Costs of retrofit measures in the Swedish residential building stock – an evaluation for three scenarios on future energy prices

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SUMMARY:
The cost of energy efficiency and CO_2 mitigation strategies for the Swedish residential building stock is modelled under three scenarios for the development of the energy system with respect to prices of energy and CO_2 emissions associated with the energy carriers used in the buildings. A baseline scenario assuming current energy prices and continuation of present trends in energy use is compared with two climate-change mitigation scenarios. The model results give that already in the Baseline scenario, it is profitable to implement energy saving measures (ESM) which reduce energy use by 30% whereas the climate change mitigation scenarios only lead to moderate increase in the profitable energy reduction. An annual increase by 0.5% in energy prices gives that a 41% reduction in energy use is profitable, while an annual increase by 1% in energy prices will only give a small additional reduction which is profitable (42% reduction).

1. Introduction

In developed countries the building stocks turnover is low and the greatest challenge for successful reduction of energy consumption and carbon dioxide (CO_2) emissions in the building sector is to find economically feasible strategies for retrofitting of existing buildings. Levine et al. (2007) showed that indeed in the building sector significant improvements are possible from applying available technologies and measures, many of which can be cost effective.

To analyse the costs and effects of such strategies, simplified methodologies and tools are required to assess which are the best steps to take according to the characteristics of an entire building stock (as opposed to detailed analysis for an individual building). Several examples in literature provide bottom-up methodologies for cost assessment of energy efficiency and CO_2 mitigation strategies for an entire building stock (see review of methodologies by Levine et al. 2007). These works have been analysed by Ürge-Vorsatz et al. (2009), who concluded that the methodologies available only consider a limited number of mitigation options, do not consider indirect costs and associated benefits, and do not take into account non-technological mitigation options. Kavgic et al. (2010) added that these methodologies should identify the effect of emission reduction strategies on indoor environmental quality. Ürge-Vorsatz et al. (2009) have compiled studies showing that the above mentioned factors might change the magnitude of the resulting potential savings and the costs, and consequently they have outlined an agenda to address such drawbacks. In line with this agenda, the authors of this work developed a simplified methodology for assessing energy efficiency and CO_2 mitigation strategies for building stocks Mata et al. (2010a). Mata et al. applied the methodology on the entire Swedish residential building for a portfolio of Energy Saving Measures (ESMs) from which potentials and costs for increased energy efficiency (€/kWh saved) together with associated reductions in CO_2 emissions (€/tCO_2 avoided) were obtained. The results suggested that, according to an estimated realistic development of the energy prices up to year 2020 (Göransson and Pettersson, 2008), the energy use and CO_2 emissions in the Swedish housing sector can be reduced by 30 to 50 % in a cost efficient way from a consumer perspective. This work continues the previous work by investigating how the profitability of the energy efficiency and CO_2 mitigation strategies change under different possible future scenarios for the energy system. A baseline scenario is compared with two climate-change mitigation scenario.

2. Methodology

2.1 Model

The analysis was performed with ECCABS model (Energy, Carbon and Costs Assessment for Building Stocks), which is a building-physics based model for assessing the effects and costs of various ESMs. The model is a bottom-up engineering model, i.e. the energy demand of individual buildings is calculated based on the physical properties of the buildings and their energy use. A building stock is described by sample buildings and the results are then scaled-up to represent a country´s building stock. Mata et al. (2010a) applied the model to the existing residential building stock in Sweden and showed that the energy use could be reduced by 55% by applying all ESMs considered (12 in total) in aggregated form and according to their cost, cheapest first. Details on the model are provided by Mata et al. (2010b).

The ECCABS model estimates investment, operation and maintenance costs for the ESMs for the building stock considered and then, based on modelling the effect on the thermal performance of the stock, calculates the cost for reducing energy use and the associated cost to reduce CO_2 emissions. This can be done for each ESM or for a combination of several measures. In the model, a measure is considered cost-effective when cost saving from applying a measure exceeds the total cost for the measure (assuming a certain interest rate). The annual energy saving cost, $Cost_E$, is written:

$$Cost_E = {}^{NAC_{EA}}/_{ES} \tag{1}$$

Where NAC_{EA} is the net annual cost of the efficiency measure (€$_{2005}$/yr) and ES is the energy saved due to the application of the measure (kWh/yr).

