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A Method for Estimating Space Heating Energy Demand in Existing Buildings Based on the Danish Building and Dwelling Register

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Abstract

The Directive on the Energy Performance of Buildings requires energy certification of buildings. This is implemented in Denmark so that houses that are sold or let must have an energy performance certificate based on the evaluation of a visit to the building. The result is that only a small part of existing houses has an energy performance certificate. The Danish Building Research Institute has described a method that can be applied to estimate the energy demand of buildings specially dwellings. This is based on the information in the Danish Building and Dwelling Register and information in the Danish Building Regulations on year of construction of the house. The result is an estimate of the energy demand of each building with a variation. This makes it possible to make an automatic classification of all buildings. It is then possible to find houses in need of thermal improvements. This method was tested on single-family houses and flats. The paper discusses the uncertainties and possible improvements of the method and in the Danish Building and Dwelling Register. The method can be applied in other countries with modifications for local building requirements, climate and building registers.

Keywords – Energy demand; Danish Building Regulations; Calculation method; Uncertainty; Energy rating

1. Introduction

In Denmark, energy performance certification been in use since 1997 with energy performance rating for new houses (since 2006), including buildings sold or let. The current system has been in use since 2006. The energy rating classifies the building on an efficiency scale ranging from A (high energy efficiency) to G (poor efficiency) [1]. The rating is important when buying and selling houses.

The problem is that many houses still do not have an energy rating, and that it will take many years to cover the entire building stock. In 2009, 13% of single-family houses had an energy rating and 24% of the blocks of flats.

In distribution on the areas, it is 17% of the single-family houses and 49% of the blocks of flats.

Energy ratings are given in connection with a visit by an energy expert and the result is a rating and a description of possible energy-saving measures. For the houses that have not been energy rated, we do not know the energy demand and possible energy saving. An automatic calculation of the energy rating would thus be very useful. It is possible that some owners would make energy saving measures, if they were informed about the energy rating of their property. It will also make it possible for the authorities to give an economic subsidy or tax deduction for the buildings with the poorest energy efficiency. The result should be more energy saved for the same money.

It is possible to use a detailed method based on hourly values and details on heating system and constructions to make energy demand calculations of existing houses like for instance BSim [2]. The problem is that we will have to visit the houses and we will not always be able to find information on the constructions at the site or in drawings. Another important point is that this will be a very time consuming and expensive method. The Danish Energy Certification Scheme for existing buildings includes energy demand calculations based on a monthly calculation method [3]. This can be used at the visit as you can find some information and have additional information from a guideline with typical constructions. The cost of this is paid by the owner before a sale of the building. As it will take many years before all buildings have officially been rated, the Danish Building Research Institute (SBi) has described a method [4] that can be used without a physical visit to the house but only based on available information.

The Danish Building and Dwelling Register (BBR) has information that can be the basis for the calculation. This has to be supplemented with information from the Danish Building Regulations [5] from the year of construction and some estimates from previous research and information collection [6] [7] at the SBi.

2. BBR Data

The following data from BBR Register is used: building (building type), year of construction, year of renovation (only if change in floor area), useful floor area (BOA) m^2, number of storeys (AET), building footprint (BBA) m^2 ,useful attic area (TAA) m^2, basement area (KAA) m^2 and external wall material.

The described method can be used for dwellings as single-family houses and blocks of flats. The construction year is used to find the actual energy requirements in the Danish Building Regulations. In Denmark, we can expect that these requirements to thermal insulation are respected. The BBR Register can state the year of renovation, if the building footprint is increased. It is though not possible to know how much. A renovation with for instance better insulation or new windows is not registered in BBR Register as the floor area is not changed. So we do not know if the building has a lower energy demand than in the construction year. We know that many buildings have got better insulation or improved windows and we take that into account in the method.

The useful floor area is used for calculating the amount of heat from persons, light, equipment and solar radiation. The number of storeys, the building footprint, useful attic area, and basement area are used in the calculation of the geometry of the building. The external wall material defines the U-value level in the Danish Buildings Regulations.

3. Geometric Model

The BBR Register contains no information on building height, length or width. So we have to make an estimate of the geometry. The simplest form is a box-shaped building. We know the roof (TA) and floor area (GA) as it is equal to the building footprint (BBA).

