Energy and financial impact of poor air tightness in existing residential buildings

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ABSTRACT

The improvement of air tightness in existing residential buildings could be triggered from the desire for better indoor comfort conditions and the expected reduction of cost for space heating. While the improvement of comfort sensation could not be easily understood from the building owner, the reduction of cost for space heating is much easier. In order to estimate the potential energy saving and the relative reduction of cost for space heating, has been calculated the annual energy saving of heating load per m³/h of infiltration for residential buildings located in various European countries. The annual reduction of cost for space heating has been estimated in absolute values (€ per m³/h) taking into account various assumptions related to the heating system and the energy source. Furthermore, it is provided a correlation between the reduction the air change rate at 50 Pa and the potential cost savings. The methodology has been implemented for estimating the potential of energy saving and the possible reduction of cost for space heating for various case studies given from existing studies.

KEYWORDS

Air tightness, Blower door test, heating load, energy conservation

INTRODUCTION

The study provides a simplified methodology for estimating the energy and financial impact of infiltration losses for residential buildings. The methodology can be applied to existing buildings and not during the design, as it requires as an input the air change rate at 50 Pa. As the methodology intend to provide a fast estimation of the potential reduction of the energy cost for heating due to poor air tightness, it cannot replace a detailed study.

The methodology has been applied to various residential buildings, taking into account air tightness measurement results given from other studies and doing appropriate assumptions.

DESCRIPTION OF THE METHODOLOGY

The results of a blower test provide the air change rate at 50 Pa (n_{50}) and usually an experienced user could propose possible improvements and estimate the potential reduction of air change rate at 50 Pa. The air change rate at 50 Pa could be used to estimate the energy losses for heating, as it can be related to infiltration rate in natural conditions (n_n).

Some existing methods which relate the two air change rates (n_{50} and n_n) are: the method of the Danish Building Research Institute, SBi (Aggerholm 2008), the Princeton method (Sherman, 1987) and the EN 13790. As the specific study is limited to European case studies, it has been selected to be used the SBi method, Eqn. 1, as it is more simple to be implemented. Following, the air flow in natural conditions and at 50 Pa in m³/h, are represented as q and q_{50} respectively.

$$q = 0.04 + 0.06 q_{50} \qquad \text{(Eqn. 1)}$$

The energy losses due to infiltration could be calculated using Eqn. 2, where V is internal insulated volume of the house (m^3), n_n is the calculated air change rate in natural conditions (h^{-1}), c_P is the thermal capacity of the air (1.005 kJ/(kg·K) at 20ºC), ρ is air density (1.205 kg/m^3 at 20ºC) and HDD is the heating degree days in Kh/a with base temperature equal with the desired operative temperature.

$$Q_{inf} = V n_n c_p \frac{24\rho}{3600} HDD \qquad \text{(Eqn. 2)}$$

There have not been taken into account the latent energy losses due to infiltration because it has been assumed that there are not existing sufficient climatic data for many places – weather stations.

It is obvious that a potential reduction of the infiltration rate will reduce energy losses and therefore the energy consumption for heating. As the final energy consumption depends on the efficiency of the heating system should be done assumptions for it. Also, there have to be done assumptions for the energy source and the cost per kWh of delivered energy. Having values of all previous parameters the cost per m³/h of infiltration and the relative cumulative cost over a time period could be estimated.

The financial cost of infiltration losses could be calculated in terms of Net Present Value, taking into account: inflation rate, savings interest rate, loan interest rate and the annual increase of fuel price. Also, it could be calculated the potential amount of cost savings due to energy conservation for heating, for a given reduction of n_{50}.

Following are given the required information for each part of the calculation methodology.

Building – heating system

As for the building and the heating systems the required information is:

- the air change rate at 50 Pa (n_{50}),
- the internal volume,
- the desired operative temperature,
- the time schedule of the heating system,
- the energy source for heating and
- the efficiency of the building system either in total or separately for the heating source, distribution system and terminal units.

