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Individual energy savings for individual flats in blocks of flats

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SUMMARY:
It is well known that similar flats in a block do not have the same energy demand. Part of the explanation for this is the location of the flat in the building, e.g. on the top floor, at the house end or in the middle of the building. It is possible to take this into account when the heating bill is distributed on the individual flats. Today, most blocks of flats have individual heat meters to save energy and to ensure a fair distribution of the cost. If all flats have the same indoor temperature, the distribution is correct.

In practice, the inhabitants of the different flats maintain different indoor temperatures. The result is that heat flows between individual flats. This decreases the energy consumption in the flat where the owner maintains a lower temperature. The neighbouring flats will have higher energy consumption. Calculations were performed for Danish blocks of flats from 1920, 1940, 1960 and 1980. Normally, we expect the reduction in energy consumption to be around 20% for a 2 °C lower temperature, but for an inner flat the reduction can be up to 71%. The owners of the adjoining flats get an increase in energy demand of 10 to 20% each. They will not be able to figure out whether this is because the neighbour maintains a low temperature or the fact that they maintain a higher temperature. The best solution is to keep your own indoor temperature low. We can also turn the problem around: if you maintain a higher temperature than your neighbours, then you will pay part of their heating bill.

1. Introduction

It is a well-known fact that energy consumption in dwellings varies significantly depending on the number of inhabitants and their individual behaviour. This has been documented in several previous publications, e.g. (Hiller 2003) showing measurements of variations in energy consumption for 38 individual single-family houses over a period of 10 years, (Pettersen 1997) presenting the mean value and standard deviation of energy consumption in more than 900 flats spread over 9 different blocks and (Mørck 2011) showing the variations in heating energy consumption for 64 individual housing units.

For blocks of flats, it is interesting to know not only the energy demand of the entire building, but also the energy demand of each flat. It is typical that flats immediately below the roof, above an unheated basement and at the building ends have a higher energy demand. This is the effect of different heat losses, but another factor also has an impact. That is the indoor temperature. A lower indoor temperature results in energy savings that are very economic as it does not cost any money. If we calculate with Danish climate conditions, a lowering of the temperature by 2 °C will result in a 20% energy saving or 10% per °C. That is the case if you live in a single-family house, where you can control the temperature yourself.

If we lower the temperature by 2 °C in all flats in the block, we get the 20% energy saving. But that is not the case when we consider lowering the temperature in a individual flat. Here, a lowering of the temperature gives a much higher energy saving as you receive heat from your neighbours if they do not lower their temperature. It is important to be aware of this effect if you make individual measurements of the heating demand and perform calculations of the expected heating bill. It is normal in Denmark to have a central heating system and each flat pays part of the total heating bill of the building. Typically this is based on measuring the indoor temperature or the heating consumption of each flat.

2. Energy calculation

The calculations of the energy demand presented in this paper is done with the model described in Nielsen 1980 based on a monthly energy balance. The model can calculate multi-zones, where each flat is a zone and staircases, basement etc. are other zones. The zones can be heated to a fixed constant temperature or the temperature in each zone can be dependent on the heat balance with other zones. In each zone, the heat loss and ventilation loss to the outdoor air and the heat gain from solar radiation, persons and equipment is taken into account. The heat flow between individual flats, i.e. transmission heat flow, is also taken into account in the model. The outdoor climate is the Danish standard climate data. The outdoor temperature is given as a monthly mean value. Solar radiation through a typical pane is given as a monthly sum depending on the orientation of the window. The calculation method also takes into account that the heat gain cannot always be fully utilized and could instead give rise to overheating. This is determined by the energy balance calculated month by month. For each heated zone (as flats), a heating demand is calculated for a constant indoor temperature of 21 °C. The heat flows between zones can be positive or negative depending on the temperature difference.

