An optimum renovation strategy for Swedish single-family house envelopes: The implications of climate zones and the age of the houses

Farshid Bonakdar
Built Environment and Energy Technology
Linnaeus University
351 95 Växjö
Sweden
farshid.bonakdar@lnu.se

Angela Sasic Kalagasidis
Civil and Environmental Engineering, Building Technology, Building Physics
Chalmers University of Technology
412 96 Gothenburg
Sweden
angela.sasic@chalmers.se

Keywords
renovation, simulation, building envelope, cost effectiveness, building retrofitting, optimisation, optimum renovation

Abstract
As a result of EU's legislations for reducing energy demands in buildings, a large number of studies have been done about cost-effective renovation of building stocks in EU. To complement the available results, in this work we take into account the microeconomic perspective of building owners, whose major challenge is to decide about limited budget allocation for energy renovation. Therefore, this work presents results of optimal and cost-effective energy renovation of single-family houses in Swedish building stock.

The houses are categorised based on the year of construction (about 1970s, 1980s and 1990s) and their location (i.e. four Swedish climate zones). The space heat demand of representative houses for each age category and climate zone is simulated to analyse optimum renovation. A reformed method of NPV is employed in order to, simultaneously, analyse the cost-optimum renovation measures of the house envelope and their cost-effectiveness.

The results indicate that the space heat demand in the representative house of 1970 is reduced from 28 % in climate zone 1 to 25 % in zone 4, when all measures are implemented to a cost-optimal level. The results of similar exercise for the houses of 1990 suggest "do nothing" scenario for energy renovation to cost-optimal level, considering discount rate of 3 %. However, if the necessity of renovation is determined, then the reduced space heat demand is from 13 % in climate zone 1 to 8 % in zone 4. As far as the cost-effectiveness is concerned, the optimum renovation of attics for the houses built during early 1970s appears to be the most cost-effective component followed by the attics of the houses built during 1980s. Renovation of exterior walls and windows to a cost-optimal level are not cost-effective, regardless the year of construction. The findings suggest strategy to prioritise the energy renovation of envelope components in existing single-family houses of Sweden, built between 1965 and 1995 in different climate zones.

Introduction
The largest share of final energy in Europe is used by buildings (EEFIG 2015). On a global scale, the building sector contributes to approximately 17 % of total direct energy-related CO_2 emissions (IEA 2013). About 75 % of existing buildings in the European Union (EU) were built during the period when energy use requirements for space heating were less strict than the current building codes (EEFIG 2015). Buildings are long term assets and it is suggested by International Energy Agency (IEA 2013) that more than 50 % of the existing buildings of the World is expected to remain in service by 2050. In Sweden, about 480,000 single-family houses were built between 1961 and 1975 (Hall and Viden 2005). The housing statistics (Dol and Haffner 2010) indicate that about 40 % of existing residential buildings in Sweden were above 60 years old in 2008 and most of these buildings are in good serviceability condition (Dol and Haffner 2010). These houses may need repair and maintenance in different envelope components though, in order to assure the structural integrity.

Buildings space heating represents about 70 % of final energy use in Sweden's residential building sector, where 21 % of total country's final energy is used (Érika Mata, Angela Sasic Kalagasidis et al. 2014). This indicates the significant role of building envelope to energy saving potential in order to fulfil the EU objective of 80–95 % GHG reduction by 2050, compared to 1990 (European parliament 2012). International Energy Agency (IEA 2013) suggests that buildings energy demand increases by 50 %, between the years 2010 and 2050 in business as usual scenario. This indicates that buildings are the greatest potential to save energy. Considering the facts, mentioned above, renovation of the existing residential buildings of Sweden appears to be crucial in order to achieve Sweden's target of reducing energy intensity by 20 % between 2008 and 2020 and lowering the emissions of greenhouse gases by 40 % in 2020 compared to 1990 (Swedish Energy Agency 2015; Swedish Energy Agency 2015).

Single-family houses are the largest consumer group of heating energy market in Sweden followed by multi-family buildings and industries (Sköldberg and Rydén 2014). Renovation of single-family house envelope is of the main interest, in this study, as building envelope appear to have significant contribution to space heat demand. Various studies (Dodoo, Gustavsson et al. 2010; Mata, Kalagasidis et al. 2010; Bonakdar, Dodoo et al. 2014; Kauko, Alonso et al. 2014) indicate the important role of thermal transmittance improvement of building envelope components on reduced heat demand for space heating.

