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Distribution of heating costs in multi-story apartment buildings

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Abstract

Under current rules in the Danish Meter Order at least 40% of the total heating costs in multi-story blocks of flats should be distributed by metering the consumption in individual apartments. This fixed share is the result of a previous study that showed that 40% of the total heating costs were used for space heating, 35% for production and heat loss associated with hot water consumption and finally 25% of heat losses in the heating system. It is interesting to investigate whether this distribution remains representative in both existing buildings, where older buildings still dominate, as in newer and future standard of blocks of flats.

Intuitively, we would like to settle 100% of the costs attributable to space heating, by individual meters. Thereby, tenants will pay for their own consumption which encourages energy savings. This is an excellent method for electricity, gas and water but for heating it is a much more complex issue. For instance, if a pensioner wants or needs a higher indoor temperature the expenses will become disproportionate due to heat transmission through internal walls, floors and ceilings. This is particularly pronounced in well-insulated buildings where the heat loss to the outdoor climate constitutes only a small proportion of the total heating consumption. It is therefore interesting to investigate the consequences for the distribution of heating costs by differentiated indoor temperatures in both older and new multi-story apartment buildings.

This paper describes an analysis of the possibilities regarding individual metering and fair distribution of heating costs in multi-story apartment buildings. The overall conclusion of the analysis is that there are several significant problems related to this issue, and it becomes even more complicated when space heating only accounts for 30% in new buildings (2010 requirement) and 5-10% in future buildings (2020 requirement).

Keywords: Heating costs; distribution; multi-storey blocks of flats

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1. Introduction

The Danish Meter Order [1] stipulates that at least 40% of the total heating costs in multi-story blocks of flats should be distributed by metering the space heating consumption in individual apartments. This share is the result of a previous study that showed that 40% of the total heating costs were used for space heating, 35% for production and heat loss associated with hot water consumption and finally 25% of heat losses in the heating system. However, there are several problems in using this method for distributing the total heating costs.

One problem is, that the energy consumption of individual but similar dwellings will depend on the number of inhabitants and their individual behavior, as shown in e.g. [2] and [3], and if indoor temperatures differ from flat to flat then the ones keeping the higher temperatures will be paying more than their actual share, as shown in e.g. [4].

Another problem occurs for new buildings or buildings that have undergone deep energy renovation where the heating of the apartments does not even account for 40% of the total heating costs, since domestic hot water consumption will be dominant. This issue will be even more pronounced in future buildings, when building regulations are further tightened and at some point even system losses will exceed the actual consumption.

This paper presents the results of a theoretical analysis of the abovementioned problems and some thoughts as to how these problems can be addressed.

2. Calculation model

The calculations are performed using a calculation model based on a simple heat balance for each apartment in a block of flats consisting of 2x5 apartments (numbered 1-10), stairwells and basement as shown in Figure 1.

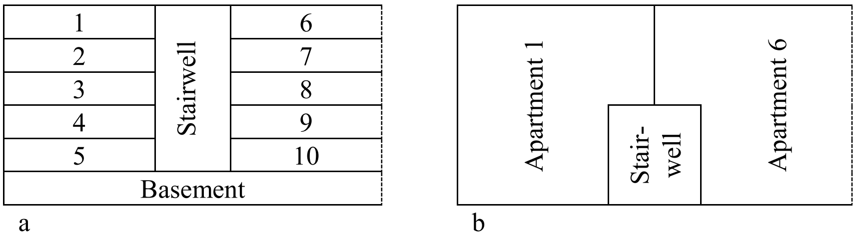


Fig. 1. (a) Vertical section of model consisting of apartments 1-10, basement and stairwell. (b) Horizontal section in apartment 1 and 6.

The apartments all have an area of 70 m^2. The building depth is 10 m, the floor height is 3 m and window area is 15 % of the floor area. The apartments on the same floor, e.g. apartment 1 and 6 have a common interior wall of half the building's depth (see figure 1b). Apartments 6-10 have neighboring flats to the right (indicated by dotted line).