This method is similar to that of Be10 (Aggerholm and Grau 2005), which is used for most small buildings in Denmark today. But Be10 only considers the building as a single zone. For multi-zone models, it is normal to use much more complex models that calculate the energy balances hour by hour, but the effect of lowering the temperature in individual flats the model by (Nielsen 1980) should be sufficient.

3. Selected buildings

In a thesis work Rasmussen 1980 calculated energy savings and energy economy in blocks of flats from different time periods. The buildings were selected as typical for the period, but it was important to have drawings and descriptions as a basis. All U-values and areas were calculated and the method by Nielsen 1980 was used in the energy calculations. The thesis work presented different calculated energy savings for individual energy-saving measures such as new windows or extra wall insulation and their economy.

The selected buildings were:

Struenseegade, Nørrebro, København, 1920, built from bricks, with wooden floors and single glazing.

Bispeparken, Bispebjerg, København, 1940, built from bricks, with floors of concrete and single glazing.

Hedeparken, Ballerup, 1960, industrialised construction built from concrete, with wooden façade elements and double glazing.

Tinggården, Herfølge, 1980, low-dense buildings with good insulation.

Eremitageparken, Lyngby, 1972, modern industrialised buildings.

This paper concentrates on “Struenseegade” from 1920 and “Hedeparken” from 1960, but the effect of later changes in the building methods, insulation levels etc. are discussed.

4. The case: Struenseegade

The buildings in Struenseegade were built in 1920. They are 5 storeys high and consist of two- and three-room flats. Calculations were done based on drawings and descriptions of the flats, and in order to represent all types and locations in the buildings, 40 flats were included in the analysis. The overall insulation level of the buildings was extremely poor with a solid brick wall thickness of 36-60 cm with a U-value ranging from 1.0 to 1.5 W/m^{2}K.

Heat flows between individual flats depend on the nature of the partition walls and floors. In 1920, Denmark did not have any particular requirements concerning thermal insulation of buildings, and there were no requirements concerning sound insulation either. In this particular building, the partition walls consisted of brick and the floors were wooden joists with clay deposits. The U-value of the partition walls were 2.2 W/m^{2}K and the U-value of the floors were 0.7 W/m^{2}K and therefore differences in indoor temperature in individual flats have had a huge impact on the energy consumption in the surrounding flats.

The block of flats was grouped with other buildings meaning that it did not have gable flats.

Figure 1 shows the individual energy demand of flats around 4 staircases in MWh per year calculated at an indoor temperature of 21 °C.

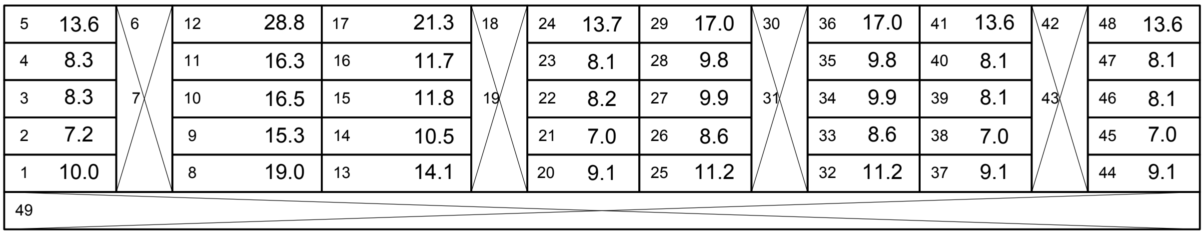

FIG 1. Energy demand of flats around 4 staircases in MWh per year

Figure 1 shows the energy demand of the flats around four staircases, if the indoor temperature was 21 °C in all flats. Flats nos. 1 to 5 were located at the building end but since the building was grouped with other buildings, they had no extra heat loss. The four staircases, nos. 6+7, 18+19, 30+31 and 42+43 as well as the basement 49 were unheated. Flats nos. 8-17 were three-room flats while the rest were two-room flats. The result was that the flats on the ground floor like nos. 1, 8, 13, 20, 25, 32, 37 and 44 had a higher energy demand than more centrally located flats. A similar effect was seen on the top floor with flats nos. 5, 12, 17, 24, 29, 36, 41 and 48 which had an even higher heat demand due to the extra heat loss through the roof.