The economic implications of space heat demand reduction, however, is crucial problem which has to be considered when the energy renovation of building envelope is evaluated in order to make a cost-effective renovation decision. A cost-optimal level of energy performance for buildings during their lifespan shall be identified as it is required by the EU Directive of 2010 (European parliament 2010). According to this directive, EU countries should define reference buildings in order to identify a comparative methodology framework for cost-optimal level of energy performance in both new and existing buildings. The later means that the energy renovation design should provide renovation strategies in a cost-optimal level. This will allow the EU countries to set cost-optimum energy renovation strategies in order to have a building stock with the maximal achievable energy efficiency, from economic perspective.

The concepts of cost-optimal level and cost-effectiveness (i.e. profitability) of building energy renovation have been analysed in various studies (Gustafsson and Karlsson 1989; Constantinescu 2010; Aggerholm, Erhorn et al. 2011; Andreas Hermelink, et et al. 2011; Bonakdar, Gustavsson et al. 2013; BPIE 2013; Wahlström, Filipsson et al. 2013; Arumägi and Kalamees 2014; Ballarini, Corgnati et al. 2014; Bonakdar, Dodoo et al. 2014; Cetiner and Edis 2014; Érika Mata, Angela Sasic Kalagasidis et al. 2014; Kuusk, Kalamees et al. 2014; Farsäter 2015; Ferrari and Zagarella 2015; Stocker, Tschurtschenthaler et al. 2015; Niemelä, Kosonen et al. 2016). Several optimisation methods have been used in order to analyse the cost-optimal level and cost-effectiveness of renovation, e.g. payback time, net present value of global cost, rate of return, life cycle cost and marginal cost difference. Farsäter, K. et al. (Farsäter 2015) conducted a synthesis of studies on a number of profitability analysis for renovation projects where several methods for renovation profitability calculation are identified.

A large variety of energy efficiency measures in either residential, educational or office buildings have been analysed in different studies to investigate the profitability of renovation measures. For instance, Wahlström, Å. et al. (Wahlström, Filipsson et al. 2013) studied cost-optimal energy efficiency in multi-family houses, using life cycle cost method in order to investigate the profitability and cost-optimal level of renovation among considered renovation packages i.e. combination of different heating systems and energy efficiency measures. Stocker, E. et al. (Stocker, Tschurtschenthaler et al. 2015) analysed cost optimum measures for school buildings renovation, considering building envelope insulation and heating systems. Arumägi and Kalamees (Arumägi and Kalamees 2014) analysed energy economic renovation for historic wooden apartment buildings, considering building envelope retrofit and building's service systems.

To complement the available results, in this work we take into account the microeconomic perspective of a building owner, whose major challenge is to decide about limited budget allocation for energy renovation. In order to do that, a single-family house, which is identified as representative house in Swedish building stock, is analysed in this study. The house represents typical single-family houses of Sweden built during different periods i.e. from 1961 to 1975, from 1976 to 1985 and from 1986 to 1995 in different climate zones of Sweden. A large number of energy balance simulations are performed to provide a broad picture of the existing single-family houses in Sweden from space heat demand perspective by considering all houses with different ages, located in different climate zones of Sweden. The existing method of NPV is reformed and the modifications are introduced in this study in order to analyse the cost-optimal level of renovation for the components of the house envelope and, simultaneously, analysing the renovation profitability. The actual cost of house envelope renovation i.e. additional insulation on attic floor and exterior walls and changing windows are calculated, using the construction work tariff of Sweden (Wikells-Byggberäkningar-AB 2013–2014). It includes all required materials and man-hour price for installation of the insulation materials and changing windows as well as required scaffolding.

The results of this study illustrate how the cost-optimal level of energy renovation of the components in house envelope and space head demand of the houses vary depending upon house characteristics and different climate conditions. The study aims to provide as complete picture as possible for the potential space heat demand reduction within the house stock of Sweden by implementing house envelope renovation to an optimal level in different climate zones and on existing single-family houses from the house owner perspective.