The calculation model is relatively simple and consists of a heat balance for each apartment. The apartments have heat losses in the form of transmission heat loss and ventilation heat loss and similarly heat gains in the form of solar radiation, internal heat gain from equipment, people, etc. and heat gains due to the heat loss from heating pipes and pipes for hot water. All values are calculated in kWh. The difference between the total heat loss and the total heat gain is the amount of heat that radiators must deliver to keep the required indoor temperature.

2.1. General assumptions

In Denmark an indoor temperature of 20 °C is typically used in calculations, however, it is well known that the vast majority of households will maintain a higher indoor temperature, typically between 21-23 °C. For these calculations an indoor temperature of 21 °C is assumed in apartments, 17 °C in stairwell and 15 °C in the basement as averages for the heating season. Basement and stairwell are not heated as such but heat losses from pipes and heating system heats the basement while transmission losses from the apartments heat the stairwell.

Hot water consumption is set to 200 l/m^2 per year. Both indoor temperature and hot water consumption is dependent on user behavior, and therefore a sensitivity analysis is carried out to illustrate how much it will affect the results if they deviate from the selected levels.

The internal heat gain in the apartments is assumed to be 5 W/m^2. The heating season period is defined as 5,832 hours, equivalent to 243 days, and it has 97,200 degree hours at an inside temperature of 21 °C.

The length of heating pipes per apartment affects the loss in the system and is set to 18 m per apartment. The temperature of the heating pipes is 40 °C (average of forward and return). The heat exchanger is located in the basement and its temperature affect system-loss. Domestic hot water has circulation and the average temperature of pipes for hot water is 50 °C and the length of pipes is 6 m per apartment. The length of pipes in the basement for heating and hot water is set to 76 m and 28 m respectively.

2.2. Period-specific assumptions

Insulation levels, heating system etc. will depend on the year of construction and therefore we define a number of different construction-periods describing this variation. The period-specific input data is given in Table 4.

U-values for the building envelope are taken from the Energy Labeling Scheme database [5], corresponding to 6 typical construction-periods; 1850-1930, 1931-1950, 1951-1960, 1961-1972, 1973-1978 and 1979-1998. Two additional categories corresponding to newer construction and future construction are also considered.

The original windows have all been replaced with traditional double-glazed windows for all periods except for the newer buildings that have low-energy windows.

Insulation levels for pipes, water heater and heating system is determined by Handbook for Energy Consultants [6]. However, heat loss coefficients for uninsulated pipes seem unrealistically high in the handbook, and therefore values are taken from engineeringtoolbox.com [7] instead. For new buildings and future buildings (2020) all values are based on the requirements given in the Danish Building Regulations [8].

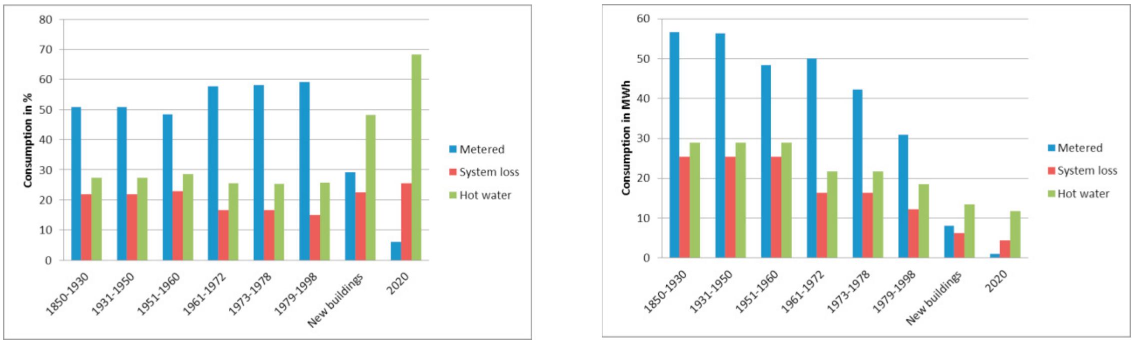
Table 1. Input for calculation model based on typical construction-periods.