The calculated energy demand of the flats varied from 7.0 MWh/year for a two-room flat placed in the centre of the building to 28.8 MWh/year for a three-room flat at the top of the building.

Temperature lowered by 2 °C		Flat Above	Flat Right	Flat Left	Flat Below
Entryway 6 and 7 Left	5 -25		12 +1		4 +6
	4 -34	5 +4	11 +1		3 +6
	3 -34	4 +6	10 +1		2 +7
	2 -36	3 +6	9 +1		1 +5
	1 -29	2 +7	8 +1		
Entryway 6 and 7 Right	12 -25		17 +4	5 +2	11 +6
	11 -35	12 +3	16 +7	4 +3	10 +5
	10 -35	11 +6	15 +6	3 +3	9 +6
	9 -36	10 +5	14 +7	2 +3	8 +5
	8 -30	9 +6	13 +6	1 +2	
Lowering everywhere		-20			

FIG 2. Energy demand of flats nos. 1-5 and 8-17 if the temperature is lowered by 2 ℃ in one flat. Small numbers are flat numbers, large numbers are changes in energy demand in % compared with normal. Negative numbers are energy savings and positive numbers increased energy consumption

Temperature lowered by 2 °C		Flat Above	Flat Right	Flat Left	Flat Below
Entryway 18 and 19 Left	17 -28		24 +2	12 +3	16 +8
	16 -40	17 +4	23 +3	11 +5	15 +7
	15 -40	16 +8	22 +3	10 +4	14 +8
	14 -42	15 +7	21 +3	9 +5	13 +6
	13 -35	14 +8	20 +3	8 +4	
Entryway 18 and 19 Right	24 -32		29 +6	17 +1	23 +7
	23 -45	24 +4	28 +10	16 +2	22 +7
	22 -45	23 +7	27 +10	15 +2	21 +8
	21 -48	22 +6	26 +11	14 +2	20 +6
	20 -41	21 +8	25 +9	13 +2	
Lowering everywhere		-20			

FIG 3. Energy demand of flats nos. 8-17 and 20-29 if temperature is lowered by 2 ℃ in one flat. Small numbers are flat numbers, large numbers are changes in energy demand in % compared with normal. Negative numbers are energy savings and positive numbers increased energy consumption

Figures 2 and 3, had the same layout as the flats located in the building. For example, if we look at flat (3) in Figure 2; if the temperature in this flat is lowered by 2 °C, the savings will be 34 %. In turn, this increased the energy consumption of the neighbouring flat (10) by 1% for the upstairs neighbour (4) 6% and the downstairs neighbour (2) 7%. Results for the other flats can be read in a similar manner.

For a single-family house you would expect savings corresponding to approximately 20% if the temperature was lowered by 2 °C, but here the results showed significantly higher savings. This was due to the transmission of heat to the flat from adjacent flats.

The savings of two-room flats were:

- Top floor (on the roof) approx. 30%
- Between floors approx. 45%
- Lower floor (against basement) approx. 30%

As a result of these savings, the energy consumption of the adjoining flats increases by up to 11%. The exact figures are shown in Figs. 2 and 3. The building's total energy consumption is almost unaffected by individual flats lowering temperature.

5. The case: Hedeparken

The buildings in ”Hedeparken” were built in 1960 as one of the large industrialised buildings consisting of four-storey blocks of flats. All flats in this block are of the same size – three-roomed. The calculation was performed based on the drawings and descriptions of the flats. The calculation was performed for three staircases in a block of flats. The thermal insulation of 75 mm mineral wool was typical for the period around 1960. The windows had double glazing with a U-value of 2.50 W/m^{2}K. The walls were a light wooden prefabricated solution with a U-value of 0.44 W/m^{2}K. The floor between the cellar and the flats had a U-value of 0.60 W/m^{2}K. The roof had a U-value of 0.48 W/m^{2}K.