Method

GENERAL APPROACH

A single-family house has been considered in this study which is one of the representative houses in Swedish building stock as it is indicated in the report of National Board of Housing, Building and Planning (Boverket 2010). The report was used to identify Swedish building typology based on official statistics available for different building envelopes in Sweden as it is introduced in Tabula project (Institute for Housing and Environment (IWU) and Mälardalens University Sweden (MDH)

Table 1. The characteristics of single-family house envelopes, built between 1961 and 1975 (house of 1970), between 1976 and 1985 (house of 1980) and between 1986 and 1995 (house of 1990).

House envelope component	Total area (m^2)	U-value (W/m^2 K)		
		Houses of 1970	Houses of 1980	Houses of 1990
Attic floor	75	0.21	0.15	0.12
Exterior walls	100	0.31	0.21	0.17
Windows	22	2.3	2.0	1.9

Figure 1. A schematic image of the representative single-family house (Boverket 2013).

Figure 2. Swedish climate zones according to Swedish building code of 2015 (Boverket 2015).

2012). In that report, Swedish building types are classified based on the times of construction i.e. between 1960 and 2005.

The considered typical single-family house was analysed and its energy balance was simulated in order to perform the optimisation analysis for the renovation of house envelope components, e.g. attic floor, exterior walls and windows. The house was assumed to be located in four different Swedish climate zones that are spanned broadly from north to south. Net present value of the saved energy cost for space heating is calculated for the considered energy efficient measures of the envelope components in order to compare with initial investment cost of implementing each measure. Ultimate target is to evaluate the implications of climate zones and the year of building construction on the energy use for space heating at the cost-optimal level of renovation and whether the optimal level is cost-effective, from house owner perspective.

REFERENCE SINGLE-FAMILY HOUSE

European countries are required to define reference buildings which should represent the entire or part of each country's building stock as it is indicated by regulation No. 244/2012 of European commission (European Commission 2012), for the purpose of cost-optimal methodology. In order to study the cost-optimal level and cost-effectiveness of house stock in Sweden, a single-family house is considered for energy balance simulation and further optimisation analysis of energy renovation of the house envelope. It is a 1.5 floor house with 148 m^2 of total heated area, heated with district heating system and is identified as a representative single-family house in different climate zones of Sweden (Institute for Housing and Environment (IWU) and Mälardalens University Sweden (MDH) 2012). A schematic image of such a house is shown in Figure 1 (Boverket 2013). It has different characteristics based on the period when it was built. About 970,000 of such single-family houses (equal to $145 * 10^6$ m^2 of heated floor area) were built during 1961 to 1995 in Sweden (Institute for Housing and Environment (IWU) and Mälardalens University Sweden (MDH) 2012).

The characteristics of the reference house, analysed in this study, are different depending upon the building age. That includes the houses built during the periods between 1961 and 1975 (specified as the house of 1970), between 1976 and 1985 (specified as the house of 1980) and between 1986 1nd 1995 (specified as the house of 1990). The components characteristics of house envelopes from different vintages are shown in Table 1.

The energy balance simulation was performed for the reference houses considering four different locations of four different climate zones in Sweden. The reference houses are suggested to have similar envelope characteristics in four climate zones (Institute for Housing and Environment (IWU) and Mälardalens University Sweden (MDH) 2012; Boverket 2013). Figure 2 illustrates four different climate zones of Sweden as it is indicated by Swedish building code (Boverket 2015).

Figure 3 illustrates the average of ambient temperature (°C) for the considered locations of the case-study building, between the years 1996 and 2005.

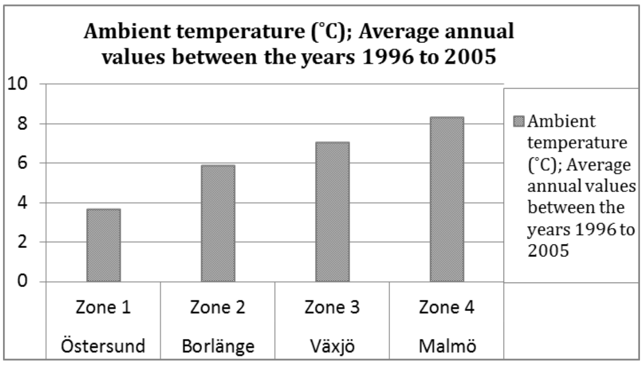

Figure 3. Ambient temperature (˚C); Average values from 1996 to 2005.

