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Analysis of cost-effective energy efficiency measures for thermal envelope of a multi-apartment building in Sweden

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ABSTRACT

A large potential for energy savings can be found in building envelopes of the existing Swedish dwelling stock. This study analyzes the final energy savings and cost implications of energy efficiency measures for an existing multi-apartment building in Sweden. Energy efficiency improvements consisting of high-performance windows as well as doors, and additional insulation to attic floor and exterior walls were modelled to the building's thermal envelope. Dynamic energy balance simulations were performed to determine the final energy savings of the improvements. The cost-effectiveness of the improvements were then analyzed considering the net present value of the energy cost savings and the investment costs of the improvement measures. The results showed that additional insulation to the attic floor is the only cost-effective measure for the building under the existing operating conditions. The other improvement measures give high final energy savings but are not cost effective due to their high investment costs.

Keywords: energy efficiency, cost effective renovation, building envelope, final energy savings, space heating

1. INTRODUCTION

Energy consumption in buildings has been a topical issue in European nations since the oil crisis in the early 1970s. In Sweden, the building sector accounts for approximately 40% of the total final energy use [1]. In this sector, multi-apartment buildings covered 29% of the total heated floor area and are located majorly in populated areas covered by district heating. Large final energy savings may be achieved when existing buildings are renovated to the passive-house criteria or at least to achieve the current Swedish building code's energy level [2]. Poor thermal insulation in exiting dwellings results in high heat losses through the building envelope and hence in low thermal comfort for building occupants. A set of energy efficiency measures (EEMs) can be integrated into the building envelope to reduce thermal losses and thereby lower energy demand for space heating.

Previous studies [2-7] have analyzed the effects of applying energy efficient measures to thermal envelopes of existing buildings. These have shown that providing improved thermal insulations to walls, roofs and floors reduce heat losses through these components, helping to maintain acceptable thermal comfort indoors [8]. Ekström and Blomsterberg [9] found that increasing the thickness of insulation in external walls of old single family buildings in southern Sweden can reduce the annual final energy use by up to 60%. In addition to the type, the thickness and point of location affect the performance of insulation in buildings [10]. Factors such as climate conditions, availability and costs affect the choice of insulation material [10]. Analyzing different insulation materials and comparing their performance will give a better understanding in the decision making process of building retrofitting. Gustavsson et al. [3] found that replacing old windows and doors to new ones with lower thermal transmittance coefficient can decrease the space heating demand by up to 26% for a multi-family building in Sweden [2].

A key challenge in energy renovation projects is to achieve high final energy savings while realizing cost effectiveness. Several studies [11-13] have investigated the economic benefits of applying energy efficiency measures to existing buildings. The selection of energy efficiency measures for a particular building is a multi-objective optimization process which depends on various parameters including specific building characteristics, budgetary constraints, building function and building envelope. Most studies use the net present value method (NPV) for economic analysis and optimization of building energy efficiency measures [12, 14, 15]. Cost optimal analysis is influenced by economic parameters such as real discount rates and annual increase in energy prices.

This study analyzes the implications of EEMs for the thermal envelope of an existing multi-apartment building in Sweden, focusing on space heating final

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energy savings and cost-effectiveness. The EEMs studied are additional insulation to attic floor and exterior walls, and replacement of old windows and doors with high performance types.

2. METHOD

A simulation model was developed to analyze the implications of EEMs for thermal envelope improvement of a case-study building. Final energy use after implementing the EEMs were compared with the building's initial final energy use, to evaluate the effect of the EEMs on space heating demand. Finally, the NPV of the energy cost savings was calculated and compared with the investment costs of the EEMs, to determine the cost-effectiveness of the EEMs.

