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Østergaard, Dorte Skaarup; Svendsen, Svend

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Theoretical overview of heating power and necessary heating supply temperatures in typical Danish single-family houses from the 1900s

Dorte Skaarup Larsen, Svend Svendsen*

**Corresponding author, Tel. +45 42 25 18 80, E-mail address: dskla@byg.dtu.dk.*

Technical University of Denmark, Department of Civil Engineering, Brovej, Building 118, DK-2800 Kgs. Lyngby, Denmark.

Abstract

As existing buildings are renovated and energy-efficiency measures are implemented to meet requirements for reduced energy consumption, it becomes easier to heat our homes with low-temperature heating. This study set out to investigate how much the heating system supply temperature can be reduced in typical Danish single-family houses constructed in the 1900s. The study provides a simplified theoretical overview of typical building constructions and standards for the calculation of design heat loss and design heating power in Denmark in the 1900s. The heating power and heating demand in six typical Danish single-family houses constructed in the 1900s were estimated based on simple steady-state calculations. We found that the radiators in existing single-family houses should not necessarily be expected to be over-dimensioned compared to current design heat loss. However, there is considerable potential for using low-temperature space heating in existing single-family houses in typical operation conditions. Older houses were not always found to require higher heating system temperatures than newer houses. We found that when these houses have gone through reasonable energy renovations, most of them can be heated with a supply temperature below 50 °C for more than 97% of the year.

Keywords: *Low-temperature district heating, low-temperature heating, single-family houses, design heat loss, design heating power, radiator over-dimensioning,*

1. Introduction

Single-family houses account for approximately 60% of the heated residential sector in Denmark [1]. When reductions in the heat consumption of Danish homes are planned, single-family houses are therefore very

important. In Denmark, approximately 40% of single-family houses are heated by district heating [1], which makes modern 4th generation district heating, with its low-temperature operation, a promising solution for improving the energy efficiency of the heat supply in areas with single-family houses [2,3]. The aim with 4th generation district heating is to get supply and return temperatures down to 55 °C and 25 °C, respectively. Such lowering of district heating temperatures will increase the efficiency of heat production and reduce the heat loss from the pipe systems. This is of great importance in low-density building areas, where the relative heat losses from district heating pipes are often high.

Earlier studies have investigated the possibility of supplying energy-efficient buildings areas with low-temperature district heating (LTDH) [4,5] and described how LTDH networks can be designed [6]. However, only a few studies have investigated the possibility of heating existing houses with LTDH. These include investigations into the potential for using LTDH in a number of single-family houses from the 1970s, in an area of single-family houses with floor heating from the 1980s, and in an old apartment building in Copenhagen [7–11]. The use of low-temperature heating has also been studied in buildings supplied by natural gas or by heat pumps [12–15], but such studies may not provide good references for investigations on LTDH, because other heat sources do not necessarily require a similar focus on achieving low return temperatures.

Most of these investigations on low-temperature district heating were case studies. While case studies can provide good references, they are not necessarily representative of the general building mass. The aim of this study was therefore to provide new knowledge about the potential for the use of LTDH in existing single-family houses in general. The results of the study provide a new theoretical foundation for future discussions on the potential of low-temperature district heating.

1.1 Over-dimensioning of radiators

It is of great importance to ensure that occupant comfort is not compromised if district heating temperatures are lowered. This implies that the radiators must be able cover the heating demands in the

existing houses with a lower temperature set than the current one. For this to be possible, the radiators must be over-dimensioned compared to the current heat demand in the buildings. Four main facts suggest that the existing radiators could be over-dimensioned to an extent that allows the heating system temperatures to be lowered for large parts of the year:

1. The radiators were dimensioned for a very low outdoor temperature that almost never occurs
2. Internal heat gains from electrical equipment has increased
3. Radiator dimensions are often larger than required because they come in a limited number of sizes
4. The energy demands of many existing buildings have been reduced due to energy renovation.

Over-dimensioning of radiators has been investigated in a number of studies. In Denmark, the effects of operating district heating networks with lower temperatures have been tested in various studies since the late 80s [16–20]. Based on measurements of supply and return temperatures in the networks, the studies conclude that it is technically possible to provide space heating in existing buildings with supply temperatures as low as 60-65 °C even in cold periods. This indicates that the radiators in the buildings investigated were over-dimensioned, because the radiators were originally dimensioned for higher supply temperatures. These findings have been supported by more recent studies of a number of district heating networks where the annual supply temperatures were successfully reduced through continuous temperature optimization and improved building installations [8,10,21]. In Sweden, a number of field studies have investigated and improved the heating system operation in typical multifamily buildings [22–24]. The studies found that the heating system temperatures in the multifamily buildings investigated were around 50 °C/30 °C and 45 °C/35 °C even at outdoor temperatures around 0 °C [23,24]. These findings indicate that traditional dimensioning of radiators according to the temperature set 80 °C/60 °C often caused radiator sizes to be large enough for the buildings to be heated by low-temperature heating for large parts of the year.

In this study, we investigated over-dimensioning of radiators from two different perspectives. First, the design heating power in the typical Danish single-family houses was compared to the current design heat

loss to evaluate whether the installed radiators are over-dimensioned compared to current design standards. Secondly, the heating system temperatures necessary to cover the heat demand in the houses at typical outdoor temperatures were calculated. The design conditions were compared to the temperature requirements during a typical year to evaluate whether the radiators are over-dimensioned for the actual operation requirements. Based on these analyses, the study would provide new insights on the definition of over-dimensioned radiators. Furthermore, the study provided new knowledge on the condition of heating systems in typical existing-single-family houses.