ENERGY BALANCE SIMULATION AND EFFICIENCY MEASURES

The final energy use of the building is calculated by programme VIP-Energy, which is a dynamic (hourly-based) simulation model. The energy flow that is calculated in this model takes climatic parameters e.g. ambient temperature, wind direction and velocity, humidity and solar radiation into account (StruSoft 2016). The methods of comparative tests between various programmes and between calculation results and measuring projects were used to validate the programme. The validation tests are performed according to ASHRAE 140-2007 and EN 15265-2007 (StruSoft (2016)).

Performing the energy balance simulations for the representative houses with different ages in different climate zones indicated the space heat demand as it is shown in Table 2.

OPTIMAL LEVEL AND THE COST-EFFECTIVENESS OF ENERGY RENOVATION:

There are various methods of optimisation of energy renovation from different perspectives, e.g. economic, sustainability and social. This study focuses on the cost optimisation of envelope renovation from micro economic (i.e. house owner) point of view. Cost optimisation of renovation maybe analysed using different methods, e.g. payback time, NPV of global cost, internal rate of return and marginal cost difference. Whilst these are different methods, they follow similar concept which involves the initial investment cost of implementing energy efficiency measures and operational cost during life span of buildings and the measures after renovation.

The optimisation method that is employed in this study has similar concept as net present value. However, NPV method is reformed in order to provide a better and clearer picture of cost-optimal level of renovation for each component of the house envelope and simultaneously provide the possibility to indicate the level of cost-effectiveness of optimum measures. This method is introduced as net present profit (NPP). The NPP is calculated by deducting the initial investment cost of renovation from present value of cash inflow i.e. present value of saved final energy cost for space heating. The NPP can be calculated as it is shown in the following equation.

$$\mathrm{NPP} = \sum_{t=1}^{n} \frac{\mathrm{Ct}}{(1+\mathrm{R})^{\wedge}\mathrm{t}} - \mathrm{INV}$$

Where

Ct net cash inflow (saved energy cost) during the building lifespan after renovation (n);

INV total initial investment of energy renovation measures implementation;

R real discount rate.

Figure 4 illustrates a sample for the trend of NPP calculation for a series of energy efficiency measures. A positive net present profit indicates that implementing the renovation measure is profitable, whilst the renovation measures with negative net present profit result in a net loss. In this study, the main concern for energy renovation of the house envelope components is the evaluation of circumstances (e.g. house age, climate zone) where the optimum level of renovation may or may not be profitable.

ENERGY EFFICIENCY MEASURES FOR OPTIMUM RENOVATION OF THE HOUSE ENVELOPE COMPONENTS

A wide range of energy efficiency measures are considered for every single component of house envelope in order to exercise the reduced space heat demand and find the optimal level of renovation for components. The considered components of the envelope in this study are limited to attic floor, exterior walls and windows.

The considered measures include windows replacement as well as extra insulation on attic floor and exterior walls. New windows with lower thermal transmittance (U_w-value) from 1.2 W/m²K to, as low as, 0.6 W/m²K are considered for optimisation analysis. Extra insulation materials, with a wide range of thickness (i.e. 10 different thicknesses, changing from 50 mm to 500 mm, taking market availability into account), are considered to be added on attic floor and exterior walls. The building energy simulation was performed for any single measure, separately for three typical houses with different ages. Similar exercise was repeated for four different climate zones of Sweden. The large number of energy balance simulations provided the results for optimum renovation in a higher level of accuracy.

DISCOUNT RATE AND ENERGY PRICE;

Discount rate reflects the cost of capital or the expected rate of return from a financial perspective. The expected rate of return reflects an investment risk. It can be either a risk-free rate or a risk premium (BPIE 2013). Discount rate also refers to the interest rate used in analysing discounted cash flow (DCF) to calculate the present value of future cash flow. The discount rate in DCF analysis takes into account not just the time value of money,

Table 2. Space heat demand of the representative houses from different ages, located in different climate zones (kWh/m².year).