2.1. Case-study building

The selected building for this study is located in Växjö, Sweden (latitude 56° 88′ N, longitude 14° 81′ E) and was built within the million homes program in the late 1960s. This concrete frame building has 3-stories with total heated floor area and ventilated volume of 1223 m^2 and 3173 m^3, respectively. Fig. 1 shows a south view of the analyzed building. Currently, the building is heated by a biomass-based district heating system. Airtightness of the buildings is assumed to be 0.8 $l/s\ m^2$ at differential pressure of +/- 50 Pa [16]. The ventilation is distributed by a mechanical exhaust system at a constant flow rate of 0.35 $l/m^2/s$. Table 1 shows the thermal transmittance values and areas of the studied building's envelope components

Fig. 1. South view of the case study building

Table1: Thermal transmittance (U-values) and areas for the building envelope components.

Building envelope component	U-value [W/ m^2 K]	Total Area [m^2]
Windows	2.90	92.7
Doors	3.00	97.9
Attic floor	0.51	407.7
Ground floor	2.70	407.7
Exterior walls	0.32	557.4

2.2. Modelling of energy efficient measures

Different measures to improve the building's envelope components were analyzed. For the attic floor and exterior walls, additional thermal insulation are analyzed. The considered insulation material is mineral wool with thermal conductivity of 0.04 W/m K. This value is assumed to remain constant for 50 years, during the lifespan of the retrofitted building. The existing windows and doors are assumed to replace to ones with low thermal transmittance coefficients. In all the cases, the supply and distribution of heat based on water borne radiators are assumed to be maintained.

Energy balance simulations were performed to determine the final energy savings of the energy efficiency improvements. The simulation tool used is IDA ICE 4.7 [17]. This innovative software provides whole year detailed and dynamic multi-zone simulation which allow for analysis of indoor climate and energy use in buildings. The simulations were based on the weather file for the city of Växjö, Sweden, obtained from the Meteonorm database [17]. Occupancy schedules were constructed and assumed to have constant profile over the year. Internal heat gain from occupants had a mean value of 1.0 W/m^2. Schedules for lighting and mechanical equipment were made and resulted in a mean internal gain of 3.4 W/m^2 [18]. Temperature control set points were 21 C˚ inside the apartments and 18 C˚ in the common areas [18]. Fig. 2 shows a three dimensional model of the case study building and its floor plan.

To determine the cost effectiveness of the improvements measures, the investment costs were calculated and compared with the NPV of the saved energy costs. Investment costs were estimated based on renovation work tariff in Sweden [19]. The NPV of the saved energy was calculated according to (Eq. 1), for a 50-year period. All costs were presented in Euros using the exchange rate of 1€ = 10.59 SEK for 2019 [20].

$$NPV = \sum_{i=1}^{n} \frac{Fi}{(1+r)^i} \tag{1}$$

Where F is the annual saved energy cost for the year i; n is the number of years; r is the real discount rate. The EEMs were assumed to have a 50-year life span.

The saved energy cost is calculated using the district heating tariff for Växjö, from the municipal district heat supplier, VEAB [21]. The tariff consists of energy, capacity and flow costs and is provided in Table 2. The energy prices are assumed to have an annual increase of 2% and the real discount rate is assumed to be 4% [1] [22].

Table 2: District heating prices in Växjö [21].

Season	Energy [€/ kWh]	Capacity [€/ kW]	Flow [€/ m³]
Winter	0.041	111.54	0.473
Summer	0.024		

The ratio of investment costs to NPV of saved final energy cost for 50 years was calculated for each implemented EEM. The measure is considered cost effective if the ratio does not exceed 1.

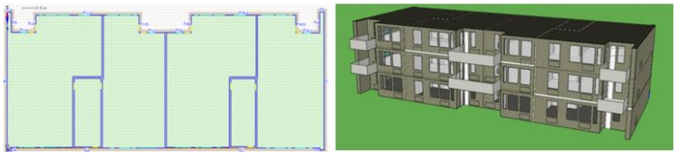

Fig. 2. Floor plan shows the zone division of the housing units (left), 3D view of the modeled building in IDA ICE (right)

3. Results

The building in its initial state has annual energy demand for space heating, domestic hot water and ventilation electricity of 97.2, 25.0 and 4.0 kWh/m^2, respectively. Table 3 shows the final energy savings for space heating after improving the insulation of attic floor.