2. Danish single-family houses and district heating

Typical single-family houses that represent the Danish building mass were identified in the TABULA project, which was aimed at developing typical building typologies for a number of European countries [25,26]. In the Danish contribution to the project, Danish homes were divided into categories depending on their construction period, changes in the building code requirements, and shifts in building traditions. The study looked at single-family houses constructed from before 1850 and down to 2011.

Not all categories of single-family houses are of equal interest for a study on low-temperature district heating. As Figure 1 shows, the single-family houses constructed after 2000 only form a small percentage of the total single-family houses in Denmark. Furthermore, only a small percentage of the single-family houses from before 1900 and after 2000 are heated with district heating. This study therefore focuses on typical Danish single-family houses constructed during the 1900s.

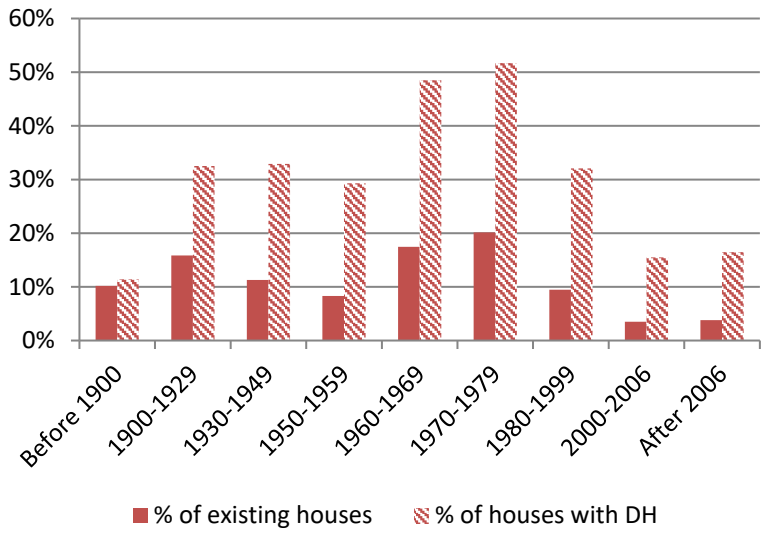

Figure 1. Danish single-family houses by year of construction and heating source [1]

In the TABULA project, the houses constructed in the 1900s were divided into six categories of typical single-family houses. Each category was exemplified by an actual house representing the typical architecture, geometry, and construction of the given time period. The investigations reported in this paper were based on these actual houses. Key data describing the houses are given in Table 1. Basements are assumed not to be heated, and basement temperatures are assumed to be equal to dimensioning ground temperatures.

Table 1 Key data for TABULA houses from 1850 to 1998 [25]. All areas are given with external measures**.**

	1850-1930	**1931-1950**	**1951-1960**	**1961-1972**	**1973-1978**	**1979-1998**
						
Heated area [m^2]	112	140	106	180	138	143
Roof area [m^2]	94	89	106	180	150	143
Wall area [m^2]	98	109	101	121	97	124
Floor area [m^2]	66	88	106	180	138	143
Window area [m^2]	15	22	28	34	22	25
Floors	2	2	1	1	1	1
Basement	Full	Full	Full	None	None	None
Ventilation	Natural	Natural	Natural	Natural	Natural	Natural

3. Method

3.1 Methods for the calculation of design heat loss

The design heating power in each of the representative single-family houses was estimated based on the design heat loss of the house at the time of construction. The procedure for calculating the design heat loss changed during the 1900s. The first Danish guideline for the calculation of dimensioning heat loss in buildings was published in 1953 by the Danish Engineering Association [27]. In the following years, it was printed in several editions, but the only major changes occurred in the version that was published in 1965 [28]. This guideline remained the main standard for the calculation of dimensioning heat losses in buildings until 1977 when the first version of Danish standard DS 418 was published. New versions of this standard were published in 1986, 2002 and 2011 [29,30].

Common for all the published standards is that the design heat loss of a building is calculated as the sum of transmission heat loss through the building components and ventilation heat loss. In the current standard, the transmission and ventilation heat losses are calculated using Equations (1) and (2) respectively.

$$\Phi_{trans} = \Sigma\, U \cdot A \cdot (T_i - T_e) + \Sigma\, \Psi \cdot l \cdot (T_i - T_e) \qquad \text{Eq. (1)}$$

where
Φ_{trans} is the transmission heat loss
U is the U-value of the building component
A is the external area of the building component
Ψ is the linear heat loss coefficient for windows and foundations
l is the length of connections around windows and foundations
T_i is the indoor temperature (20 °C)
T_e is the external temperature (−12 °C for air and 10 °C for ground).

$$\Phi_{vent} = c \cdot \rho \cdot \frac{q_a}{1000} \cdot A \cdot (T_i - T_e) \qquad \text{Eq. (2)}$$

where
Φ_{vent} is the ventilation heat loss
c is the heat capacity of air (1005 J/kg K)
ρ is the air density (1.205 kg/m^3)
q_a is the air change rate (0.3 l/s pr. m^2 heated floor area)
A is the heated floor area.

