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User behaviour impact on energy savings potential

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KEYWORDS: *User behaviour, energy upgrading, energy savings potential, indoor temperature, internal heat gain, domestic hot water consumption, air change rate*

SUMMARY: (Style: Summary Heading)
When buildings are to undergo energy upgrading in Denmark, the national compliance checker, Be10, is often used to calculate expected energy savings for different energy-saving measures. The Be10 calculation is, however, very dependent on a variety of standard assumptions concerning the building and the residents' behaviour and if these defaults do not reflect actual circumstances, it can result in non-realisation of expected energy savings. Furthermore, a risk also exists that residents' behaviour change after the energy upgrading, e.g. to obtain improved comfort than what was possible before the upgrading and this could lead to further discrepancies between the calculated and the actual energy savings. This paper presents an analysis on how residents' behaviour and the use of standard assumptions may influence expected energy savings. The analysis is performed on two typical single-family houses corresponding to different levels of energy consumption. The purpose of the analysis is to identify the importance of each of the four primary user-related parameters in terms of their relative and combined impact on the overall energy needs before/after upgrading; 1) Indoor temperature, 2) Internal heat gain, 3) Domestic hot water consumption and 4) Air change rate. Based on the analysis, a methodology is established that can be used to make more realistic and accurate predictions of expected energy savings associated with energy upgrading taking into account user behaviour.

1. Introduction

User behaviour plays an important role for a building's energy consumption and in connection with energy upgrading of existing buildings, user behaviour may lead to non-realisation of expected energy savings. Most often failure to achieve energy savings occur because users gain the possibility and focuses on increased comfort instead, e.g. through a slight increase in temperature or air change rate.

User behaviour influence on energy consumption in buildings has been dealt with in numerous articles and reports and is not a new topic, e.g. (Lundström, 1986). A state-of-the-art review on occupants influence on the energy consumption in buildings was performed by Larsen et al (2010).

This analysis was performed as part of the Danish Energy Agency "Network for Energy Renovation" aiming to support the establishing of future energy-policies in Denmark.

The purpose of the analysis is to identify the importance of four primary user-related parameters in terms of their relative and combined impact on the overall energy consumption before/after the energy upgrading:

1. Indoor temperature
2. Internal heat gain
3. Domestic hot water consumption
4. Air change rate

Based on the analysis, a methodology is established that can be used to make more realistic and accurate predictions of expected energy savings associated with energy renovation taking into account

user behaviour. The purpose is to develop a method which provides an energy calculation, based on a specific combination of parameters corresponding to a specific family in a specific building.

Furthermore, the purpose of the analysis is to provide an overview of how user behaviour affects the expected energy savings in buildings, and thus try to establish a method for determining the expected energy savings, taking into account user behaviour.

2. Method

The analysis is performed using 2 buildings representing typical single-family houses from 2 different periods; the 1930s and the 1960s. The following gives a brief description of the 2 buildings.

2.1 1930s

The house is a typical bungalow from 1932 with a gross heated area of 103 m^2. The building has a full, unheated basement less than half below ground level with a gross area of 103 m^2. The total window area on the ground floor is 16% of the floor area. The total glass area on the ground floor is 12.0 m^2.

FIG 1. Typical single-family house from 1930s.

2.1.1 U-values for building constructions

The U-values are summarised in Table 1. Note that windows are assumed to have been changed during the 1960s, and now correspond to traditional double-glazed windows.

TABLE 1. U-values for building constructions

Building construction	U-value [W/m^2K]
Floor separation	1.02
Exterior wall, mean	1.45
Ceiling	0.55
Windows	2.70
Basement wall	1.24
Basement floor	0.40

2.1.2 Heating and ventilation

The house has an old oil boiler in the basement connected to a 2-pipe heating system. All pipes are insulated with 10 mm insulation. The hot water tank holds 200 l with 30 mm insulation.

The building has natural ventilation and can be categorised as leaky, which means that the total air change rate in the house is set at 0.45 l/s per m^2.

2.1.3 Calculated energy consumption

Calculation of energy consumption is based on the Danish compliance checker, Be10 (Aggerholm and Grau, 2012). The calculation covers energy consumption for heating, cooling, ventilation and domestic hot water. The 1930s house has a calculated energy consumption of 417 kWh/m^2 per year.

2.2 1960s

The house is a typical single-family house from the 1960s with a gross heated area of 108 m^2. The house consists of lounge, kitchen/dining area, utility room/bathroom, hall, toilet and 3 bedrooms. The total window area is 22% of the floor area. The total glass area is 19.9 m^2.