Table 3: Different insulation thicknesses, final energy savings of space heating and improved U-values for the attic floor.

Added insulation thickness [mm]	U-Value [W/ m^2 K]	Annual final energy for space heating [kWh/m^2]	Annual saved final energy [kWh/m^2]
0	0.510	97.2	-
50	0.314	92.6	4.6
100	0.225	90.2	7.0
150	0.176	88.5	8.7
200	0.144	87.3	9.9
250	0.122	86.2	11.0
300	0.106	85.7	11.5
350	0.094	85.4	11.8
400	0.084	85.1	12.1

The annual final energy savings of additional insulation to the exterior walls are presented in Table 4. The table also shows the changes in U-values when applying different thicknesses of external wall insulation to the building.

Table 4: Different insulation thicknesses, final energy savings of space heating and improved U-values for the exterior walls.

Added insulation thickness [mm]	U-Value [W/ m^2 K]	Annual final energy for space heating [kWh/m^2]	Annual saved final energy [kWh/m^2]
0	0.323	97.2	-
45	0.235	93.7	3.5
70	0.204	92.1	5.1
95	0.181	90.8	6.4
120	0.163	89.7	7.5
145	0.148	88.5	8.7
170	0.135	87.8	9.4
195	0.130	86.8	10.4
215	0.125	86.4	10.8
240	0.109	86.1	11.1
265	0.102	85.7	11.5
290	0.096	85.5	11.7
340	0.086	85.1	12.1
410	0.075	84.5	12.7
510	0.063	83.9	13.3

Tables 5 and 6 show the reduction in final energy for space heating after replacement of windows and doors, respectively.

Table 5: Annual energy savings from replacing existing windows with lower U-value units.

U-value [W/ m^2 K]	Annual final energy for space heating [kWh/m^2]	Annual saved final energy [kWh/m^2]
2.9 (existing)	97.2	-
1.9	90.1	7.1
1.1	87.1	10.1
0.8	85.8	11.4

Table 6: Annual energy savings from replacing existing doors with lower u-value units.

U-value [W/ m^2 K]	Annual final energy for space heating [kWh/m^2]	Annual saved final energy [kWh/m^2]
3.0 (existing)	97.2	-
1.1	92.9	4.3

Changing the existing windows U-value from 2.9 to 0.8 W/ m^2 K lowered the annual final energy for space heating by 11.7%. Improved doors resulted in 4.4% reduction of the annual final energy for space heating.

The investment costs for additional insulation to the attic floor and NPVs of the saved final energy cost, and their resulting ratios are presented in Table 7. The most cost-effective insulation thickness for the attic floor is 100 mm. Applying this results in a total decrease of 7.2% of the annual final energy for space heating of the building.

Table 7: Investment costs and NPVs of saved final energy cost after adding insulation to the attic floor.

Added insulation thickness [mm]	Investment cost [€]	NPV of saved energy [€]	Investment cost /NPV for saved energy
50	3,130	11,886	0.26
100	4,164	18,584	0.22
150	7,294	23,123	0.32
200	8,327	26,678	0.31
250	11,458	29,738	0.39
300	12,491	31,073	0.40
350	11,187	31,710	0.35
400	12,220	32,205	0.38

Table 8 shows the investment costs and NPV of saved energy cost for additional insulation to the exterior walls. Figure 3 shows the resulting ratios, vis-à-vis the additional insulation thicknesses.

Table 8: Investment costs and NPV of saved final energy cost after adding insulation to the exterior walls.