The calculation procedure was modified slightly from the publication of the first standard to the current. The old guidelines applied dimensioning temperatures of 18-22 °C indoors and −15 °C outdoors, while more recent standards prescribe an indoor temperature of 20 °C and an outdoor temperature of −12 °C. Furthermore, the areas of building components were based on internal measurements in the old standards, while more recent standards mainly apply external measurements. In the old guidelines additional heat losses were included for rooms with several building elements facing the external air or for roof constructions that were affected by heat radiation to the sky. Linear heat losses were not included in the older standards. Equation (3) shows the procedure for the calculation of transmission heat loss from a building according to the oldest standard from 1953.

$$\Phi_{trans} = f_1 \cdot \Sigma U \cdot A \cdot (T_i - T_e) \cdot f_2 \qquad \text{Eq. (3)}$$

where
Φ_{trans} is the transmission heat loss
U is the U-value of the building component
A is the internal area of the building component
T_i is the indoor temperature (18-22 °C)
T_e is the external temperature (−15 °C and 8 °C for ground)
f_1 is a factor adding 3% to the heat loss for each additional cold surface (in this study assumed to be 1.075 for houses with 1 floor and 1.045 for houses with two floors)
f_2 is a factor which is 1.15 for roofs and 1.0 for other constructions.

The procedure for the calculation of ventilation heat losses has changed completely since the first standard. At that time, the ventilation heat loss was calculated on the basis of the length of connections around windows/doors and their frames. The calculation was carried out by estimating the lengths of connections between each window and the window frames as well as between the window frame and the external wall. The length of the connections was multiplied by a typical heat loss coefficient depending on the expected wind profile of the area where the building was situated. The calculation was based on Equation (4). Figure 2 shows the procedure for estimating the length of the connections.

$$\Phi_{vent} = f_3 \cdot f_4 \cdot \Sigma F \cdot L \cdot (T_i - T_e) \qquad \text{Eq. (4)}$$

where
Φ_{vent} is the ventilation heat loss

f_3 is a factor between 0.75-1.0 reducing heat loss in rooms where windows have different orientations (here assumed to be 0.75)

f_4 is a factor between 1.0-1.3 depending on the orientation of the windows (here assumed 1.15)

F is the heat loss pr. m connection length (1.2)

L is the length of connections

T_i is the indoor temperature (18-22 °C)

T_e is the external temperature (−15 °C).

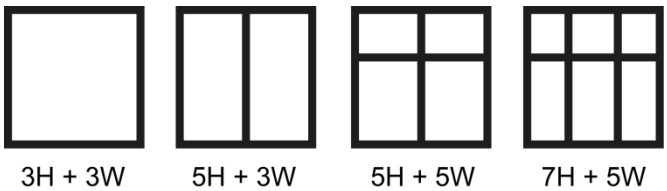

Figure 2 Length of connections between windows/doors and wall

Figure 3 gives a summary of the changes in the calculation procedures on the publication of new standards.

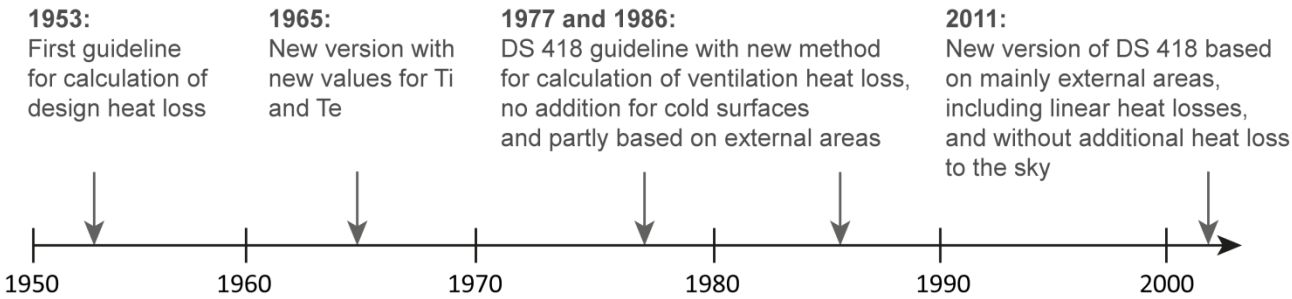

Figure 3 Timeline showing the changes in the methods for the calculation of design heat loss in Danish standards.

3.2 Building constructions

The constructions of the original houses were determined based on information from the TABULA project [25] as well as Danish building regulation requirements and guidelines on typical constructions in old Danish buildings [31,32]. The constructions and insulation levels applied in the calculation of the original design heat loss in the houses are given in Table 2. The estimated U-values of the constructions are shown in Figure 4.

Table 2 Typical components, insulation levels, and window types in Danish single-family houses constructed in different time periods.

