energy retrofit, it is instead crucial that architectural elements, which influence the indoor temperatures are mapped and preserved or even developed as part of the retrofit. In these cases, the orientation of the house and its functions can rarely be changed, but elements providing sun shading, such as trees or an overhanging roof, can contribute to the avoidance of indoor overheating.

This paper focuses on Danish detached houses specifically, however, it is often easier to regulate the indoor environment of detached houses than apartments or terraced houses, simply because they consist of one single unit, whereas the other types mentioned are surrounded by other units. Thus, research concerning the indoor environment and overheating of other building types, such as apartments and terraced houses is encouraged as the thermal challenges could be even bigger here.

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