For buildings without attic and basement, we use a box-shaped building. We need the building width (BB). Based on typical Danish buildings, we estimate the building width to be 9 m for single-family and terraced houses. For multi-family dwellings, the estimate is 12 m. Calculations with other length/width proportions show that it doesn't influence the surface area very much. The building length is then BBA/BB.

The storey height (EH) is assumed to be 2.8 m for single-family and terraced houses. For multi-family dwellings is it 3 m. These are typical values.

The volume (VOL) can be calculated as length (BL) multiplied by width (BB) multiplied by number of storeys (AET) multiplied by floor height (EH): VOL = BL*BB*AET*EH.

The wall area (VA), including windows can be calculated as: VA = (BL+BB)*2 *AET *EH.

Houses with Attic

If the building has a useful attic area (TAA) we get an extra wall area based on the attic is also a box. The box is placed on top of the building box and does not change the floor or roof area.

The length of the attic (BL_T) is estimated to be the length of the building (BL).

The width of the attic (BB_T) is the attic area divided by the attic length: BB_T=TAA/BL.

The volume of the attic (VOL_T) is calculated as length multiplied by width multiplied by height: VOL_T = BL_T*BB_T*EH.

The wall area of the attic **(**VA_T**)**, including windows is calculated as: VA_T = (BL_T+BB_T)*2*EH.

Buildings with Basement

The basement is calculated as a box placed under the building. As it is placed underneath the building, there is no change in floor or roof area. The walls of the box give the basement wall area. Note: We calculate as if the whole basement area is heated, as most people use it like that.

The length of the basement (BL_K) is estimated to be equal to the length of the building: BL_K = BL.

The width of the basement (BB_K) is the basement area divided with the length of the basement: BB_K = KAA/BL_T.

The volume of the basement (VOL_K) can now be calculated as: VOL_K = BL_K*BB_T*EH.

The basement wall area can now be calculated as: VA_K = (BL_K+BB_K)* 2*EH

Areas Used in the Energy Calculations

The roof area (TA) and the floor area (GA) are both equal to the building footprint (BBA).

The wall area is the sum of the wall areas of the building box and the attic box: SUM_VA = VA+VA_T.

The volume of the building is the sum of the volume for the three boxes: SUM_VOL = VOL+VOL_T+VOL_K.

This is a simplification as some part of the volume could be unheated, e.g. staircases.

Windows

The last area is the area of the windows in the building, as the windows have a greater heat loss than the rest of the wall area. There is no information on window area or number of glass panes in the BBR Register, so we need to estimate the values. The window area also includes door areas.

It is estimated that before 1960 most buildings had a window area (VIN) covering 15 % of the façade area. For blocks of flats, the window ratio is higher. The assumptions are shown in Table 1, based on [6] and [7].

Table 1. Window areas in buildings

Single-family houses		Apartment blocks and terraced houses	
Before 1999	15 %	Before 1961	15 %
From and after 1999	22 %	1961 to 1978	20 %
		From 1979	25 %

The basement has no windows. If we have an attic, then we estimate a window area (VIN_T) covering 10 % of the attic wall area. Now we can calculate the window area for the building based on the construction year and possible attic as: VIN_AR = VA*VIN+VA_T*VIN_T.

The wall area excluding windows is found as: VA_BYG = SUM_VA-VIN_AR.

4. U-value Model

U-values for the different building parts are taken from the Danish Building Regulations [5] that was in effect when the building was constructed. The energy requirements were changed in 1961, 1967, 1972, 1977, 1982, 1985, 1995, 1998 and 2008. The five U-values used in the calculation are outer wall, basement wall, floor, roof and window. We do not take into account that we can have different outer wall constructions in the same house.