CONSTRUCTIONS	1900-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998
Roof insulation	None	25mm	100mm	100mm	100mm	200mm
Floor insulation	Clay	Clay	Clay	Singles	50mm	150mm
Wall type and insulation thickness	Cavity wall 0mm	Cavity wall 0mm	Cavity wall 0mm	Cavity wall 80mm	Brick/LWC 80mm	Brick/LWC 120mm

Window type	1 layer	some double	Thermo	Thermo	Thermo	Thermo

3.3 Design heating temperatures

The heating systems in the houses were assumed to consist of two-string radiator-systems which is the most common Danish heating system. The radiators were assumed to be dimensioned in accordance with the design heat loss of each house as calculated according to the original constructions and the standards at the time of construction. The radiators were assumed to be over-dimensioned by 5% due to limitations in radiator sizes available. The design heating power of the radiators depends on the heating source and the design heating temperatures at the time when the radiators were installed in the houses. For instance, some houses were originally heated by an oil boiler, whereas they are now equipped with district heating. When the first hydraulic heating systems with radiators were introduced in the 1920s, the heating was typically delivered from stoves supplied by coal or coke. Oil-burners became more typical in the 1950s at the same time as district heating expanded rapidly. Natural gas was introduced in the 1980s [33,34].

For the oldest houses, we assumed the design temperatures were 90 °C/70 °C, because Danish radiators were tested for this temperature set until the new European norm DS/EN 442 was published in the mid-1990s [35]. Heating systems supplied by natural gas may have been designed according to this temperature set at first, but from the mid-1980s, it became common to use a temperature set of 80 °C/60 °C [36,37]. Since the mid-1990s the building code has required gas-fired heating systems to be dimensioned according to a mean temperature of 55 °C (corresponding to a temperature set of 62.5 °C/47.5 °C) [38]. The same building code required that heating systems supplied by direct and indirect district heating systems should be designed for temperature sets of 70 °C/40 °C and 65 °C/35 °C respectively. Earlier heating systems supplied by district heating were typically designed for a temperature set of 80 °C/60 °C [31] or 80 °C/40 °C [32].

The dimensioning temperature sets that were used for the dimensioning of the radiators in the TABULA houses investigated are shown in Table 3.

Table 3 Design heating system temperatures applied for the calculation of design heating power.

	1851-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998
Dimensioning temperatures [°C]	90/70	90/70	90/70	80/60	80/40	70/40

3.4 Design heating power

The design heating power installed in the houses was estimated based on the calculated design heat loss in the original houses at the time of construction. The design heat loss of each of the six single-family houses was calculated for the original building constructions as shown in Table 2 and in accordance with the calculation standard at the time of construction. The design heating power was calculated on the basis of the design heating temperatures at the time of construction as given in Table 3. An additional 5% heating power was added to the calculated design heating power to take into account over-dimensioning of the radiators due to limitations in radiator sizes available. The heating powers with the original temperature sets were converted to the temperature set 60 °C/40 °C, which is the currently required temperature set for houses supplied by district heating in Denmark. The conversion was carried out using Equations (5) and (6). The radiator exponent was given the standard value of n = 1.3.

$$\phi = \left(\frac{\Delta T}{\Delta T_0}\right)^n \cdot \phi_0 \qquad \text{Eq. (5)}$$

where
Φ_0 is the design heating power of the radiators in the house at the original temperature set
Φ is the heating power of the radiators at the temperature set 60 °C/40 °C
ΔT is the logarithmic mean temperature the temperature set 60 °C/40 °C
ΔT_0 is the logarithmic mean temperature difference at the dimensioning temperatures
n is the radiator exponent.

$$\Delta T = \frac{T_s - T_r}{\ln\left(\frac{T_s - T_i}{T_r - T_i}\right)} \qquad \text{Eq. (6)}$$

where
T_s is the supply temperature
T_r is the return temperature
T_i is the indoor temperature.

3.5 Current design heat loss

The current design heat loss of the houses depends on the renovations carried out since the construction of the houses. As a minimum, the houses from the first half of the 1900s were expected to have gone through

general maintenance. This was assumed to correspond to a renovation where old windows were replaced by thermo windows and roofs were equipped with a minimum of 50mm insulation. A large proportion of the houses constructed during the 1900s have been renovated to a further extent, adding insulation to the cavity walls or bringing windows or roof insulation to comply with modern standards. The design heat loss in the houses was calculated for two different stages of refurbishment corresponding to either general maintenance of the houses or a thorough energy refurbishment. The U-values of the constructions in the two scenarios are shown in Figure 4 along with the original U-values of the constructions.