Financial

In order to estimate the annual energy cost for the present year, the only required information is the fuel price per kWh. Furthermore, in order to estimate the energy cost over a time period the required information is:

- the fuel price per kWh,
- the time period for which will be done the estimation,
- the annual inflation rate,
- the percentage of the annual increase of the fuel price
- the interest rate of a saving account or
- the interest rate of a loan

Additional information

The additional information refers to:

- hourly ambient temperature in order to estimate the heating degree days, assuming as base temperature the desired operative temperature
- the CO_2 emissions for the selected fuel,

IMPLEMENTATION OF THE METHODOLOGY

Assumptions

The methodology has been implemented in order to extract the potential energy saving per m³/h, for fourteen European cities and for a predefined heating system and heating time schedule. Table 1 contains the assumptions concerning the heating system and schedule. For the specific example the operative temperature has been assumed to be 16 and 21ºC. As it has been assumed that the building has pure air tightness, the operative temperature has been defined to be one degree higher than usual (Per Ingvar Sandberg et al, 2007). The increase of the operative temperature happens in order to meet the comfort conditions, as buildings with poor air tightness tent to have building elements with lower surface temperature and higher long wave radiation asymmetry.

TABLE 1: Assumptions concerning the building and the heating system

<table>
<tr><td rowspan="5">Heating system</td><td>gas boiler</td><td colspan="2" rowspan="3">Efficiency</td><td>96 %</td></tr>
<tr><td>distribution system</td><td>97 %</td></tr>
<tr><td>radiators</td><td>95 %</td></tr>
<tr><td rowspan="2">natural gas</td><td rowspan="2">emissions</td><td>CO_2</td><td>196.3 g/kWh</td></tr>
<tr><td>NO_x</td><td>152.0 g/kWh</td></tr>
<tr><td rowspan="4">Heating schedule</td><td rowspan="4">Time / operative temperature</td><td colspan="2">00:00 – 06:00</td><td>16 ºC</td></tr>
<tr><td colspan="2">06:00 – 08:00</td><td>21 ºC</td></tr>
<tr><td colspan="2">08:00 – 17:00</td><td>16 ºC</td></tr>
<tr><td colspan="2">17:00 – 00:00</td><td>21 ºC</td></tr>
</table>

The financial assumptions refer to two different case studies. For the first case study it has been assumed that the money saved each year due to the reduction of heating cost are getting into a savings account for a time period of ten years. For the second case study, it has been assumed that the money saved each year due to the reduction of heating cost are used for the repayment of a loan, for a time period of ten years. In any case, the final savings over the period of ten years due to the reduction of heating cost are affected from the potential increase of the fuel price and the inflation rate. Table 2 contains the financial assumptions, except of the fuel prices, which are given in Table 3. The fuel prices refer to November 2011, as given to Europe's Energy Portal (www.energy.eu).

Table 3, except of the fuel prices, contains the heating degree days (HDD) for the fourteen European cities for base temperature of 20ºC and taking into account the heating schedule and relative operative temperatures given in Table 1. For calculating the heating degree days has been used hourly temperature for one meteorological year from the Meteonorm software (www.meteonorm.ch).

TABLE 2: Assumptions concerning financial issues – except fuel price

General issues	Annual inflation rate	2.5%
	Annual increase of fuel price	3.5%
Loan	Interest rate	7.0%
	Years to compare	10
Savings account	Interest rate	2.0%
	Years to compare	10

TABLE 3: Fuel prices and Heating Degree Days

Country	City	Fuel price (€/kWh)	Heating Degree Days	
			20 ºC	schedule
Belgium	Uccle	0.0646	3788	3104
Bulgaria	Sofia	0.0456	3789	3190
Denmark	Thyborn	0.1166	4222	3517
France	Paris	0.0622	3301	2671
Germany	Stuttgart	0.0615	4088	3430
Greece	Athens	0.0719	1638	1241
Ireland	Dublin	0.0573	3614	2899
Italy	Milan	0.0831	3325	2768
Netherlands	Amsterdam	0.0772	3804	3111
Poland	Warsaw	0.0552	4439	3795
Romania	Bucharest	0.0301	3694	3133
Spain	Madrid	0.0590	2758	2217
Sweden	Stockholm	0.1134	4902	4229
UK	London	0.0465	3405	2738

Results

The results refer to the final energy consumption corresponding to 1 m^3/h of infiltration in natural conditions and the relevant CO_2 and NO_X emissions for one meteorological year. Additional is given the net present value of the potential savings due to the reduction of infiltration losses per m^3/h over a time period of 10 years. The results are given for all examined places and with the assumptions given above (Table 4 and Table 5).