The net annual costs are:

$$NAC = EAC - S \tag{2}$$

$$EAC = \left({}^{C \cdot r}/_{1 - (1 + r)^{-n}}\right) + M \tag{3}$$

Where EAC is the equivalent annual cost (i.e. the annual cost of the investment required to apply the measure over its entire life) (€$_{2005}$/yr); S is the annual cost of the energy saved (€$_{2005}$/yr), based on the energy saved, ES, and on the energy prices for the different scenarios and time periods; C is the investment cost of the measure (€$_{2005}$); r is the discount rate (0-1); n is the lifetime of the measure over with the annual cost saving is supplied (yr); and M is the extra maintenance cost of the efficient alternative (€$_{2005}$/yr).

The cost of the measure, C, can be provided in € per heated area, in € per surface to be retrofitted or in € per dwelling. The costs consist of the cost of material and labour related to the ESM implementation. This means that most of the measures are assumed to be applied at the same time, such as facades or roofs renovation, and, therefore, only extra costs for energy savings are taken into account. Thus, if, for example, the facade is to be renovated, the insulating material is taken into account, but not the scaffolding, as observed in Verbeeck and Hens (2005) and recommended by Hermerlink (2009). Costs for planning, information retrieval and other client costs are not included (i.e. indirect costs have not been considered at this stage). All costs include taxes (i.e. consumer prices, excluding VAT).

The total energy saving potential per measure – the parameter ES in Equation (1) – is the same for all the scenarios and time periods. Specific values of the energy savings that could be achieved by the application of each measure are given in Table 2 based on findings by Mata et al. (2010a).

2.2 Scenarios

In this work a scenario is a description of a possible future development of the energy system in terms of energy prices and CO_2 emissions associated with the different energy carriers used in the buildings. Thus, scenarios should not be seen as an attempt to forecast the future development of the energy market but as a tool to investigate the possibilities and costs for transforming the building stock, given different futures. Three scenarios are applied to the overall European energy system (AGS, 2011):

The Baseline scenario extrapolates historical trends of increased energy use and associated CO_2 emissions.

In the Market scenario targets are set for CO_2 reduction without explicit targets for energy savings or renewable energy. It is then up to the market to find solutions in order to meet these targets. The major policy measure is a cost associated with emitting CO_2 and, as a consequence, the scenario assumes that the production of district heating and electricity will be almost CO_2 free by 2050 (by fuel shifts, some energy efficiency measures, application of renewable energy sources and carbon capture and storage technologies).

The Policy scenario is a policy driven pathway for climate change mitigation, in line with the current EU politics. This means that there are not only targets for reduction of CO_2 emissions, but also targets for energy savings and use of renewable energy sources, which will be promoted through policy instruments. Thus, although there is a cost to emit CO_2, certain amounts of renewables and energy efficiency measures are imposed.

TABLE 1. Inputs to modelling, i.e. assumptions on consumer Energy Prices (EP) (€$_{2005}$cents/kWh) and CO_2 emissions associated to the production of energy carriers used in the buildings (CI) (gCO_2/kWh), for the 10 year periods.

Year	Scenario	EPel	EPo	EPg	EPbw	EPdh	CIel	CIo	CIg	CIbw	CIdh
2010	All	12.0	9.7	8.0	7.8	8.4	15	270	400	10	70
2020	BA	8.9	9.2	7.1	5.4	8.4	15	270	400	10	70
2030	BA	8.9	9.3	7.2	3.9	8.5	15	270	400	10	70
2040	BA	8.7	9.5	7.2	3.9	8.5	15	270	400	10	70
2050	BA	8.7	9.5	7.2	3.9	8.6	15	270	400	10	70
2020	MA	13.6	10.8	8.8	8.5	9.2	38	270	400	10	70
2030	MA	14.0	11.7	9.7	9.6	9.8	45	270	400	10	70
2040	MA	14.3	12.2	10.0	10.3	10.2	34	270	400	10	70
2050	MA	15.2	12.9	10.6	11.4	10.8	25	270	400	10	70
2020	PO	12.4	10.7	8.7	8.5	9.1	27	270	400	10	70
2030	PO	11.6	11.0	9.1	9.2	9.2	21	270	400	10	70
2040	PO	12.1	11.4	9.4	10.3	9.6	19	270	400	10	70
2050	PO	12.1	12.0	9.9	11.7	10.1	19	270	400	10	70

BA= Baseline, MA=Market, PO=Policy; el=Electricity, o=Oil, g=Gas, bw=Biomass/Waste, dh=District Heating.