Added insulation thickness [mm]	Investment cost [€]	NPV of saved energy	Investment cost /NPV for saved energy
45	37,608	8,985	4.19
70	45,688	14,221	3.21
95	41,182	16,656	2.47
120	42,092	19,661	2.14
145	44,882	22,891	1.96
170	45,812	24,941	1.84
195	46,736	27,603	1.69
215	51,420	29,138	1.77
240	52,473	29,449	1.78
265	53,428	30,461	1.75
290	54,383	30,887	1.76
340	56,994	32,157	1.77
410	59,671	33,779	1.77
510	63,455	34,812	1.82

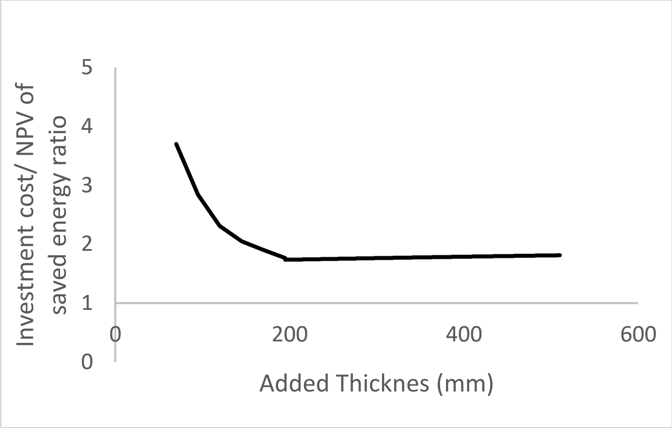

Fig 3. Relationship between the ratio of investment cost to NPV of saved energy and added thickness for exterior walls.

Fig.3 shows that the insulation thickness which yields the highest energy saving with lowest investment thickness is 195 mm. Adding this amount of insulation reduce the annual final energy for space heating by 11%. However, this measure is still not cost effective as the investment costs is higher than cost of saved energy for 50 years.

Table 9 presents the investment costs and NPV of saved energy cost when windows and doors are improved.

Table 9: Investment costs and NPVs of saved final energy cost after replacing windows and doors.

U-value [W/ m^2 K]	Investment cost [€]	NPV of saved energy [€]	Investment cost/ NPV of saved energy
Windows			
1.9	47087	20,349	2.31
1.1	63011	27,945	2.26
0.8	83690	30,344	2.76
Doors			
1.1	44348	11,910	3.72

The results show that replacing windows and doors are not effective from a cost-benefit perspective. However, windows with U-value of 1.1 w/m^2 K give the lowest investment cost and highest NPV of saved energy cost among the options for improved windows.

4. Discussion

Energy balance simulations were performed to explore the space heating final energy and costs implications of EEMs for a Swedish multi-apartment building. The study results indicated that adding insulation to the attic floor was the most cost effective measure for the studied multi-apartment building. This EEM yields the highest final energy savings for space heating with the lowest investment cost. Improving the attic floor insulation is found to be a cost effective EEM in other building located in the same climate [23]. This indicates the importance of prioritizing this EEM in similar renovation projects. On the other hand, improving the insulation of the exterior walls entails higher investment costs which reduce the cost effectiveness.

Calculated ratios of investment cost to NPV of saved energy cost for each insulation thickness added indicated that the optimum thickness for attic floor was 100 mm. This study will be extended by performing a sensitivity analysis to analyze the effect of different economic parameters for the NPV of saved energy cost, to give better representation of different future economic scenarios. Also, to determine which building standard could be achieved when the measures are cumulatively applied.

5. Conclusion

In this study the cost effectiveness of integrating EEMs to the building envelope of a multi-apartment was analyzed. The analysis indicates that despite the significant reduction in the final energy for space heating, it is not cost effective to implement most of the EEMs due to their high investment costs. The results show that adding insulation to the attic floor is the most cost effective EEM for the studied building.