Also, the methodology has been applied for Stuttgart meteorological dataset, assuming various building's volumes and have been calculated the potential financial savings in relation with the possible reduction of the air change rate at 50Pa (Δn_{50}). The calculation results are given in Table 6, while Figure 1 shows the linear behavior between the reduction of air change rate at 50Pa (Δn_{50}) and the net present value of savings over a time period of 10 years, without assuming a loan.

TABLE 4: Energy and financial impact of infiltration

Country	City	Sensible infiltration losses in kWh/a per m³/h	Finally energy consumption in kWh/a per m³/h	Emissions in kgr/a per m³/h		NPV of savings in € per m³/h
				CO_2	NO_x	
Belgium	Uccle	25.06	28.62	5.62	4.35	21.20
Bulgaria	Sofia	25.76	29.42	5.78	4.47	15.38
Denmark	Thyborn	28.39	32.43	6.37	4.93	43.36
France	Paris	21.57	24.64	4.84	3.74	17.57
Germany	Stuttgart	27.69	31.63	6.21	4.81	22.30
Greece	Athens	10.02	11.44	2.25	1.74	9.43
Ireland	Dublin	23.41	26.74	5.25	4.06	17.56
Italy	Milan	22.35	25.52	5.01	3.88	24.32
Netherlands	Amsterdam	25.12	28.69	5.63	4.36	25.40
Poland	Warsaw	30.64	35.00	6.87	5.32	22.15
Romania	Bucharest	25.29	28.89	5.67	4.39	9.97
Spain	Madrid	17.90	20.45	4.01	3.11	13.83
Sweden	Stockholm	34.14	39.00	7.66	5.93	50.70
UK	London	22.10	25.25	4.96	3.84	13.46

TABLE 5: Energy and financial impact of infiltration, assuming a loan

Country	City	Sensible infiltration losses in kWh/a per m³/h	Finally energy consumption in kWh/a per m³/h	Emissions in kgr/a per m³/h		NPV of savings in € per m³/h
				CO_2	NO_x	
Belgium	Uccle	25.06	28.33	5.56	4.31	14.07
Bulgaria	Sofia	25.76	29.11	5.71	4.43	10.21
Denmark	Thyborn	28.39	32.10	6.30	4.88	28.78
France	Paris	21.57	24.38	4.79	3.71	11.66
Germany	Stuttgart	27.69	31.30	6.14	4.76	14.80
Greece	Athens	10.02	11.32	2.22	1.72	6.26
Ireland	Dublin	23.41	26.46	5.19	4.02	11.66
Italy	Milan	22.35	25.26	4.96	3.84	16.14
Netherlands	Amsterdam	25.12	28.40	5.57	4.32	16.86
Poland	Warsaw	30.64	34.63	6.80	5.26	14.70
Romania	Bucharest	25.29	28.59	5.61	4.35	6.62
Spain	Madrid	17.90	20.23	3.97	3.08	9.18
Sweden	Stockholm	34.14	38.59	7.58	5.87	33.65
UK	London	22.10	24.99	4.90	3.80	8.93

TABLE 6: Relation between reduction of air change rate at 50Pa and financial impact (Stuttgart)

Reduction of air change rate in 50Pa (Δn_{50})	NPV of savings for time period of 10years (€) for building's volume of:					
	300 m³	450 m³	600 m³	900 m³	1500 m³	3000 m³
0,20	289	434	578	867	1.445	2.890
0,40	578	867	1.156	1.734	2.890	5.780
0,60	867	1.301	1.734	2.601	4.335	8.670
0,80	1.156	1.734	2.312	3.468	5.780	11.561
1,00	1.445	2.168	2.890	4.335	7.225	14.451
1,20	1.734	2.601	3.468	5.202	8.670	17.341
1,40	2.023	3.035	4.046	6.069	10.115	20.231