	1850-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998	New	2020
U-values for building envelope [W/m^{2}K]								
$U_{exterior\ wall}$	0.85	0.93	0.84	0.64	0.49	0.52	0.20	0.15
U_{roof}	0.36	0.36	0.28	0.28	0.23	0.24	0.10	0.10
U_{floor}	0.85	0.93	0.86	0.66	0.53	0.52	0.12	0.12
U_{window}	2.27	2.3	2.28	2.25	2.13	2.23	1.40	1.00
$U_{internal\ wall}$	1.20	1.20	1.20	1.20	1.20	0.80	0.50	0.50
$U_{separating\ floor}$	1.10	1.10	1.10	0.70	0.60	0.60	0.40	0.40
g-values for windows [-]								
g_{window}	0.63	0.63	0.63	0.63	0.63	0.63	0.50	0.50
Heat loss coefficients for pipes, hot water tank and boiler [W/mK and W/K]								
$q_{heating\ pipes}$	0.60	0.60	0.60	0.29	0.29	0.29	0.14	0.10
$q_{hot\ water\ pipes}$	0.60	0.60	0.60	0.29	0.29	0.29	0.14	0.10
$q_{hot\ water\ tank}$	7.10	7.10	7.10	6.10	6.10	4.90	4.30	4.30
q_{boiler}	9.20	9.20	9.20	5.80	5.80	4.00	3.00	3.00
Ventilation ratios [l/s per m^2]								
$q_{ventilation}$	0.00	0.00	0.00	0.00	0.10	0.10	0.30	0.30
$q_{infiltration}$	0.34	0.16	0.22	0.10	0.40	0.25	0.13	0.07
$q_{ventilation\ total}$	0.34	0.30	0.30	0.30	0.40	0.35	0.19	0.12

The values of $q_{ventilation}$ and $q_{infiltration}$ are average values taken from measurements of typical buildings [9], and $q_{ventilation\ total}$ is the value used in the calculations and it corresponds to the total equivalent amount of outside air taking into account all types of ventilation and heat recovery. The period referred to as the "new" corresponds to buildings constructed after 2010 and these buildings will typically have heat recovery with an efficiency of 80%. Future buildings, i.e. 2020-buildings is assumed to have an efficiency of 85% and a lower infiltration rate.

3. Results

The model described in the previous chapter provides a distribution of "metered consumption", "system loss" and "hot water consumption" as shown in Figure 2.



a b

Fig. 2. (a) Distribution of heating consumption in % and (b) in kWh.

For the first three periods (1850-1960) the results are very similar with a metered consumption of approx. 50% of the total, 22% heat loss in the system and 28% for domestic hot water consumption.

The following three periods (1961-1998) are also very similar and here the metered consumption rises to 58%, while the heat loss in the system drops to 17% and consumption of hot water is 25%.

For the new buildings the picture is significantly different and metered consumption represents only 29% of the total, while the heat loss of the system is 22% and hot water accounts for 49%. For future buildings, i.e. 2020, domestic hot water consumption will dominate the total heating consumption, and the metered heating consumption in apartments is reduced to only 6%. Moreover, it can be noted from the figure that heat losses in the system is now also substantially larger than the individually metered heating consumption.

It is clear that the metered heat consumption in apartments is higher than the 40% minimum that according to law must be settled using individual meters for the older buildings. However, it is also clear that in the newer buildings hot water consumption makes up the largest part of the total heat consumption, and the metered heat consumption is less than 30% of the total. In the oldest buildings heating and distribution of hot water accounts for 28% whereas in the newer buildings it accounts for 54% and in 2020-buildings for almost 70%.

3.1. Sensitivity analysis

The calculation model has many assumptions that will influence the results. Therefore a series of sensitivity analysis have been carried out, aiming to determine the robustness of the model and thereby the results.

The indoor temperature in multi-story buildings will vary depending on the individual needs of the tenants. Therefore it is relevant to examine how this influences the calculations and an extra set of calculations have been performed where indoor temperature in general is 22 °C instead of 21 °C. Figure 3a shows the results.