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REFERENCES

1. *Energy in Sweden* 2020, energimyndigheten"Swedish Energy Agency": Eskilstuna, Sweden.
2. Janson, U., *Passive Houses in Sweden. From Design to Evaluation of Four Demonstration Projects*, in *Department of Architecture and Built Environment*. 2010, Lund University: Sweden.
3. Gustavsson, L., et al., *Primary energy implications of end-use energy efficiency measures in district heated buildings.* Energy and Buildings, 2011. **43**(1): p. 38-48.
4. Dodoo, A., L. Gustavsson, and R. Sathre, *Life cycle primary energy implication of retrofitting a wood-framed apartment building to passive house standard.* Resources, Conservation and Recycling, 2010. **54**(12): p. 1152-1160.
5. Dodoo, A., L. Gustavsson, and R. Sathre, *Building energy-efficiency standards in a life cycle primary energy perspective.* Energy and Buildings, 2011. **43**(7): p. 1589-1597.
6. Liu, L., P. Rohdin, and B. Moshfegh, *Evaluating indoor environment of a retrofitted multi-family building with improved energy performance in Sweden.* Energy and Buildings, 2015. **102**: p. 32-44.
7. Hamburg, A., et al., *Realisation of energy performance targets of an old apartment building renovated to nZEB.* Energy, 2020. **194**: p. 116874.
8. Cabeza, L.F., et al., *Experimental study on the performance of insulation materials in Mediterranean construction.* Energy and Buildings, 2010. **42**(5): p. 630-636.
9. Ekström, T. and Å. Blomsterberg, *Renovation of Swedish Single-family Houses to Passive House Standard – Analyses of Energy Savings Potential.* Energy Procedia, 2016. **96**: p. 134-145.
10. Al-Homoud, M.S., *Performance characteristics and practical applications of common building thermal insulation materials.* Building and Environment, 2005. **40**(3): p. 353-366.
11. Bonakdar, F., A. Dodoo, and L. Gustavsson, *Cost-optimum analysis of building fabric renovation in a Swedish multi-story residential building.* Energy and Buildings, 2014. **84**: p. 662-673.
12. Dodoo, A., L. Gustavsson, and U.Y.A. Tettey, *Final energy savings and cost-effectiveness of deep energy renovation of a multi-storey residential building.* Energy, 2017. **135**: p. 563-576.
13. Dodoo, A., L. Gustavsson, and N. Le Truong, *Primary energy benefits of cost-effective energy renovation of a district heated multi-family building under different energy supply systems.* Energy, 2018. **143**: p. 69-90.
14. Remer, D.S. and A.P. Nieto, *A compendium and comparison of 25 project evaluation techniques. Part 1: Net present value and rate of return methods.* International Journal of Production Economics, 1995. **42**(1): p. 79-96.
15. Remer, D.S. and A.P. Nieto, *A compendium and comparison of 25 project evaluation techniques. Part 2: Ratio, payback, and accounting methods.* International Journal of Production Economics, 1995. **42**(2): p. 101-129.
16. ZOU, Y., *Classification of buildings with regard to airtightness*, in *Department of Civil and Environmental Engineering*. 2010, Chalmers University of Technology: Göteborg, Sweden.
17. *METEONORM 7: global meteorological database for engineers, planners and education*. 2019, Meteotest.

18. *Brukarindata Böstader "User data in buildings"*. 2012, SVEABY, Branschstandard för energi i byggnader: Stockholm.
19. Wikells-Byggberäkningar-AB, *sektionsfakta – Rot. Teknisk- ekonomisk sammanställning av Rot-Byggdelar.* . 2015, Växjö,Sweden: wikells.
20. *ECB euro reference exchange rate: Swedish krona (SEK)*. 2020; Available from: https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-sek.en.html.
21. *Prislista Fjärrvärme "Price list for district heating"*. 2020, Växjö Energi: Växjö.
22. *Notices from European Union Institutions, Bodies, Offices and Agencies on the Energy Performance of the Buildings (2012/C 115/01)*. 2012, Official journal of the European Union: Brussels, Belgium.
23. Farshid Bonakdar, L.G., Ambrose Dodoo. *Implications of energy efficiency renovation measures for a Swedish residential building on cost, primary energy use and carbon dioxide emission*. in *5A. Cutting the energy use of build ings: Projects and technologies*. 2013. ECEEE.