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Finding the balance between energy efficiency measures and renewable energy measures in building renovation: An assessment based on generic calculations in 8 European countries

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Abstract

Within the framework of the IEA Energy in Buildings and Communities Programme's Annex 56 (Cost effective energy and carbon emissions optimization in building renovation), generic calculations have been carried out to investigate the balance, synergies and trade-offs between renewable energy measures on the one hand, and energy efficiency measures on the other hand. The assessment was carried out for Austria, Denmark, Italy, Norway, Portugal, Sweden, Switzerland, and Spain. Results of this investigation show that in many cases, the cost-optimal renovation package for energy efficiency measures on the building envelope in a given building is the same regardless of the type of energy carrier being used. Furthermore, a switch to renewable energy sources has been found to reduce emissions more strongly than energy efficiency measures, often also at lower costs.

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Keywords: energy efficiency, renewable energies, building renovation, cost effectiveness

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1. Introduction

The reduction of energy use and greenhouse gas emissions in existing buildings is a major challenge. Until now related standards and regulations have mainly focused on energy efficiency measures reducing energy need; however, measures based on renewable energies might to some extent reach environmental objectives more cost-effectively in building renovation. Consequently, there is a need to investigate the balance between these two types of measures and related implications for renovation strategies as well as design of and target setting in standards and regulations.

2. Method

Generic calculations have been carried out for Austria, Denmark, Italy, Norway, Portugal, Sweden, Switzerland, and Spain. They were based on reference buildings from these countries, related climate conditions, prices, primary energy factors and greenhouse gas emission factors of different energy carriers, conversion efficiencies of the heating systems, as well as costs and effects of different renovation measures comprising both measures reducing energy need and measures to use renewable energy. The life-cycle-cost and cost-effectiveness calculations were carried out dynamically with the annuity method. The INSPIRE tool was used to carry out the calculations.

Table 1 summarizes the assumptions made related to the generic reference buildings. By default, a 30% price increase for energy prices was assumed for the 40-years period investigated compared to prices from 2010, which is compatible with the price increases suggested to take into account by the EPBD regulatory framework.[1] A real interest rate of 3% per year is used. Emission factors and primary energy factors include upstream emissions associated with the production, transport and delivery of these energy carriers. Country mixes for electricity are based on the sources of electricity consumed. For Norway, the import and export of guarantees of origin is also taken into account.

Table 1. Assumed characteristics of reference buildings for Austria, Denmark, Italy, Norway, Portugal, Spain, Sweden, and Switzerland before renovation. SFB means single-family building, MFB multi-family building.

Parameter	Unit	Austria – SFB	Denmark – SFB	Italy – MFB	Norway – SFB	Portugal – SFB	Spain – MFB	Sweden – SFB	Switzerland – SFB
Gross heated floor area	m^2	242	108	1804	113	156	1872	125	210
Façade area (exkl. windows)	m^2	185	90	1230	146	115	2049	111	206
Roof area pitched	m^2	181	130	-	54	81	416	-	120
Roof area flat	m^2			361		5.4	-	106	
Attic floor	m^2		108	-			-	-	
Area of windows to North	m^2	10	5.9	113	2	2.7	-	7.3	3.3
Area of windows to East	m^2	9.1	1.3	113	1.7	8.6	177	3.7	8.3
Area of windows to South	m^2	10	14	-	14	5.6	194	7.3	13
Area of windows to West	m^2	9.1	3.2	-		11	-	3.7	8.3
Area of ceiling of cellar	m^2	145	108	361	51	74	312	106	80
Average gross heated floor area per	m^2	60	27	30	28	31	40	32	60