The consumption of hot water is also variable and dependent on user behaviour. To assess how the consumption of hot water affects the distribution of the total heating consumption a calculation where hot water consumption is set to 250 l/m^2 instead of the original 200 l/m^2 is performed. Figure 3b shows the results.

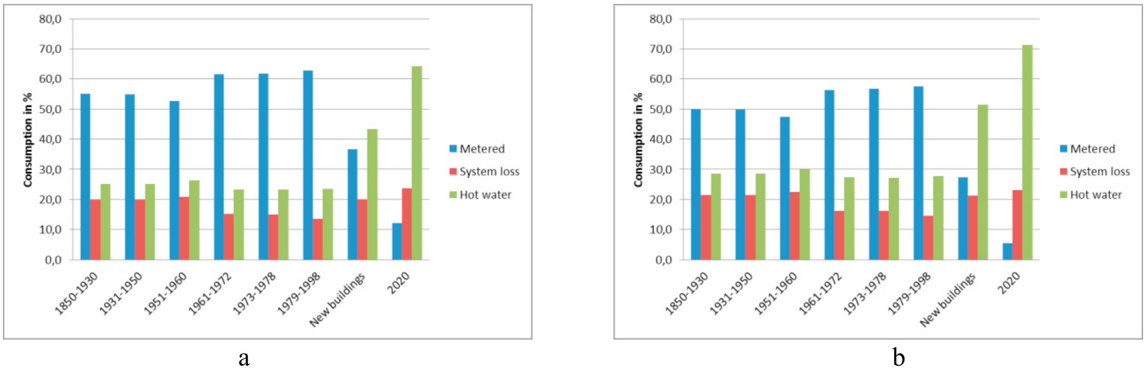


Fig. 3. (a) Indoor temperature is 22 °C instead of 21 °C (b) domestic hot water consumption is 250 l/m^2 instead of 200 l/m^2.

Comparing the results in figure 3a with the results from figure 2a, the overall picture is the same, but the metered consumption will of course be higher with a higher indoor temperature. Again, you can group the first three periods and the subsequent three periods, as the results are very similar. The result for the new and future buildings again has a distinctly different distribution of heat consumption. Increasing the indoor temperature increases the metered consumption by 4, 4 and 7 percentage-points (pp) per year respectively for the three groups of periods.

An increase in the hot water consumption from 200 l/m^2 to 250 l/m^2, i.e. comparing figure 3b with figure 2a, will only have very little impact on the overall results. Metered heating consumption in apartments is slightly reduced, while heating consumption for domestic hot water increases a bit, and therefore variations in the domestic hot water consumption do not influence results very much.

3.2. Difference in indoor temperatures between apartments

If an apartment increases the indoor temperature by 1 °C compared to the rest of the apartments the heating bill for this apartment will be disproportionate, as the apartment will transmit heat to the surrounding apartments, who in turn, will end up paying less.

The apartment should generally expect a theoretical increase in the total heating demand of approx. 6% per 1 °C increase in temperature (since the number of degree hours increase by 6% from 97,200 to 103,000). This would happen if all the residents raised the temperature 1 °C.

Table 2 shows the actual percentage increase in total heating demand for individual apartments if they raise the temperature from 21 °C to 22 °C.

Table 2. Percentage increase in heating demand for individual apartments if they alone increase temperature by 1 °C. Results denoted by "-" means that the model cannot calculate values correctly since heating consumption in surrounding apartments will be less than 0.

	1850-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998	New	2020
#1	10.6	10.6	11.0	11.2	11.0	10.9	14.8	22.5
#2	18.1	18.0	18.6	17.5	16.5	17.0	24.7	-
#5	14.2	14.1	14.4	14.2	13.8	13.9	18.1	27.1
#6	13.8	13.9	14.5	15.2	14.6	13.9	19.4	29.4
#7	25.5	25.9	26.5	25.4	22.8	23.1	34.1	-
#10	18.4	18.6	18.9	19.4	18.2	17.9	23.3	37.7

Table 2 clearly illustrates the problem with individually metered consumption. The apartments raising the temperature would expect an increase in heating consumption of 6%, but actual increase ranges from 10.6% to 37.7%. The future buildings are worst, underlining that this issue will be a problem, when new buildings have extremely low consumption and older buildings will be renovated and decrease consumption significantly.