The implications of the scenarios for the residential sector are introduced in the model in form of different future energy prices and CO_2 emissions associated with the different energy carriers used in the buildings. Such assumptions are shown in Table 1, where one can see that energy prices exhibited an annual average decrease of 0.5% in the Baseline scenario. Reasons for this decrease are that the CO_2 tax assumed in this work on electricity, oil and gas (corresponding to 20€/ton CO_2) is only applied up to 2020, and the price of biomass is assumed to be drastically reduced in 2020. There is an annual average increase in energy prices by 0.7% in the Market scenario and by 0.5% in the Policy scenario, resulting in energy prices being on average 36% and 28% higher, respectively, in year 2050 in comparison to the Baseline (for further details, see AGS 2011). Specifically, electricity prices for Sweden are taken from AGS (2011), while the prices of the other energy carriers are based on data of average EU values from Axelsson and Harvey (2010). Distribution costs and excise taxes are added from IEA (2009), and VAT rates for the residential sector are based on current rates (EC 2010). Average CO_2 emissions from electricity production in Sweden are taken from AGS (2011).

2.3 Period of investment

When running the cost calculations according to Equation (1), the energy saving cost $Cost_E$ in each scenario is calculated in the model for every 10 year period using the inputs shown in Table 1. For example, the values for year 2010 are average values of the period 2005-2015. Thus, the energy saving cost given represents the amount of money that one would invest (if the resulting cost is positive) or earn (if the resulting cost is negative), when applying the measure any of the years of the considered 10 year period. Since the time of investment is not known, the costs per energy saved and CO_2 emissions avoided are assessed using two different approaches.

In the first approach, the costs are calculated as weighted net present values for the whole period 2010-2050 according to Equation (4), in €$_{2005}$/kWh:

$$Cost_{E_{NPV}} = \sum_{i=2010}^{i=2050} \left({Cost_{E_i}} \Big/ {(1+R)^{N_i}} \right) \tag{4}$$

Where $Cost_{E_i}$ is the annual energy saving cost as defined by Equation (1) (€/kWh); R is the discount rate (0-1); N are the years to be discounted from the investment year back to year 2005 (yr). The specific values obtained are given in Table 2. As seen in Equation (2) both the investments and the savings are annualized, therefore Equation (4) implies a continuous investment perspective for the period 2010-2050.

In the second approach, the possibility to invest in different time periods is assessed in an undiscounted way (i.e. Equation [1]) for the measures with a life time shorter than 40 years (referring to the period 2010-2050). The results are given in Table 3. For example, for the measures with a life time of 20 years, i.e. measures 5-7 and 11, the investment can be done either in the period 2010-2030 (if the building already needs retrofitting) or in second or third decade (2020-2040 or 2030-2050). One might also argue that this last option is actually not possible, since a system with lifetime of 20 years which was already installed in 2005 has to be replaced in 2025 the latest. However in such case, one would have to reinvest in the later period again. For measures with lifetimes of 15 years (measures 9, 10 and 12), the same applies. For the measures which have lifetime equal to the period assessed (40 years, measures 1 to 4, 7 and 8) the only option is to invest once during the period studied (2010-2050), therefore they are not shown in Table 3.

3. Results

3.1 Average costs over the period 2010-2050

Weighted average costs for the ESMs for the different scenarios are shown in Table 2, ranked according to their increasing cost-effectiveness for the Baseline scenario (i.e. most cost-effective on top of the table). As can be seen, the resulting ranking of the measures is very similar for all the scenarios. On the top of the ranking, a reduction by 50% of electricity for lighting and appliances appear as profitable measures (negative costs) because the investment cost is considered to be zero, since soon there will be no other choice than to buy more efficient equipment. It is also profitable to reduce indoor temperature because only the cost of the thermostats has been considered in this work. Finally, heat recovery is profitable for single family dwellings, where normally there is not a heat recovery system. In contrast on the bottom of the rank, the replacement of hydro-pumps by more efficient ones and the retrofitting of all the parts of the envelope (i.e. attics, basements and facades) appear as the most expensive ESMs.