Parameter	Unit	Austria – SFB	Denmark – SFB	Italy – MFB	Norway – SFB	Portugal – SFB	Spain – MFB	Sweden – SFB	Switzerland – SFB
person									
Typical indoor temperature (for calculations)	°C	20	20	min 20 winter / max 25 summer	20	min 20 winter / max 25 summer	20	21	20
Average electricity consumption per year and m^2 (excluding heating, cooling, ventilation)	kWh/ $(a*m^2)$	22	44	24	27	24	49	25	22
U-value façade	W/ (m^2*K)	1.4	0.46	1.15	0.5	1.1	1.3	0.3	1.0
U-value roof pitched	W/ (m^2*K)	0.9	0.39	-	0.4	2.5	1.8	-	0.85
U-value attic floor	W/ (m^2*K)			-			-	-	1
U-value roof flat	W/ (m^2*K)			1.5		2.5	-	0.21	1
U-value windows	W/ (m^2*K)	2.9	2.6	4.9	2.7	3.9	3.5	2.3	3
g-value windows	Factor	0.76	0.75	0.86	0.71	0.88	0.80	0.7	0.75
U-value ceiling of cellar	W/ (m^2*K)	0.97	0.9	1.25	0.5	1.6	2.0	0.27	0.9
Energy need for hot water	kWh/ $(a*m^2)$	14	22	17	27	25	26	18	14
Energy need for cooling	kWh/ $(a*m^2)$			7.6		1.8			

For each of the reference buildings investigated, series of measures are defined and applied in calculations as renovation packages.[2],[3],[4] Starting from the reference case, which implies some rehabilitation measures without improving the energy performance, nine renovation packages are investigated denominated M1 to M9 which have progressive ambition levels related to the resulting energy performance of the building. Renovation packages distinguish themselves both by the number of building elements included in improvement of energy performance, and in the thickness of the chosen insulation or in the U-value of the chosen window. Table 2 summarizes the related assumptions. A replacement of the heating system is assumed in all cases. For each reference building, combinations with three different types of heating systems are considered.

Table 2. Renovation packages investigated for the different reference buildings. "Ref" is the reference case and means a refurbishment to restore functionality, without improvement of energy performance; M1 to M9 are the renovation packages. Material is abbreviated as follows: MW for mineral wool, GR for granulate, CM for a cement/glass wool composite material.The U-value of the window refers to the entire window.

Renovation package	Austria – SFB	Denmark – SFB	Italy – MFB	Norway – SFB	Portugal – SFB	Spain – MFB	Sweden – SFB	Switzerland – SFB
Ref	Wall, windows repainted Roof refurbished	Joints in wall repaired; windows repainted	Wall and roof refur-bished, windows repainted, repaired	Wall refur-bished, windows repainted and repaired	Wall refur-bished, roof repaired, windows repainted	Wall repaired, roof refurbished	Wall and, roof refur-bished, windows repainted, repaired	Wall repaired and repainted, roof refurbished

Renovation package	Austria – SFB	Denmark – SFB	Italy – MFB	Norway – SFB	Portugal – SFB	Spain – MFB	Sweden – SFB	Switzerland – SFB
M1	Wall: 12 cm MW	Cellar: 8 cm MW	Roof: 6 cm EPS	Windows U: 1.2	Roof: 5 cm XPS	Wall: 12 cm CM	Wall: 6 cm MW	Wall: 12 cm MW
M2	Wall: 20 cm MW	Cellar: 12 cm MW	Roof: 8 cm EPS	Windows U: 0.8	Roof: 8 cm XPS	Wall: 20 cm CM	Wall: 16 cm MW	Wall: 30 cm MW
M3	Wall: 40 cm MW	M2 + Roof: 14 cm GR	M2 + 5 cm EPS	Windows U: 0.7	M2 + Cellar: 4 cm XPS	Wall: 30 cm CM	Wall: 30 cm MW	M2 + Roof: 12 cm MW
M4	M3 + Roof: 14 cm MW	M2 + Roof: 30 cm GR	M2 + 6 cm EPS	M3 + Cellar: 8 cm MW	M2 + Cellar: 5 cm XPS	M3 + Roof: 14 cm	M3 + Roof: 14 cm MW	M2 + Roof: 36 cm MW
M5	M3 + Roof: 30 cm MW	M4 + Windows U: 1.6	M4 + Windows U: 3	M3 + Cellar: 12 cm MW	M4 + Wall: 4 cm EPS	M3 + Roof: 20 cm	M3 + Roof: 30 cm MW	M4 + Cellar 10 cm MW
M6	M5 + Cellar: 8 cm MW	M4 + Windows U: 1.0	M4 + Windows U: 2.4	M5 + Roof: 20 cm MW	M4 + Wall: 6 cm EPS	M5 + Cellar: 8 cm	M5 + Cellar: 8 cm MW	M4 + Cellar 16 cm MW
M7	M5 + Cellar: 12 MW	M4 + Windows U: 0.7	M6 + Wall: 4 cm EPS	M5 + Roof: 44 cm MW, airtight	M6 + Windows U 2.7	M5 + Cellar: 12 cm	M5 + Cellar: 12 cm MW	M6 + Windows U: 1.3
M8	M7 + Windows U: 1.0	M7 + Wall: 12 cm MW	M6 + Wall: 6 cm EPS	M7 + Wall: 15 cm MW	M6 + Windows U: 2.5	M7 + Windows: U: 2.7	M7 + Windows U 1.8	M6 + Windows U: 1.0
M9	M7 + Windows U: 0.7	M7 + Wall: 30 cm MW	-	M7 + Wall: 40 cm MW	M6 + Windows U: 2.3	M7 + Windows: U: 1.0	M7 + Windows U 1.0	M6 + Windows U: 0.8