Table 2. Typical U-values and requirements in different periods

Heavy outer wall (> 100 kg/m^2)	Roofs	Windows
Before 1930 1.2 W/m^2K 1931-1950 1.5 W/m^2K 1951-1960 1.5 W/m^2K 1961-1971 1.1 W/m^2K 1972-1976 1 W/m^2K 1977-1994 0.4 W/m^2K 1995-2007 0.3 W/m^2K From 2008 0.2 W/m^2K	Before 1950 0.97 W/m^2K 1951-1960 0.6 W/m^2K 1961-1976 0.4 W/m^2K 1977-1994 0.2 W/m^2K From 1995 0.15 W/m^2K	Before 1930 3.7 W/m^2K 1931-1994 2.9 W/m^2K 1995-2007 1.8 W/m^2K From 2008 1.5 W/m^2K Note: We estimate most old windows are upgraded.

Information from the BBR Register of the exterior wall material is used to decide whether it is a light or heavy wall as the Danish Building Regulations has different U-values for these wall types. The data about older houses have to be supplemented by the experience of SBi, see [6] and [7]. Table 2 is an example of the U-value variation over the years for heavy outer walls, roofs and windows. Data for other construction types and periods are found in the Danish report [4].

5. Model for Energy Balance

Transmission Heat Loss

The total transmission heat loss TRANS in W/K is found by multiplying the areas with the U-values from the construction year and make a summation of all constructions in the house. For floor and basement walls, we reduced the heat loss by 30 %.

TRANS = VA_BYG*U_outer wall + TA*U_roof + VIN_AR *U_windows + 0.7 * (VA_K*U_basement wall + GA*U_floor).

If there has been a renovation of the building at a recent year noted in BBR Register, we do not know the total area before the renovation took place, only after. The estimate is that 75 % of the area has U-values like in the original construction year and 25 % in the year of the renovation.

Model for Calculation of Ventilation Loss

The volume of the building is calculated from the geometric model. As mentioned, the volume also includes internal construction and unheated areas such as staircases and basement. The ventilation is estimated based on SBi's experience from other projects. The air change rate (LS) (air changes per hour) for different building types are given in Table 3.

Table 3. Air change rate in buildings in different periods

Single-family houses		Blocks of flats and terraced houses	
Before 1961	0.45 1/h	Before 1979	0.7 1/h
1961-1978	0.4 1/h	1979-2005	0.6 1/h
After 1979	0.35 1/h	From 2006	0.5 1/h

The ventilation loss (VENT) in W/K is calculated as the volume multiplied with the air change rate multiplied with 0.34 (heat capacity of air): VENT = SUM_VOL*LS *0.34.

Model for Calculating Heat from Sun, Persons, Equipment etc.

It is theoretically possible to calculate the solar radiation through the windows, but there are uncertainties in both the areas and orientation of the windows. The heat from persons, light, equipment etc. is also very uncertain.

Another problem is that only part of this heat will reduce the energy demand in the building. The solution is to use a value for the useful part of the internal loads from SBi [6] and [7].

The useful internal heat gain (TIL) is 55 kWh/m^{2}year, where the sun accounts for half the amount.

6. Module for Calculation of the Energy Demand

To calculate the energy loss, it is necessary to know the indoor and outdoor temperature. The indoor temperature is fixed at 20 °C. In Denmark, the traditional heating season begins on 24 September and ends on 15 May, or 7½ months with an average outdoor temperature of 3.5-4.5 °C. From this can be calculated a degree-day number of 3 600 (base 17 °C). In the calculation, we use degree-hours (GTT) as 86 400 °C*h.

The useful internal heat gain (TIL) is calculated for the living area (BOA) (given in BBR Register), and does not include for instance basement areas not accepted for living. So the useful internal heat gain is: TIL*BOA.

The energy demand for heating the building EX (kWh/year) can then be calculated as: EX = (TRANS+VENT)*GTT/1000-TIL*BOA.

7. Uncertainty of the Parameters

The calculated energy demand (EX) is the best estimate based on the information in the BBR Register and the estimates made by SBi based on the knowledge of the Danish building stock. Table 4 lists all the uncertainty parameters.

Table 4. List of uncertain parameters

Geometry	U-values	Energy calculation
Width Length Storey height Volume Attic area and width Basement area and width Window area	Walls Roof Floors Window type, number of glass layers, translucent area, glass coating, orientation	Degree of ventilation Airtightness Useful heat (solar, persons, light and equipment) Degree-hour number Renovation

The method ignores complex geometric buildings like U or L shaped ones. The uncertainty of the U-values is large for buildings constructed before the first Danish Building Regulation in 1961 – after that time the uncertainty is lower as buildings are normally built according to the Building Regulations. There is no information in the BBR Register as to whether extra insulation has been added after the construction year. In practice, we can expect that energy saving measures have been implemented in many older buildings.