Despite of that the ranking of the ESMs investigated is the same in the three scenarios, the average annual cost of the ESMs differ, as can be seen from Table 2. The average cost for the period 2010-2050 is -1.2 €cent/kWh/yr in the Baseline scenario, -1.7 €cent/kWh/yr for the Market scenario and -1.3 €cent/kWh/yr for the Policy scenario. The results are of course influenced by changes in energy prices. Starting with the low priced Baseline scenario, simulations give heat recovery and reduction of power used for the production of hot water as low cost ESMs. As for the retrofitting of the envelope, replacement of windows can be much less expensive than the retrofitting of the facade or basement, while the potential savings *ES* to be achieved by each measure are similar. Second, higher energy prices in the Market scenario give ESMs as more profitable than in the other scenarios. Thus in this scenario the upgrading of ventilation systems with heat recovery and the reduction of hot water demand also show as profitable. Finally, medium prices assumed for the Policy scenario lead to an intermediate level of profitability for all the ESMs.

TABLE 2. Average annual costs of the measures per building (€$_{2005}$cents/kWh), for the period 2010-2050. Rightmost column shows the total technical potential Energy Saved (ES) for each measure (% of the baseline consumption), as given in Mata et al. (2010a).

Measure No.	Measure description	Baseline	Market	Policy	ES (%)
	Average	-1.2	-1.7	-1.3	Total 65.5
8	50% reduction in power for lighting	-15.4	-16.1	-14.7	1.0
7	50% reduction in power for appliances	-14.9	-15.5	-14.2	0.3
12	Use of thermostats to reduce indoor air temperature by 1.2ºC down to 20ºC	-3.5	-4.0	-3.9	13.8
5	Ventilation with heat recovery (SFD)	-0.4	-1.0	-0.9	12.4
9	Reduction of power used for the production of hot water to 0.80 W/m^2 A$_{temp}$ (SFD)	0.2	-0.4	-0.2	2.7
10	Reduction of power used for the production of hot water to 1.10 W/m^2 A$_{temp}$[1] (MFD)	0.8	0.2	0.3	2.2
6	Ventilation with heat recovery (MFD)	1.0	0.5	0.5	10.0
4	Replacement of windows (U-value)	1.2	0.7	0.8	6.7
3	Change of U-value of attics/roofs (different types)	5.3	4.8	4.9	2.8
11	Hydro Pump Replacement	10.0	9.5	9.7	0.6
1	Change of U-value of cellars/basements	12.4	11.9	12.0	5.5
2	Change of U-value of facades (different types)	16.0	15.5	15.6	7.5

SFD= Single-Family Dwelling, MFD= Multi-Family Dwelling, A$_{temp}$= Heated floor area.

If one assumes that only the profitable measures would be applied up to the year 2050, energy demand in the Swedish housing could be reduced by 30% in the Baseline scenario, by 42% in the Market scenario and by 41 % in the Policy scenario. However, as shown in Table 2, the profitability is higher in a Market scenario. It is well known that cost efficient measures are often not implemented due to presence of what is sometimes referred to market failures and barriers. Thus, not all of cost efficient measures in Table 2 can be expected to be implemented. On the other hand, there may of course be a

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[1] Heated floor area (A$_{temp}$) is the floor area of spaces to be heated to more than 10 ºC limited by the inner side of the building envelope. A$_{temp}$ is the measure used in the mandatory building codes, and also is the unit used in the definition of Swedish Environmental Objectives Council’s (EOC 2011*)* efficiency targets.

different situation in some decades from now, considering policies, available technologies and institutional frameworks etc, which could make more of the measures to be implemented.

Comparing the results of this work with literature, agreement is found with Levine et al. (2007) who report that worldwide, energy-efficient lighting is identified as the most attractive measure, in terms of both reduction potential and cost effectiveness. In addition, Levine et al. conclude that in developed countries it is "interesting" to upgrade water heating equipment (including EU-15 as investigated by Joosen and Blok, 2001). Yet, profitable measures differ between EU countries. For instance SGSR (2009) report for Scottish housing a similar ranking of measures to the ranking presented in Table 2, namely (1) short term upgrade package (unspecified), (2) low energy lights, (3) advanced heating controls, (4) Air Source Heat Pump and (5) cavity wall insulation. Verbeeck and Hens (2005) obtain a different ranking of the cost effectiveness for ESMs applied to Belgian houses[2], namely (1) insulation of the roof, (2) insulation of the floor (3), thermally better performing glazing, (4) more energy efficient heating system, (5) renewable energy systems. The reason for these differences is likely to be due to differences in regional condition (e.g. building stock and climate).