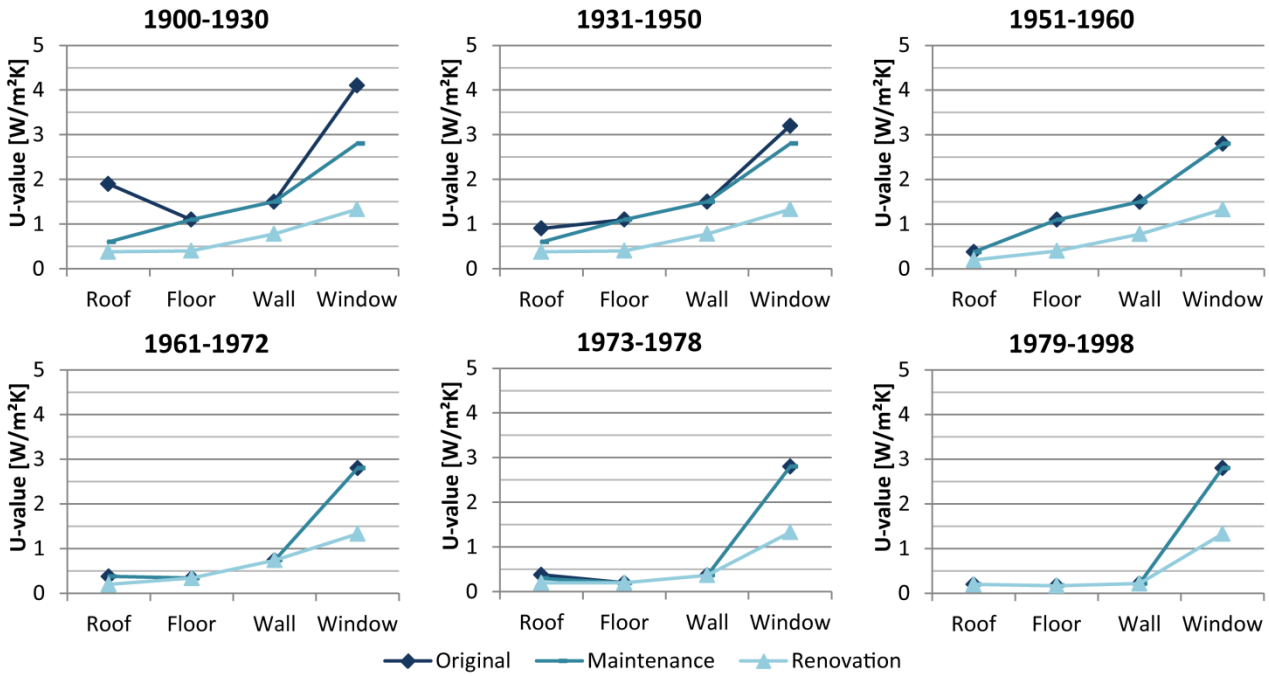

Figure 4. U-values of the constructions in the TABULA houses in their original state, after general maintenance, and after thorough energy renovation.

The design heat loss calculations were carried out in accordance with the current calculation standard. The design heat loss was compared to the design heating power in the houses, so that we could evaluate whether the existing radiators are over-dimensioned compared to the current design heat loss and current design heating temperatures.

3.6 Actual heating demand

The actual heat demands in the houses at typical outdoor temperatures were calculated using stationary calculations. It was assumed that the indoor temperature in the houses was kept at 21 °C. Transmission and ventilation heat losses were calculated according to Equations (1) and (2) and applying the key data for each house given in Table 1 and renovated constructions as shown in Figure 4. Internal heat gains from occupants and equipment were included in the calculations and assumed to be a constant 5 W/m^2 as suggested in the Danish standards [39]. Heat gains from the Sun and extra heat losses due to high wind velocities were ignored, and no dynamic behaviour was included in the calculations.

The total heating demands in the houses were given as the sum of the transmission heat loss and the ventilation heat loss at each given outdoor temperature. The heating supply temperature necessary to cover the heat loss at the given outdoor temperature was calculated in accordance with the design heating power in the houses using Equations (5) and (6). The cooling of the heating system was assumed to be 20 °C corresponding to the temperature difference between the supply and return temperature in the current design temperature set 60 °C/40 °C. The radiator exponent was assumed to be n = 1.1, because a recent study has shown that the radiator exponent describing heat emissions from typical Danish radiators during low-temperature operation is well below 1.3 [40]. The results were visualised in graphs (see Figures 7 - 9 below) showing how large a percentage of the year a given supply temperature is sufficient to heat each of the houses.

4. Results and discussion

4.1 Estimated heating power and design heat loss in the TABULA houses

Figure 5 shows the calculated design heat loss in typical Danish houses at the time of construction and in the current situation after either general maintenance or energy renovation. The design heating power of the radiators in the houses with a temperature set of 60 °C/40 °C is also included in the figure.

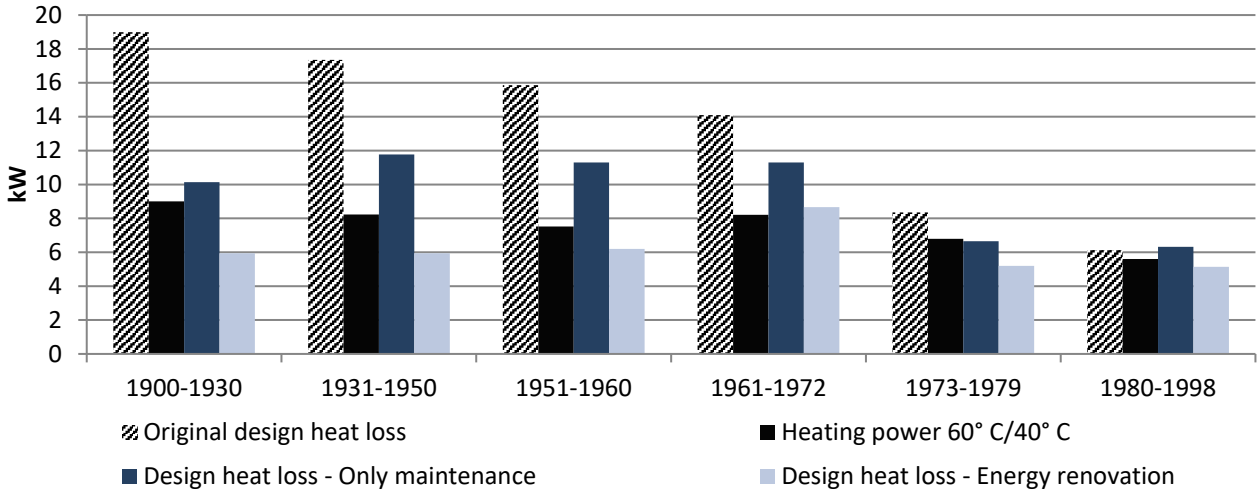

Figure 5 Heating power and design heat loss of the houses after general maintenance and after energy renovation