Houses vintage	Zone 1	Zone 2	Zone 3	Zone 4
1970	181.3	158.1	143.8	127.6
1980	157.6	136.9	124.3	109.9
1990	147.8	128.3	116.4	102.7

but also the risk or uncertainty of future cash flows; the greater the uncertainty of future cash flows, the higher the discount rate (Investopedia-LLC 2016). The significant contribution of discount rate to the profitability of renovation has been indicated in various studies, e.g. (Bonakdar, Gustavsson et al. 2013; Bonakdar, Dodoo et al. 2014; Érika Mata, Angela Sasic Kalagasidis et al. 2014). As the main aim of this study is to illustrate the implications of the characteristics of existing single-family houses in different climate zones of Sweden on the cost-optimal level of envelope renovation and its profitability as well as the potential energy saving for space heat demand in the entire Swedish building stock, discount rate of 3 %, which is suggested by BPIE (BPIE 2013), is used in this study. As far as the energy price for space heating is concerned, mean value of 0.091 Euro/kWh of district heating for single-family houses is used, as it is suggested in (Boverket 2013). District heating price is assumed to increase by 1.5 % per year as it is suggested in (Boverket 2013).

COST ESTIMATION OF RENOVATION WORK

The cost that is required to implement the considered energy efficiency measures consist of various details e.g. materials, man-hour, and facility to provide accessibility such as scaffolding. Renovation and construction work tariff of Sweden (Wikells-Byggberäkningar-AB 2013–2014) is used to estimate total cost for every single energy efficiency measure to implement. In this study, we assumed that the renovation work is only for the energy conservation purpose and there is no need to undertake renovation for repair and maintenance.

Results

The net present profit of all considered renovation measures for house envelope components were calculated. This exercise was performed for three different representative houses of different ages while each exercise was repeated for four different climate zones of Sweden.

Figures 5 to 7 illustrate the trends of net present profit of extra insulation on attic floor, for the houses from three different construction periods (i.e. 1970, 1980 and 1990), considering four different climate zones. Figure 8 illustrates the values for space heat demand reduction, when attic floor is renovated to a cost-optimal level for the houses in different climate zones. We used a trend line of NPP results for the further evaluation of cost-optimum measures and their cost-effectiveness. This is due to uncertainty which exists in NPP calculation because of renovation cost for each measure. The cost of materials in the market, man-hour work and installation method could have significant effect on the cost of implementing the efficiency measures on house envelope and may cause the fluctuations that appear in NPP results of consecutive measures.

Similar analysis and calculations were performed for renovation of exterior walls by implementing extra insulation and the results are illustrated in Figures 9 to 12.

The results of cost-optimal analysis of exterior walls renovation indicate that the cost-optimal thickness for extra insulation changes between about 250 mm to 350 mm, from climate zone 4 to zone 1 in the house of 1970. This is between about 150 mm to 250 mm respectively, for the house of 1980 and between 100 mm to 200 mm for the house of 1990. However, none of the optimum thickness of extra insulation appears to be profitable.

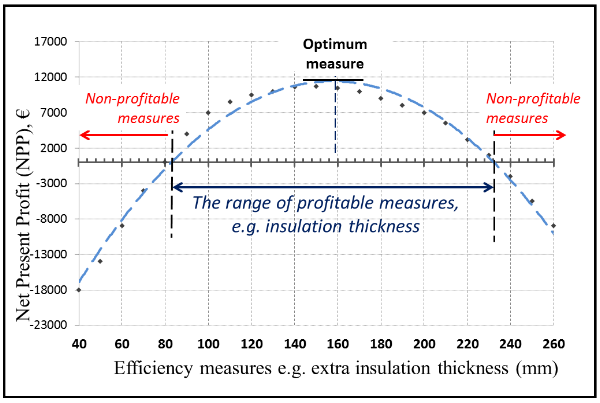

Figure 4. A sample of NPP calculated results for different insulation thicknesses in an energy renovation analysis.

The results of the cost-optimal level and cost-effectiveness analysis performed for windows thermal transmittance improvements (i.e. replacing existing windows) are illustrated in Figures 13 to 16.

The results of cost-optimal analysis of windows replacement indicate that the cost-optimal level for windows thermal improvement is using windows with the U-value of 1.2 W/m^2K, although even this thermal transmittance appears to be non-profitable in all climate zones for all single-family houses from the considered construction periods.

Considering the total number of the studied representative houses in Sweden from three construction periods of 1970, 1980 and 1990, and the entire heated floor area of these houses in all four climate zones (Institute for Housing and Environment (IWU) and Mälardalens University Sweden (MDH) 2012), the total saved energy for space heating due to cost-optimal renovation of house envelope components has been calculated and the results are illustrated in Figure 17. This is to illustrate the contribution of the cost-optimal renovation for every single envelope component to final energy conservation in Swedish building stock.