3. Results

Figures 1 to 3 illustrate for three of the countries investigated the evaluation that was carried out. Resulting cost effectiveness, greenhouse gas emissions and primary energy use of renovation packages with different heating systems were compared, on a yearly basis and specific per m2 heated area. In each graph, three different curves are shown, representing the application of the different renovation packages on the building envelope in combination with the installation of different heating systems. Each dot in the curves represents the application of a different renovation package. The point with highest emissions or highest primary energy use represents the reference case. As more measures are added to the renovation packages, emissions and primary energy use decrease.

Results of this investigation show that in many cases, the cost-optimal renovation package for energy efficiency measures on the building envelope in a given building is the same regardless of the type of energy carrier being used. This suggests that in many cases energy efficiency measures and renewable energy measures do not adversely affect each other. The assessment also shows that the number of building elements included in building renovation determines energy performance of the building and cost-effectiveness of the building renovation more than the efficiency levels of single building elements. Furthermore, a switch to the renewable energy sources investigated here, mainly heat pumps and wood pellets, has been found to reduce emissions more strongly than energy efficiency measures, often also at lower costs.

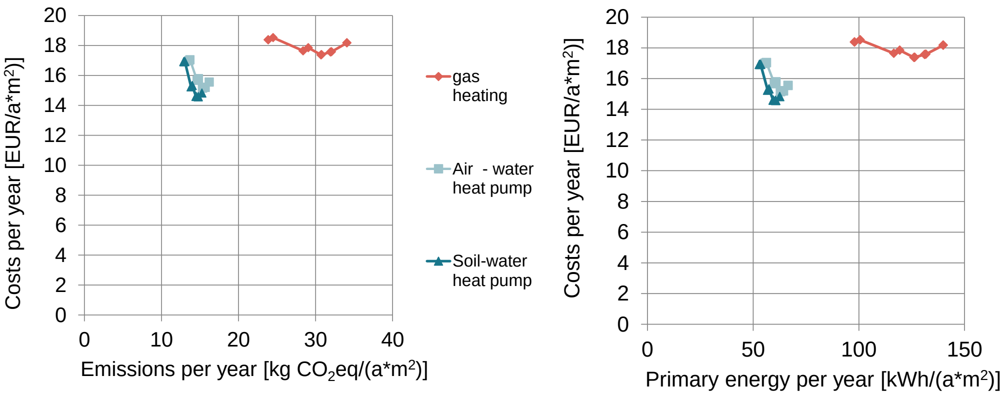

Fig. 1. Comparison of cost effectiveness of energy efficiency renovation measures for different heating systems and related impacts on greenhouse gas emissions (left) and primary energy use (right) in a multi-family building in **Italy**