8. Total Uncertainty of the Result

Measurements of energy demand in buildings show large variations for individual buildings [8] in spite of them being equal in construction. This is caused by the influence from the users and variations in workmanship etc. This calculation method is based on the variations in the building and does not take into account the variation for the users and their use of the building. If that variation was included, the variation would be much larger.

An estimation of the uncertainty in the calculations depends on the construction year. Old houses have a large variation and new houses a lower variation. The method provides an upper and a lower limit, as given in Table 5. These limits are in reality upper and lower quartiles as we estimate that:

25 % of houses have an energy demand higher than the upper limit and
25 % of houses have an energy demand lower than the lower limit

Table 5. Variations in upper and lower limits during different periods

Upper limit (EXØ); EXØ = EX * GRØ	Lower limit (EXN); EXN = EX * GRN
Before 1961: EX * 1.25 (it is 25 % above the average) 1961-1971: EX * 1.15 From 1972: EX * 1.10	Before 1931: EX * 0.60 (it is 40% below the average) 1931-1961: EX * 0.70 1962-1977: EX * 0.80 1978-1995: EX * 0.85 After 1995: EX * 0.90

The lower limit has more variations than the upper limit which is explained by the fact that many old houses have been retrofitted with extra insulation and new windows. The result is an energy demand that is well below the average calculated with method.

The primary calculation result is the energy demand for space heating in the buildings in kWh/year.

Upper limit energy demand - EXØ
Average energy demand - EX
Lower limit energy demand – EXN

The values in kWh/year can be calculated as energy demand per m^2 (ES). When the calculation results are compared with the official energy certification system, then the area must be given as the heated area.

The heated area can be the same as the useful floor area (BOA) from the BBR Register with the exception of the basement. Some part of the basement can be part of the useful floor area, but that is not always the case. Typical cases show that most buildings have a heated basement, so the whole basement area is included in the heated area in the calculation.

Heated area = Useful floor area (BOA) + Basement area (KA)
Energy demand per m^2 = ES/heated area

It is important to use energy demand per m^2 as a basis, as this is used in the Danish energy performance certification system.

The living area is used for calculation of the amount of internal heat gains from persons, light, equipment and solar radiation. The number of floors and the building footprint, useful attic area and basement area are used in the calculation of the geometry of the building.

If we calculate the average value for a number of buildings, the variations are reduced and our prediction of the energy demand for the combination of these houses is more certain.

9. Examples of Single-Family Houses

In the 1980, detailed calculations were made [9] for a number of single-family houses based on drawings and descriptions as a basis for possible energy savings. Some of these houses are accessible in the BBR Register today and extracted data see Table 6. For five of the houses, an automatic calculation is made using the method described here. This is compared with the original detailed calculations.

Table 6. BBR data for the five houses.

Construction year	1962	1929	1973	1961	1950
Building footprint	77 m^2	93 m^2	133 m^2	84 m^2	93 m^2
Useful floor area	130 m^2	161 m^2	133 m^2	84 m^2	93 m^2
Storeys	1	1	1	1	1
Top floor	53 m^2	66 m^2	0 m^2	0 m^2	0 m^2
Basement	0 m^2	86 m^2	0 m^2	36 m^2	27 m^2
Wall construction	Lightweight concrete	Lightweight concrete	Bricks	Bricks	Bricks

The result of the detailed calculation in Table 7 should be between the upper and the lower limits. This is the case for the houses built in 1950, 1961 and 1973. For the houses built in 1929 and 1962 the value is a little above the upper limit. For the house built in 1929 (before general Danish Building Regulations), the U-values in the automatic calculation are uncertain. The 1962 house is a 1½ storey house, where the model can be too simplified. But we still have to remember that some houses exceed the limit.