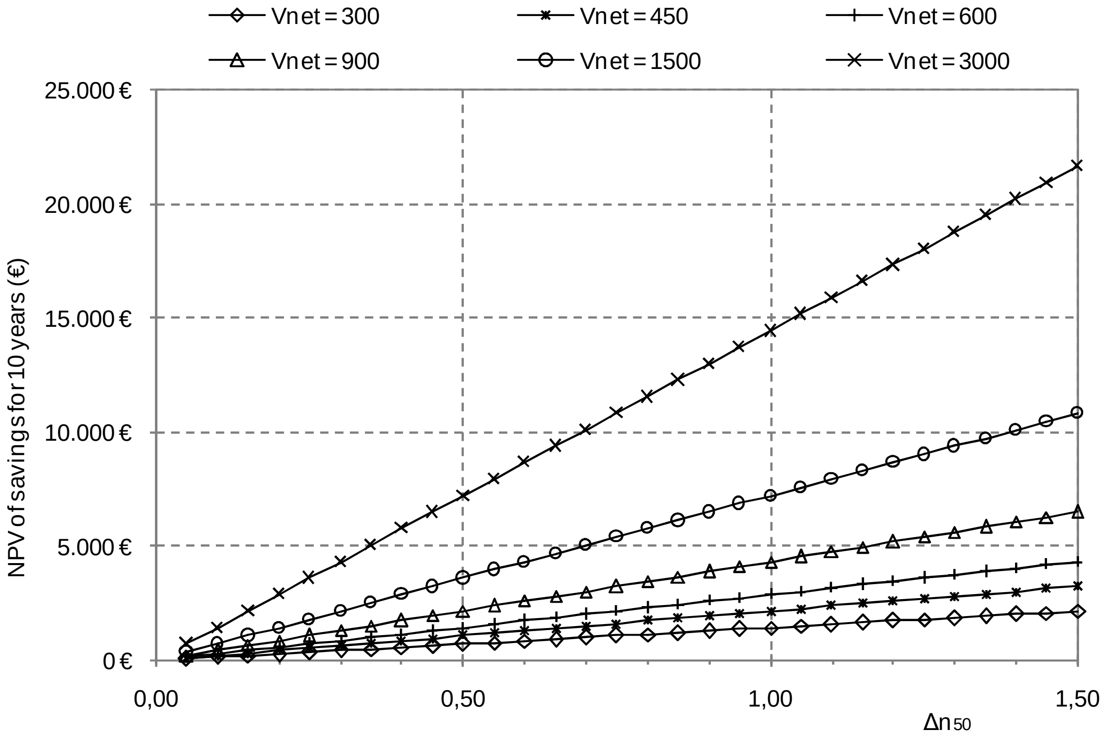

Figure 1: Reduction of air change rate at 50 Pa and NPV of savings (Stuttgart)

Implementation to specific building

The methodology has been implemented for specific buildings, using the outcomes of air tightness measurements as they are given to various published papers (A. Sfakianaki et al, Carsten Rode et al, Targo Kalamees) and making the appropriate assumptions. In all examined cases studies, the improvement of air tightness could lead to significant impacts in any of the terms of the energy, environmental or financial performance of buildings.

CONCLUSIONS

The study provides a simplified methodology for estimating the energy and financial impact of infiltration losses for existing residential buildings. The methodology does not take into account the latent losses due to ex- an infiltration and as well the impact of building's thermal mass and the dynamic performance of its systems. Therefore the methodology cannot replace a detailed study.

The methodology intends to provide a fast estimation of the potential reduction of the CO_2 emissions and energy cost for heating due to the improvement of air tightness, over a predefined time period. The results could be used to trigger buildings improvements and even more to specify the relevant financial budget.

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