FIG 2. Typical single-family house from 1960s.

2.2.1 U-values for building constructions

The U-values are summarised in Table 1.

TABLE 2. U-values for building constructions

Building construction	U-value [W/m^2K]
Exterior wall, heavy	0.46
Exterior wall, light	0.49
Ceiling	0.39
Windows	2.70
Slab on ground	0.30

2.2.2 Heating and ventilation

The heating distribution system is a 2-pipe heating system with a flow temperature of 80 °C and return temperature of 60 °C. The heating system is an old oil boiler unit located in the utility room. All pipes are insulated with 30 mm insulation. Domestic hot water is produced in a 200 l hot water tank with 30 mm insulation.

The building has natural ventilation and can be categorised as leaky, which means that the total air change rate in the house is set at 0.45 l/s per m^2.

2.2.3 Calculated energy consumption

The single-family house has a calculated energy consumption of 240 kWh/m^2 per year.

2.3 Energy-saving measures

For each building, 2 packages of energy-saving measures are suggested.

2.3.1 1930s, energy-saving measures, Package 1

The following measures are carried out:

1. Floor separation: 70 mm clay replaced by 75 mm insulation
2. Ceiling: New 300 mm insulation
3. Exterior wall: 150 mm exterior insulation
4. Windows: Replaced by Class A windows (U = 0.9 W/m^2K and g = 0.62)
5. Heating supply: Connection to district heating instead of old oil boiler

The total energy consumption is reduced from 417.3 kWh/m^2 per year to 143.8 kWh/m^2 per year.

2.3.2 1930s, energy-saving measures, Package 2

The following measures are carried out:

1. Floor separation: 70 mm clay replaced by 75 mm insulation
2. Ceiling: New 300 mm insulation
3. Exterior wall: 150 mm exterior insulation
4. Windows: Replaced by Class C windows (U = 1.3 W/m^2K and g = 0.62)
5. Air tightness: Improved (from 0.45 to 0.30 l/s per m^2)
6. Mechanical ventilation: 90% heat recovery
7. Heating supply: District heating instead of old oil boiler

The total energy consumption is reduced from 417.3 kWh/m^2 per year to 126.6 kWh/m^2 per year.

2.3.3 1960s, energy-saving measures, Package 1

The following measures are carried out:

1. Exterior wall: 160 mm insulation for the heavy wall and 125 mm insulation for the light wall
2. Ceiling: New 200 mm insulation added to existing 100 mm
3. Windows: Replaced by Class A windows (U = 0.9 W/m^2K and g = 0.62)
5. Air tightness: Improved (from 0.45 to 0.30 l/s per m^2)
6. Mechanical ventilation: 90% heat recovery
7. Heating supply: Ground source heat pump instead of old oil boiler

The total energy consumption is reduced from 239.9 kWh/m^2 per year to 78.5 kWh/m^2 per year.

2.3.4 1960s, energy-saving measures, Package 2

The following measures are carried out:

1. Exterior wall: 160 mm insulation for the heavy wall and 125 mm insulation for the light wall
2. Ceiling: New 200 mm insulation added to existing 100 mm
3. Windows: Replaced by Class A windows (U = 0.9 W/m^{2}K and g = 0.62)
5. Air tightness: Improved (from 0.45 to 0.30 l/s per m^2)
6. Heating supply: District heating instead of old oil boiler

The total energy consumption is reduced from 239.9 kWh/m^2 per year to 97.7 kWh/m^2 per year.

3. Energy savings as a function of user behaviour

Chapter 2.3 has shown expected energy savings for two different buildings and for different energy saving measure packages. These calculations are based on standard assumptions concerning user behaviour, e.g. 20 °C indoor temperature etc. To evaluate influence of user behaviour, new sets of calculations are performed where four primary user-related parameters vary. Table 5 shows variations.

TABLE 5. Variation of parameters in calculations

Parameter	Variation	Unit
Indoor temperature	18 – 23	°C
Internal heat gain	2.0 – 7.0	W/m^2
Domestic hot water consumption	150 – 400	l/m^2
Air change rate (natural ventilation)	0.30 – 0.45	l/s per m^2
Air change rate (infiltration)	0.13 – 0.31	l/s per m^2

Calculations are performed for each individual package for the parametric variations shown in Table 5. Calculation results for the 1930s single-family house are shown in Tables 6 – 9.