Table 7. Auto calculation of energy demand with BBR data

Construction year	1962	1929	1973	1961	1950
Auto average value EX	17.950	36.865	17.214	15.742	29.341
Detailed calculation	23.300	49.000	14.800	16.500	25.300
Auto upper limit EXØ	20.642	46.081	18.935	18.104	36.676
Auto lower limit EXN	14.360	22.119	13.771	11.020	17.605

10. Automatic Energy Rating

The described method to perform automatic energy demand calculations can be used for automatic energy certification and rating of the houses that do not have an official energy certificate. The auto rating method can be described as follows:

Using the average energy demand per m^2 (EX) as a basis for automatic rating result in a number of houses getting a better value than if they had received a visit from an energy expert. This problem is solved by calculating the energy demand from the upper limit energy demand (EXØ). Use of this value makes nearly all houses obtain a better rating when an official certification is made later.

Table 8. Distribution of the energy ratings for 56 single-family houses calculated based on average (EX) and upper limit (EXØ).

Basis	A	B	C	D	E	F	G	Total
EX	0	1	1	10	25	15	3	56
EXØ	0	0	2	4	7	26	17	56

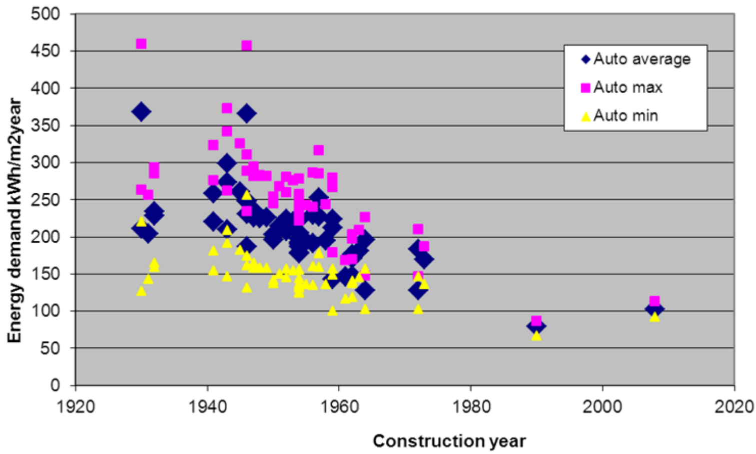

Fig. 1. Calculated energy demand for 56 single-family houses versus construction year.

The two methods have been used in a case study for a street with 56 single-family houses. Figure 1 shows variations in energy demand, based on the construction year. It is seen that most houses are built from 1940 to 1960. Most houses with an automatic rating are rated either F or G, the two lowest ratings. The results of the two methods are given in Table 8.

In Table 9, we compare the official energy rating for the five houses that have an official energy certificate with the result of the automatic rating method based on the BBR Register. For the first four houses (a to d), it is seen that the officially calculated energy demand by the energy expert lies between the upper and lower limits of the automatic method. As expected, the value is closer to the lower limit, as some energy saving activities was made. These are typically additional insulation, tightening and retrofitting of windows and new heating system. The last house (e) has a lower energy consumption than the automatically calculated one. In the report from the visit, it is seen that this house has been extra insulated and renovated and that there is not much more to do in this house in an economic sense.

Table 9. Five single-family houses that have an official energy certificate with calculated energy demand kWh/year compared with the automatic calculation (EXØ and EXN) and automatic ratings kWh/YEAR.

	Const. year	Autocalc. max EXØ	Autocalc. min EXN	Autorat. (EXØ)	E-calcu-lated	E-label
a	1930/60	59,300	28,450	F	30,500	F
b	1941	43,000	24,100	G	33,900	F
c	1954	46,700	26,150	F	32,300	D
d	1951	47,200	25,400	F	39,600	G
e	1946	57,500	32,200	G	26,100	C2

11. Conclusion and Use in Other Countries

The comparison between the official Danish energy certification scheme and the automatic system shows that the automatic system can be used to identify buildings with high energy consumption. This can be done based on information in the BBR Register and knowledge of typical Danish buildings. This provides a possibility of targeting incentives for better energy performance in the buildings, where you get the highest energy savings for the investment.

This method can also be used in other countries using similar basic building registers, building regulation over time, climate and experience of the typical building methods used in the country.

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