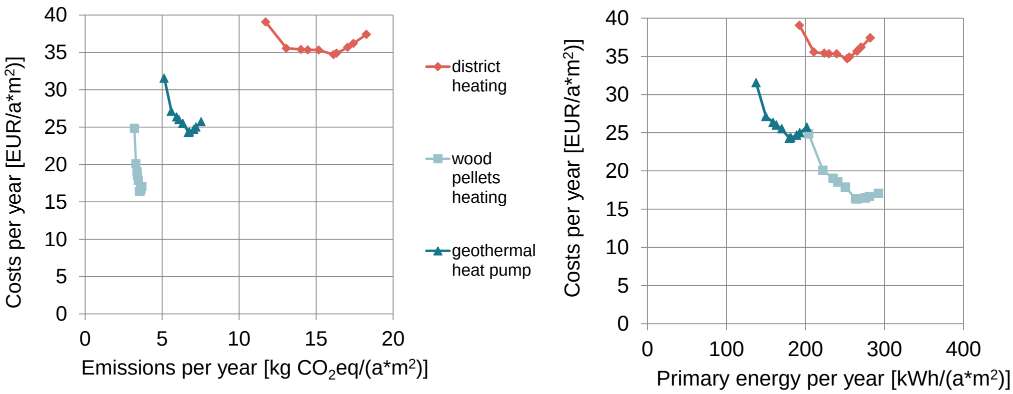

Fig. 2. Comparison of cost effectiveness of energy efficiency renovation measures for different heating systems and related impacts on greenhouse gas emissions (left) and primary energy use (right) in a single-family building in **Sweden**

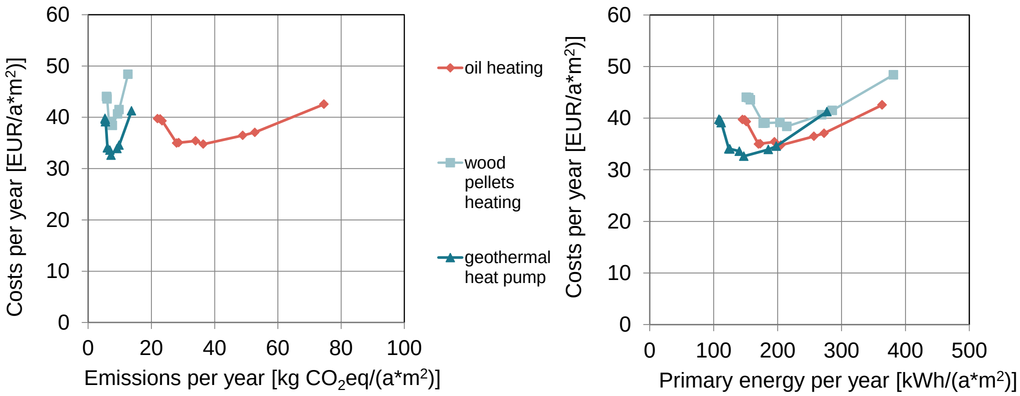

Fig. 3. Comparison of cost effectiveness of energy efficiency renovation measures for different heating systems and related impacts on greenhouse gas emissions (left) and primary energy use (right) in a single-family building in **Switzerland**

Conclusions

As heating systems based on renewable energies usually have lower annual operational energy costs than conventional heating systems, it could be expected that the cost-optimal energy efficiency level of the building envelope is already reached at a lower ambition level, if a switch to renewable energies is carried out. However, the results show that if measures reducing energy need are combined with a replacement of the heating system, there are to a large extent synergies and not trade-offs between energy efficiency measures reducing energy need and renewable energy measures. This can be explained by the fact that demand side measures reduce peak capacity of the heating system which reduces costs more strongly for renewable energy systems with higher initial investment costs than for conventional heating systems. For heat pumps, there is an additional synergy between energy efficiency measures and renewable energy measures, as heat pumps work more efficiently if the energy need is lowered by energy efficiency measures on the building envelope. It could also be shown that in order to reduce the impact of buildings on primary energy use and greenhouse gas emissions, it is advisable to promote the renovation of several elements of the building, rather than setting only higher energy efficiency levels for individual building elements. To reduce greenhouse gas emissions, it is furthermore recommendable to promote more strongly a switch to renewable energies. The results underline the importance of changing to a renewable energy based heating system and to combine this with energy efficiency measures on the building envelope in order create synergies.

The findings are specific to the reference buildings investigated, yet these reference buildings are drawn from different countries and take into account different framework conditions, which strengthens the conclusions derived. Nevertheless, the results remain sensitive to several assumptions, in particular to energy prices and the energy performance of the buildings prior to renovation. The results can be further tested and refined by pursuing the research on the input data, by extending the comparisons to more reference buildings for other building types, energy characteristics, countries, or climate zones, and by taking into account also other renovation measures which are not described here.

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