TABLE 6. 1930s, Package 1. Relative energy savings in % as a function of indoor temperature before/after energy upgrading.

		Indoor temperature after [°C]					
		18	19	20	21	22	23
Indoor temperature before [°C]	18	**100.0**	96.7	93.1	89.3	85.7	81.9
	19	103.0	**100.0**	96.6	93.1	89.8	86.3
	20	106.0	103.1	**100.0**	96.7	93.6	90.4
	21	108.6	106.0	103.1	**100.0**	97.1	94.0
	22	110.9	108.4	105.6	102.8	**100.0**	97.2
	23	112.9	110.6	108.0	105.3	102.7	**100.0**

TABLE 7. 1930s, Package 1. Relative energy savings in % as a function of internal heat gain before/after energy upgrading.

		Internal heat gain after [W/m^2]					
		2	3	4	5	6	7
Internal heat gain before [W/m^2]	2	**100.0**	102.3	104.5	106.8	109.0	111.0
	3	97.7	**100.0**	102.2	104.5	106.7	108.8
	4	95.4	97.7	**100.0**	102.3	104.5	106.6
	5	93.1	95.4	97.7	**100.0**	102.2	104.3
	6	90.9	93.2	95.4	97.8	**100.0**	102.1
	7	88.7	91.1	93.4	95.7	97.9	**100.0**

TABLE 8. 1930s, Package 1. Relative energy savings in % as a function of domestic hot water use before/after energy upgrading.

		Domestic hot water use after [l/m^2]					
		150	200	250	300	350	400
Domestic hot water use before [l/m^2]	150	**100.0**	99.1	98.1	97.2	96.2	95.2
	200	100.9	**100.0**	99.1	98.1	97.1	96.1
	250	101.9	101.0	**100.0**	99.0	98.1	97.1
	300	102.9	101.9	101.0	**100.0**	99.0	98.0
	350	103.8	102.9	101.9	101.0	**100.0**	99.0
	400	104.8	103.9	102.9	102.0	101.0	**100.0**

TABLE 9. 1930s, Package 1. Relative energy savings in % as a function of air change rate before/after energy upgrading.

		Air change rate [l/s per m^2]			
		0.30	0.35	0.40	0.45
Air change rate [l/s per m^2]	0.30	**100.0**	98.0	96.0	94.0
	0.35	102.0	**100.0**	97.9	95.9
	0.40	104.2	102.1	**100.0**	97.9
	0.45	106.4	104.3	102.2	**100.0**

The tables show the relative energy savings, e.g. if the indoor temperature is 20 °C before the energy upgrading and 22 °C after, then the relative energy savings are 93.6% of the expected energy savings. The “before” situation could also correspond to a situation where no data is available and therefore a standard value is assumed.

Similar calculations are performed for the remaining packages, i.e. Package 2 for 1930s and Packages 1 and 2 for 1960s.

A cross comparison shows that the lower the total energy consumption is, the more the relative savings are influenced, i.e. the expected energy savings for the 1960s building are more sensitive to discrepancies between parameters in the “before” and “after” situations.

4. Discussion

4.1 Indoor temperature

The indoor temperature greatly affects the energy consumption of the building, and the analysis shows that for every degree the inside temperature deviates from standard assumptions, the energy consumption is increased/decreased by 6 – 8%. This applies regardless of the level of the total energy consumption.

The analysis also shows that the higher the indoor temperature, the greater energy savings will be achieved in connection with an energy upgrading. If the indoor temperature changes in connection with an energy upgrading, e.g. 2 °C, then the relative savings are reduced by 4 – 7% in a house from the 1930s and 8 – 12% in a house from the 1960s.

4.2 Internal heat gain

The internal heat gain greatly affects the energy consumption of the building and the lower the energy consumption of the building, the greater the relative importance of variations in the internal heat gain. In the non-upgraded buildings, 1 W/m^2 deviation in the internal heat gains influences the energy

consumption by 2 – 3%, for the upgraded buildings from the 1930s about 4 – 5% and the upgraded buildings from the 1960s about 5 – 6%.

The analysis also shows that the energy savings achieved are largely independent of the level of the internal heat gain if it is the same after as before. The energy-saving potential is thus largely independent of the internal heat gain. If the internal heat gain changes in connection with energy upgrading, then the relative savings are reduced by 2 – 3% in a house from the 1930s and 3 – 4% in a house from the 1960s for each 1 W/m^2 change.