The figure shows that the heating power covers approximately 50% of the original design heat loss in the older houses, when the current design heating temperatures are taken into account. However, the design heat losses of the old houses are reduced greatly when the current standard and general maintenance of the houses is taken into account. Figure 6 shows the radiator over-dimensioning in the houses according to the design calculations. The displayed minimum and maximum over-dimensioning correspond to the two scenarios of general maintenance and energy renovation of the houses, respectively.

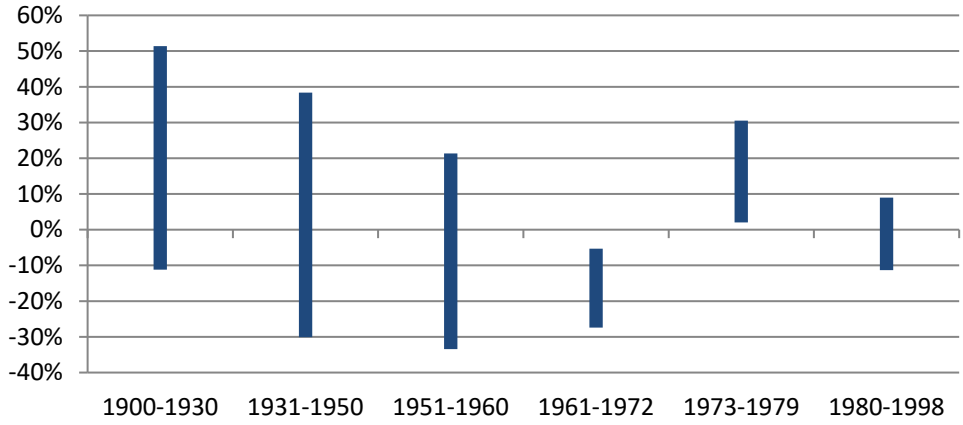

Figure 6 Minimum and maximum over-dimensioning of design heating power of radiators versus design heat loss

The figure shows that the radiator systems in most of the houses from the 1900s are under-dimensioned in relation to the design temperature set if the houses have only gone through general maintenance. The heating systems in houses constructed between 1931 and 1972 can be under-dimensioned by as much as

30% in relation to the current design temperature set. The 1961-1972 house represents a case where there was a reasonable level of insulation in the original house and where the heating system was designed for high temperatures. The results show that the design heating power in this type of house can be expected to be lower than the design heat loss with the current design temperature set, even after energy renovation. However, the figure also shows that the heating systems in most of the houses from the 1900s can be expected to be over-dimensioned by 20-50% compared to current standards when the houses have gone through reasonable energy renovations.

4.2 Required heating system temperatures

Figures 7 - 9 show the supply temperatures that are necessary to cover the calculated actual heat demand in the current houses. The figures are based on a return temperature that is 20 °C lower than the supply temperature. The outdoor temperatures have been converted to annual percentages in proportion to the occurrence of the temperatures in the weather data set for the design reference year in Copenhagen 2001-2010. The upper line of the areas marked corresponds to the situation where the house has gone through only general maintenance, while the lower line corresponds to the situation where the house was subject to an energy renovation. The areas marked between the lines visualise the expected supply temperatures necessary to cover the heating demands in typical existing Danish single-family houses at various levels of refurbishment. Figure 7, for example, shows that a Danish single-family house constructed between 1900 and 1930 that has gone through general maintenance requires a heating supply temperature above 55 °C for approximately 5% of the year in order to maintain a 21 °C indoor temperature. The figures are based on a 20 °C cooling in the heating system.