3.2 Average costs for the different investment periods

Table 3 shows an undiscounted assessment of the profitability of the different time periods in which one could make the investment. For measures which are cost-efficient during the entire period 2010-2050 (negative values in Table 2, measures 5, 9 and 12), in both Market and Policy scenarios they will also be cost efficient, even if they are implemented in later periods. Thus, even when it might turn up to 62% more profitable in the Market scenario and up to 51% in the Policy scenario to invest in the later periods (since the energy prices are then higher, as shown in Table 3), this would result in "a loss" because of lost opportunities during the time period before investment is made. This leads to some obvious conclusions. Firstly, if the measure is profitable, greater savings are made with an early investment. In addition, for some of the measures which are not profitable the investment may become profitable in the future when, according to the scenarios assessed, the energy prices are higher (for measure 10 from year 2020 and for measure 6 from year 2030 in the Market scenario). Similar results are obtained in the Policy scenario, but with a 10 years delay.

TABLE 3. Undiscounted average annual costs per building of the measures for the scenarios (€$_{2005}$cents/kWh), for different time periods in which the investment could be made. The measures are presented by their order number; see Table 2 for a full description.

	Period of time of the investment (i.e. application of the measure)						
	For measures whose lifetime is 15 years				For measures whose lifetime is 20 years		
Measure no.	2010-20	2020-30	2030-40	2040-50	2010-30	2020-30	2030-50
Market scenario							
5	-	-	-	-	-2.3	-3.0	-3.7
6	-	-	-	-	0.6	-0.2	-1.0
9	-0.7	-1.6	-2.2	-2.9	-	-	-
10	0.6	-0.3	-1.0	-1.8	-	-	-
11	-	-	-	-	18.4	17.6	17.1
12	-8.1	-8.9	-9.5	-10.2	-	-	-
Policy scenario							
5	-	-	-	-	-1.7	-2.1	-2.6
6	-	-	-	-	1.0	0.3	-0.4
9	-0.4	-0.6	-0.9	-1.5	-	-	-
10	0.7	0.2	-0.4	-1.3	-	-	-
11	-	-	-	-	19.6	19.6	19.7
12	-7.8	-8.0	-8.4	-9.0	-	-	-

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[2] The sample studied represented 63% of Belgian real state.

4. Conclusions

The cost of energy efficiency and CO_2 mitigation strategies for the Swedish residential building stock has been assessed under three scenarios for the development of the energy system with respect to prices of energy and CO_2 emissions associated with production of the energy carriers used in the buildings. Under the assumptions made, an annual increase by 0.7% in energy prices (corresponding to the Market scenario) would lead to a reduction by12% in energy use (compared to the baseline) by applying profitable ESMs, while from an annual increase by 0.5% in energy prices (corresponding to the Policy scenario) a reduction by11% in energy (compared to the baseline) is achievable by applying profitable ESMs. As a sensitivity analysis, we have tested to double the energy prices of the Market scenario (72% increase compared to baseline prices in 2050, corresponding to an annual increase by 1% of energy prices throughout the period 2010-2050), which gave 17% more cost effective energy savings than in the baseline. However, the profitability of applying the cost efficient ESMs are the highest in the Market scenario. Another more obvious conclusion is that the more profitable a measure is the more there is to gain with implementing it as soon as possible, while some of the measures require higher prices of energy to become profitable.

Improvements in energy end-use efficiency that have been reported to be profitable in a similar way as reported in this work (based on direct costs), are often not undertaken by consumers through their daily market decisions. Thus, one cannot expect the cost efficient potentials of this paper to be implemented in reality (cf. Wilson and Swisher (1993) and Bailie et al. (1996) and more recently Brown (2004), Jaffe et al. (2004) and Jaccard (2004, 2009). Further work is required to understand how the cost efficient potential identified in this work can be realized, e.g. incorporating indirect costs and analysing the additional benefits associated with implementing energy saving strategies in line with what has been proposed by Ürge-Vorsatz et al. (2009) and Kavgic et al. (2010). In this context, it can be noted that the Directive on Buildings Energy Performance (EPDB) 2010/131/EU EPBD recast will only refer to direct costs.

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