4.3 Domestic hot water consumption

Consumption of domestic hot water affects the total energy consumption of the building with the same level, regardless of the building's overall energy state, and therefore the deviations in hot water consumption is most important in buildings that have undergone extensive energy upgrading. The analysis shows that for every 50 litres/m^2 per year, the consumption of hot water differs from the standard assumption of 250 litres/m^2 per year, the total energy consumption is increased/decreased by approximately 1% for the non-upgraded buildings and approximately 2 – 3% for the energy-upgraded buildings.

The analysis also shows that the energy savings achieved are largely independent of the consumption of domestic hot water, if the level of consumption is the same after as before. The energy-saving potential is thus largely independent of the consumption of domestic hot water. If the consumption of domestic hot water changes in the course of an energy upgrading e.g. increases by 50 litres/m^2 per year, then the relative savings are reduced by approximately 1% in a house from the 1930s and 1-2% in a house from the 1960s.

4.4 Air change rate

The air change rate affects the energy consumption of the building to some extent and the lower the energy consumption the greater the significance of the air change rate. In the 1930s house an increase in air change of 0.05 l/s per m^2 results in an increase in energy demand of approximately 4%. In the 1960s house, an increase in air change results in an increase in energy demand of approximately 6%.

The analysis also shows that the lower the air change rate, the greater the savings that are achieved in the context of an energy upgrading. The energy-saving potential is thus dependent on air change rate. If the air change rate increases, e.g. 0.05 l/s per m^2 in the context of an energy upgrading, then the relative savings are reduced by approximately 2% for the 1930s house and approximately 4% for the 1960s house.

4.5 Combined effects

Domestic hot water consumption does not influence the energy balance of the building and effects can be calculated independently of other parameters. The other three parameters are, however, interdependent, and the overall impact on the building's energy needs cannot be determined by a simple summation of individual effects. However, the effect of combining parameters is still quite limited and the only case where it is actually necessary to adjust the total energy savings is for the combination of “indoor temperature” and “ventilation rate”. This can be achieved by a simple calculation of the extra ventilation heat loss that occurs based on the change in temperature (compared to 20 °C) and the change in air change rate (compared to 0,13 l/s pr. m^2), i.e.:

$$\Phi_v = 1005 kg/m^3 \cdot 1{,}205 J/kgK \cdot (v_a - 0{,}13) l/s\ pr.m^2 \cdot (T_a - 20) K$$

Where v_a is the actual ventilation rate in l/s pr. m^2 and T_a is the actual temperature in °C.

The error introduced by simply adding the individual effects but taking into account the above-mentioned correction for combinations of “indoor temperature” and “ventilation rate” will be in the

order a few percent maximum. This way a method for predicting the energy saving potential can be based on similar analysis for different types of buildings and building use.

5. Conclusions

This analysis has shown that the levels of the internal heat gain and the consumption of domestic hot water only has a modest impact on the energy-saving potential of buildings, as long as the value of the parameters does not change in the course of an energy upgrading. None of these parameters are directly related to comfort, and therefore they will typically not be changed in the process.

The indoor temperature and air change rate in the building both affect the energy-saving potential. Both parameters are directly related to the comfort in the buildings and are therefore parameters that could potentially be changed in connection with an energy upgrading.

The indoor temperature is clearly the more important of the two parameters, and the results of the analysis shows that for every degree the indoor temperature is raised after an energy upgrading, the expected savings are reduced by approximately 6 – 8%, i.e. the lower the total energy demand of the building the more significant the influence of the indoor temperature.

The air change rate is less important, but it is clear that if there are large differences between the assumption of level and actual level it can affect energy savings significantly. The significance of the air change rate is highly dependent on the building's total energy consumption and the lower the energy consumption, the greater the significance of the air change rate. The results of the analysis show that for every 0.01 l/s per m^2 difference between the air change rate before and after the energy upgrading, the expected energy savings are reduced by approximately 0.4 to 0.8%, depending on the overall energy consumption. This may not sound of much, but if the air change rate changes from the minimum requirement for new buildings (0.30 l/s per m^2) to a level where it can be categorised as a leaky building (0.45 l/s per m^2), the expected energy savings are reduced by up to 12%.

Based on the analysis a relatively simple method for determining of energy savings for energy upgrading measures can be developed. The aim would be to develop a method that can predict energy savings for specific energy saving measures in a specific building, taking into account user behaviour.

6. Acknowledgements

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