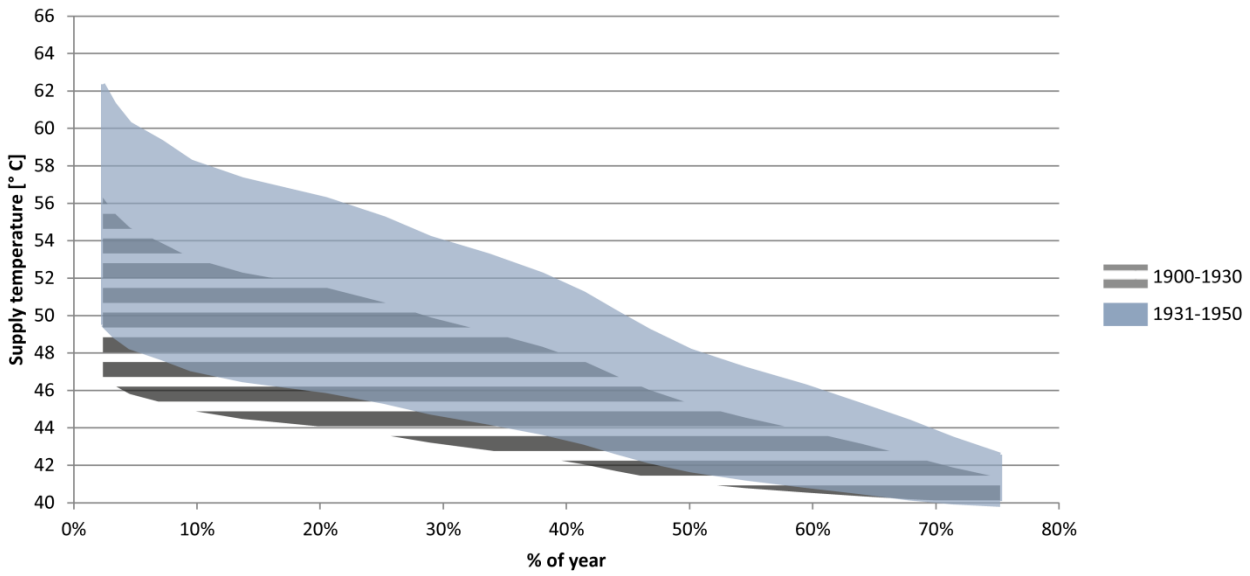

Figure 7 Comparison between design heating power of the radiators in the TABULA houses calculated according to the old methods and the current stationary heating demand of the houses at different outdoor temperatures.

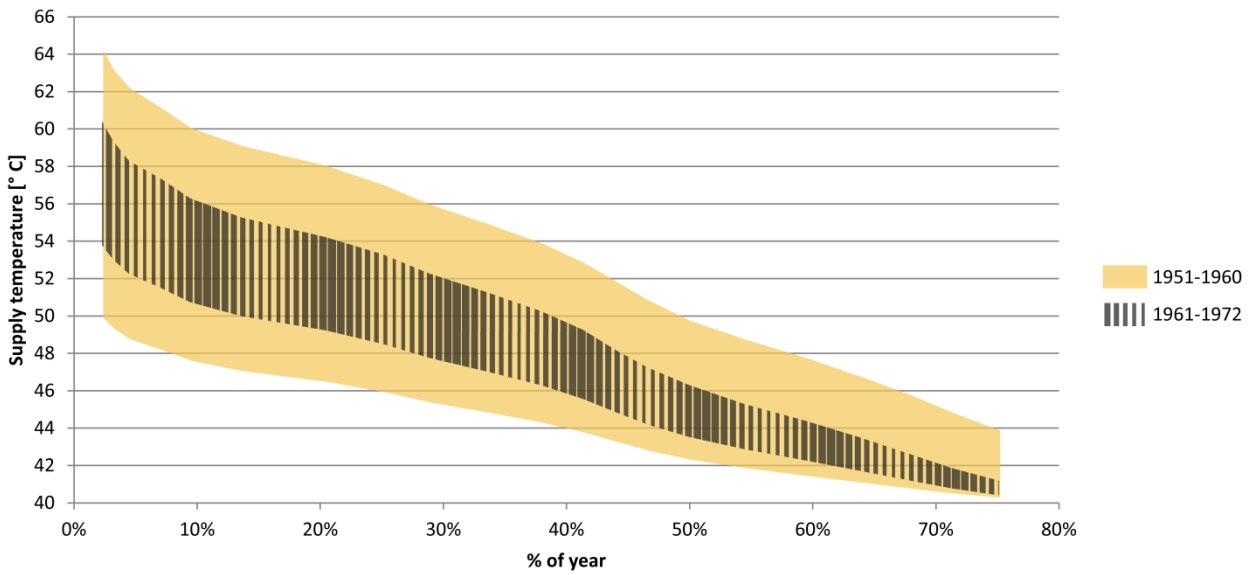

Figure 8 Comparison between design heating power of the radiators in the TABULA houses calculated according to the old methods and the future stationary heating demand of the houses at different outdoor temperatures.