4. Discussion

Under current rules, at least 40% of the total heating costs in blocks of flats must be distributed based on metering in individual apartments. This analysis has shown that the actual heat consumption in older buildings will be 50% or more, while in new buildings it will be around 30% and in future buildings it will be as low as 6%. The existing (older) buildings will however undergo relatively extensive energy renovation in the coming years if we are to create a low carbon society in 2050, and thus the distribution of the total heat consumption in the older buildings will move towards the distribution seen for newer buildings. Therefore, it is questionable to retain a requirement that 40% of the total heating costs should be distributed based on individual metering.

Another problem is that if individual apartments are heated to different indoor temperatures the distribution of heating costs will not be fair, and warmer apartments will end up paying a disproportionate part of the total heating costs. This also speaks against distributing 40% of total heating costs based on individual metering.

However, if the proportion of heat consumption distributed by heat cost allocators is reduced, the incentive for energy savings by tenants will also be reduced, and therefore it could be necessary to consider alternative ways to encourage energy savings in multi-story apartment buildings.

5. Conclusion

The calculations carried out in this project clearly shows that the development of a method of cost-genuine and equitable sharing of heating costs in multi-story apartment buildings is difficult, especially as we move towards more and more energy efficient buildings. It will require a combination of heat meters and temperature sensors to compose a cost-genuine distribution of heating costs, and it will require a much greater level of detail in the measurements (e.g. hourly values). Cost-genuine, and thereby fair, allocation of the heating costs in multi-story apartment buildings are therefore almost impossible to handle without introducing excessive complexity.

On the positive side, the analysis shows that heat consumption in buildings of the future will only amount to 30% or less of the total consumption, and therefore it is perhaps less important whether this small part of the total consumption is allocated 100% fairly. However, it is of course important at the same time not to create an incentive to squander energy.

It could also be argued from this analysis that a requirement for individual measurement of domestic hot water consumption in new buildings and buildings undergoing deep energy renovation is strongly advisable, since distribution of overall heating costs will not be fair based only on measurements with heat cost allocators.

Acknowledgements

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References

[1] Danish Meter Order (Målerbekendtgørelsen), BEK nr. 563 af 02/06/2014, https://www.retsinformation.dk/Forms/R0710.aspx?id=163405

[2] Pettersen, T. D. 1997; Uncertainty analysis of energy consumption in dwellings, NTNU, Trondheim, Doktor ingeniøravhandling 1997:122, Høgskolen i Narvik, Norway.

[3] Mørck, O., Thomsen, K. E. and Rose, J. 2012; The EU CONCERTO project Class 1 - Demonstrating cost-effective low-energy buildings - Recent results with special focus on comparison of calculated and measured energy performance of Danish buildings, Applied Energy, Vol. 97, 09.2012, pp 319-326.

[4] Nielsen, A. and Rose, J. 2014; Individual energy savings for individual flats in blocks of flats, Nordic Symposium on Building Physics 2014: 10th Nordic Symposium on Building Physics 15-19 June 2014 Lund, Sweden: Full papers.

[5] Danish Enterprise and Construction Authority. 2016. The Energy Labelling Database (Energimærkningsdatabasen), SEEB-Secretariat.

[6] Danish Ministry of Energy, Utilities and Climate. 2015; Håndbog for energikonsulenter (HB2016), BEK nr. 1759 af 15/12/2015. https://www.retsinformation.dk/Forms/R0710.aspx?id=161845

[7] http://www.engineeringtoolbox.com/steel-pipes-heat-loss-d_53.html

[8] Trafik- og Byggestyrelsen. 2015; Bygningsreglement 2015. (14.12.2015), Copenhagen, Denmark.

[9] Bergsøe, N. C. 2014; Analyse 1.2: Målte værdier fra tætheds-prøvninger i eksisterende bygninger, Danish Building Research Institute, Aalborg University.