The heat flows between the individual flats depend on the constructions in the building. The Danish Building Regulations from 1960 specify rules for the sound insulation between the flats but there are no regulations concerning heat flow. To achieve good sound insulation, it is important to use heavy constructions, e.g. concrete. This, however, results in a high U-value. The partition walls between flats were 150 mm concrete with a U-value of 2.8 W/m^{2}K. For floors between flats the U-value was 1.35 W/m^{2}K.

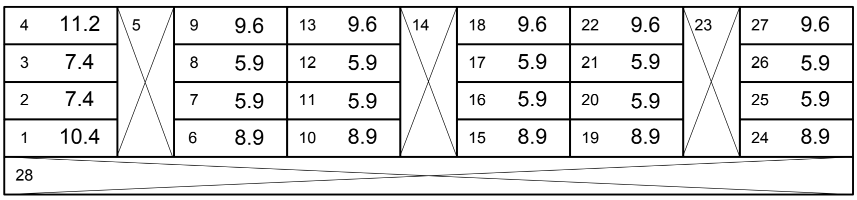

FIG 4. Energy demand of flats around three staircases in MWh per year

The drawing in Figure 4 shows the energy demand for the flats around three staircases, if the indoor temperature was 21 °C in all flats. Flats nos. 1 to 4 are located at the gable with extra heat loss. The three staircases nos. 5, 14 and 23 were calculated as unheated. The only heat comes from the adjoining flats and solar radiation. Below the block of flats was a basement – no. 28, which was also unheated. The result was that the flats nos. 1, 6, 10, 15, 19 and 24 on the ground floor had a higher energy demand than most inner flats. The calculated energy demand of the flats varied from 5.9 MWh per year in an inner flat to 11.2 MWh per year for the flats at the top floor at the gable. The average temperature in the staircases had a variation from 17.0 °C in December to 21.2 °C in July. The variation in energy demand gives a variation on the energy bill of the flats, also if we had the same indoor temperature and free heat from solar radiation, electricity and persons. In real life, the energy bill depends on the inhabitants' use of the flats, i.e. some have a higher temperature and some could have more ventilation and also an effect of the variation in the number of inhabitants in each flat.

Temperature lowered by 2 °C			Flat Above	Flat Right	Flat Left	Flat Below
Entryway 5 Left	4	-35		9 +5		3 +17
	3	-54	4 +11	8 +8		2 +16
	2	-54	3 +16	7 +8		1 +12
	1	-38	2 +17	6 +6		
Entryway 5 Right	9	-47		13 +11	4	8 +5
	8	-71	9 +11	12 +16	3 +7	7 +18
	7	-71	8 +18	11 +16	2 +7	6 +13
	6	-51	7 +20	10 +13	1 +6	
Lowering everywhere			-20			

FIG 5. Energy demand of flats nos. 1-9 if temperature is lowered by 2 °C. Small numbers are flat numbers, large numbers are changes in energy demand in % compared with normal. Negative numbers are energy savings and positive numbers increased energy consumption

Figure 5 shows the result of a calculation on the energy demand of flats nos. 1-9 if the temperature was lowered by 2 °C – from 21 °C to 19 °C. This is not unrealistic if you want to save energy and reduce your energy bill. For flats in the middle of the building, like nos. 7 and 8 the energy demand for heating and ventilation would be reduced by 71%. The result was of course that flats above, below and next door to the left and right had a higher energy demand and a higher bill. The increase of these flats was 7-18%.

If we take an example flat no. 8, the saving were 71%. For the flat above no. 9, the increase was 11%. For the flat below no. 7 the increase was 18%. For the neighbours to the right, no. 12, the increase was 16%. For the neighbour to the left, no. 3, the increase was 7%.