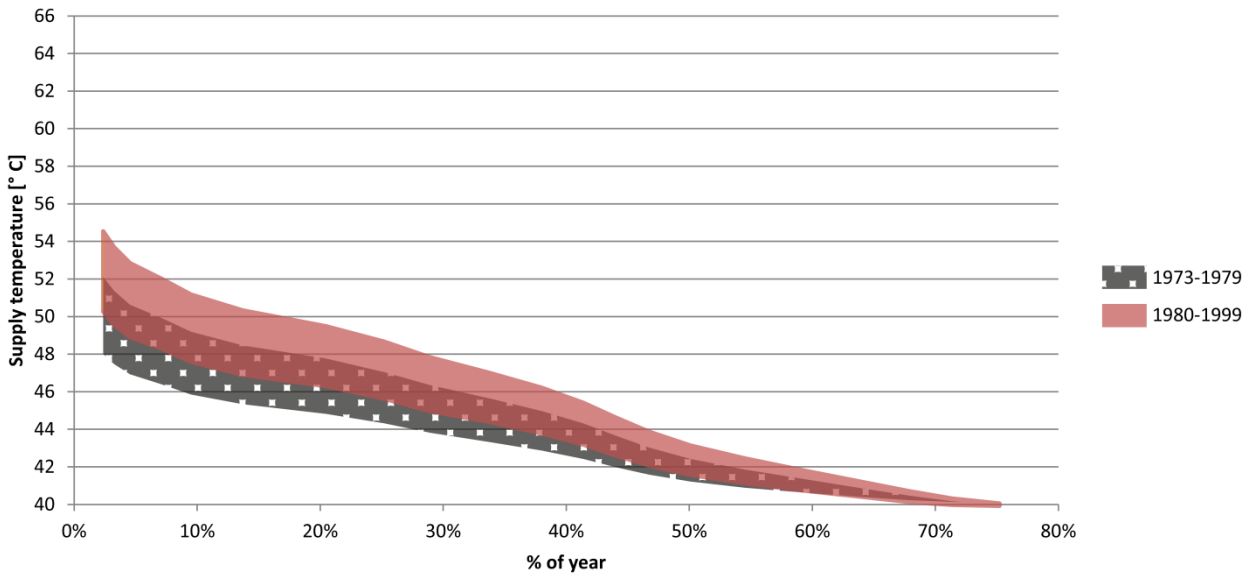

Figure 9 Comparison between design heating power of the radiators in the TABULA houses calculated according to the old methods and the future stationary heating demand of the houses at different outdoor temperatures.

Figure 9 shows that typical Danish single-family houses that were constructed after 1973 can be heated with a supply temperature of 55 °C for more than 97% of the year. Most of the houses built before 1973 can be heated with supply temperatures below 55 °C for the majority of the year as well. This means that there is not necessarily a correlation between the age of the house and the supply temperature required to heat the house. However, the old houses form a less uniform mass. In some cases, there is a difference of more than 10 °C between the supply temperatures required in an energy renovated house and those required in a house that has only gone through general maintenance.

The results show that the houses can be heated with a supply temperature below 60 °C for 97% of the year, even in a case where the heating system in a house is under-dimensioned by 25% compared to the current design heat loss. If all existing single-family houses go through reasonable energy renovation measures, a supply temperature below 54 °C was found to be sufficient to heat the houses for more than 97% of the year. In this respect, it could be argued that it is likely that the existing radiators in typical single-family houses from the 1900s are over-dimensioned for the actual heating demands in the houses. However, this would indirectly suggest that heating systems are generally over-dimensioned when current design methods are applied.

5. Uncertainties and assumptions

The results presented in this paper are subject to a number of uncertainties, because the study conducted was largely theoretical. The results should only be used therefore as an overall indication of tendencies in the existing Danish building stock. The houses investigated were typical Danish single-family houses identified in the TABULA project [25], so they do not represent all existing Danish single-family houses. Original building constructions may differ from the constructions analysed in this study, as may the design heating system temperatures and the energy renovation measures that might be considered reasonable to carry out. These parameters have a large influence on the results, and the focus on a few representative houses means that a number of other building constructions were not analysed. However, the typical houses analysed in this study show a wide range of different types of construction and design heating system temperatures. This means that they may be used to draw some general conclusions on the potential for using low-temperature district heating in existing single-family houses.

The estimated heating powers available in the existing houses were based on calculations of design heat loss. This method does not necessarily provide a reasonable estimate of the actual radiator heating power in existing houses. It can be expected that radiators were sometimes dimensioned according to the rule of thumb, engineering experience, or practical considerations, such as fitting the radiator into the available area under a given window or using similar radiators in all rooms of a house. Such design methods may have met the building regulations at the given time, but probably added to the over-dimensioning of the radiators in some houses and rooms. This means that radiators may be over-dimensioned to a larger extent than is illustrated in this study.

Because the study was based on a simplified analysis of data from the TABULA project, the building constructions and ventilation losses were not known or analysed in detail. The calculations carried out were simple stationary calculations, in which dynamic properties were not taken into account. This means that the results only provide an indication of the possibility of heating existing houses with low-temperature

heating. A detailed analysis should include the dynamic properties of, for example, heating systems, thermal building mass, and heat gains from direct sunlight.

To heat existing single-family houses with low-temperature heating as suggested in this study, the heating systems in the houses must function well and the heating power must be distributed evenly in the houses. The study does not take into account room partitions. This may be an important factor because radiator sizes may differ from room to room, or occupants may have changed or removed some radiators during refurbishment of their houses. If the radiators in some rooms are greatly under-dimensioned for the heating demand in a given room, it may be necessary to increase the supply temperature to maintain a 21 °C indoor temperature in all rooms. It can therefore be expected that it will be necessary to replace a few critical radiators in some houses to be able to use the low supply temperatures suggested in this study.

This study should be seen as a theoretical investigation of a number of standard houses that can serve as background knowledge about radiator dimensions in existing single-family houses. Furthermore, the study provides a reference for future investigations and an indication of the overall tendencies in the heating systems and heating demands of typical Danish single-family houses from the 1900s.

6. Conclusion

The results of this study indicate that it is not always accurate to assume that the radiators in typical Danish single-family houses from the 1900s are over-dimensioned compared to the design heat loss. On the other hand, the radiators might often be considered to be “over-dimensioned” for the current heat demands in the single-family houses.

The study found that typical existing Danish single-family houses can be heated with low-temperature heating with supply and return temperatures below 55 °C/35 °C for large parts of the year. Houses that have gone through reasonable energy renovations can often be heated with a supply temperature below 50 °C for more than 97% of the year. The results of the study indicate that the houses constructed in the beginning of the 1900s are not more difficult to heat with low-temperature heating than houses

constructed in the latter half of the 1900s. However, there is a larger span between the heating system temperatures required in older houses, depending on the renovation measures that have been implemented in the houses. Typical house constructions after 1973 were found to have rather similar heating system temperature requirements.

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