For the top floor, the saving was 47% and for the first floor above the basement 38%.

The energy saving was less if you lived in a flat at the gable. The savings were:

Top floor at the end and under the roof:	35%
Floors 2 and 3 at the end:	54%
First floor at the end and above basement:	38%

All the savings and extra heat demand of the neighbours are given in Figure 5.

These savings correspond to the obtained 20% saving if all flats reduced the indoor temperature by 2 °C.

All calculation were performed with a lower temperature but we can reverse it so a 2 °C higher temperature for a flat in the inner part of the building gets a 71% higher energy demand. If you have a higher temperature than your neighbours, then you get a high energy bill as you also pay for your neighbours' heating. They would save 7-18% on their individual energy bills.

6. Discussion

Calculations for the other buildings show similar effects of variations in energy demand between the flats and that lowering the temperature in an individual flat gives much more saving than the 20% for 2 °C. The numerical values can be less but the effect of the heat flow between the flats is very important for the savings. Is this still relevant today – many years after the calculation? The answer is yes. Many of the buildings have been extra insulated or had new windows so the energy demand of the flats has been reduced. But you cannot do anything with the heat flow between flats. So there is still a heat flow between the flats if we lower the temperature and the saving from a lower temperature is the same or slightly higher.

New buildings are typically built with constructions as described in Rasmussen 2011 in order to obtain the necessary sound insulation. There are no rules regarding thermal insulation between flats. Looking at the cases in the report, we can find the best insulated constructions. For the floor, this is 25 mm insulation and for the wall it is 50 mm insulation material, if the construction is made as cavity wall with a 60 mm space with 50 mm mineral wool. In reality, this wall construction is seldom used as it is quite complicated to build.

We can now look at Hedegården and look at the changes that will occur if extra insulation is added. For walls between flats, the extra 50 mm insulation decreases the U-value from 2.80 W/m^2K to 0.62 W/m^2K. For floors between flats, the extra 25 mm insulation decreased the U-value from 1.35 W/m^2K to 0.73 W/m^2K.

If we again look at flat no. 7, Table 1 shows the effect of a change in the constructions.

TABLE 1. Savings with original wall/floor or better insulated wall/floor between flats

	Original	New constructions	Realistic
Flat 7	-71%	-40%	-58%
Flat 8 above	18%	10%	14%
Flat 6 below	13%	7%	10%
Flat 2 left	7%	2%	5%
Flat 11 right	16%	4%	13%

The new constructions reduces the heat flow between the flats as flat 8 goes from 18% to 10% increase of energy demand. The savings in flat 8 is now reduced to 40%, but still a very large effect. The new constructions are a theoretical case as there are some practical problems. If we look at the solution with 25 mm insulation; this is only possible under a wooden floor and not under inner walls in the flat and probably not under bathrooms and toilets. So there will be thermal bridges and some areas that do not have 25 mm insulation. We must also remember that some of the sound insulation solutions do not have thermal insulation. A best estimate is given in the last column. For the wall between flats it is, as mentioned, more complicated to build the wall as two separate walls with thermal insulation between, so only few houses will have this solution. A more realistic estimate is therefore shown in the right column of Table 1.

7. Conclusions

The calculations presented in this paper show that it is much easier to achieve energy savings by lowering the temperature in a flat in the central part of a block than for flats closer to the top, bottom or end of the building since it will receive heat from the flats around it. This effect is still relevant even in new blocks of flats as the floors and walls between individual flats typically do not have specific thermal insulation. The most efficient way of saving energy is that all inhabitants know that you increase savings if the neighbours do not lower the temperature. If all flats lower the temperature, we will achieve the highest total energy savings.

Is it possible to determine whether your neighbours are "stealing" your heat? This is probably not possible as there will always be variations in the behaviour and number of people in the flats. So you have to take the risk, but we could also look at it, so that if your neighbour maintain a high temperature you will achieve an energy saving.

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