Total heat demand of single-family houses in Sweden in 2013 was estimated to be 6 TWh (Swedish Energy Agency 2015) for both space heating and hot water of the houses which are connected to DH system. Figure 18 illustrates the contribution of envelope component renovation to saved heat demand for all representative houses.

Discussion and Conclusions

The contribution of single-family house characteristics in different climate zones of Sweden to cost-optimal level and the profitability of house envelope renovation has been analysed in this study. The corresponding saved heat demand for each optimal level of house envelope components renovation has been calculated too. Reference single-family houses from three construction periods (i.e. 1970, 1980 and 1990), located in four different climate zones were used for the analysis in order to obtain an overall, yet representative picture of the existing single-family houses in Swedish building stock for setting strategies of potential saving space heat demand from house owner perspective.

The results of the analysis indicate that the renovation of attic floor, to an optimal level are profitable for the house of 1970

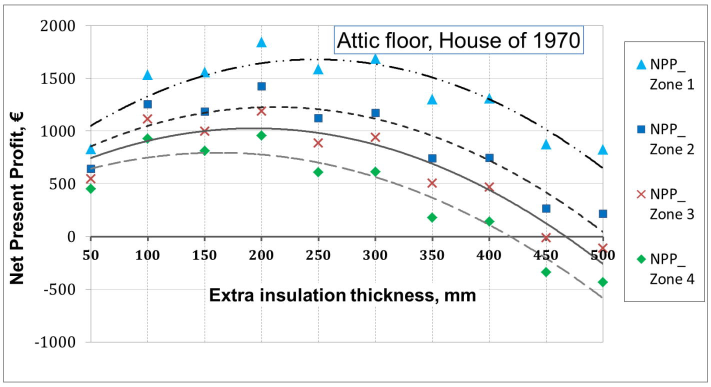

Figure 5. The trends of NPP when the extra insulation thickness of attic floor varies for the house of 1970, considering different climate zones.

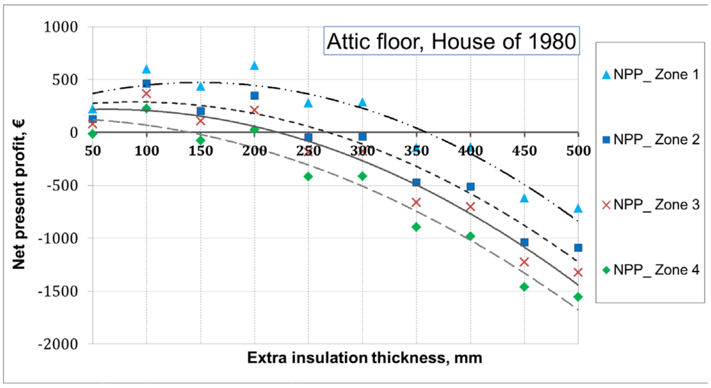

Figure 6. The trends of NPP when the extra insulation thickness of attic floor varies for the house of 1980, considering different climate zones.

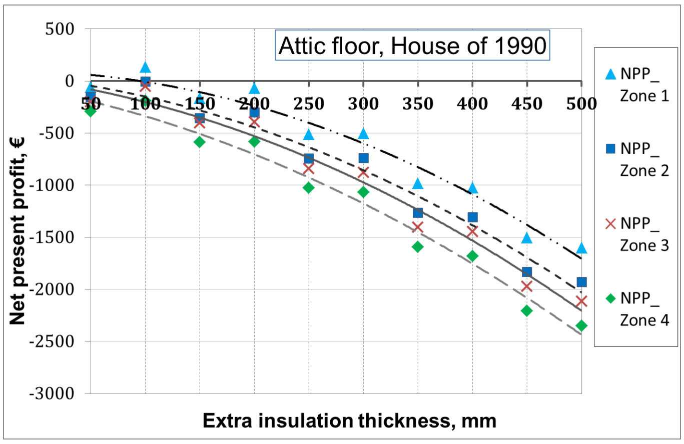

Figure 7. The trends of NPP when the extra insulation thickness of attic floor varies for the house of 1990, considering different climate zones.

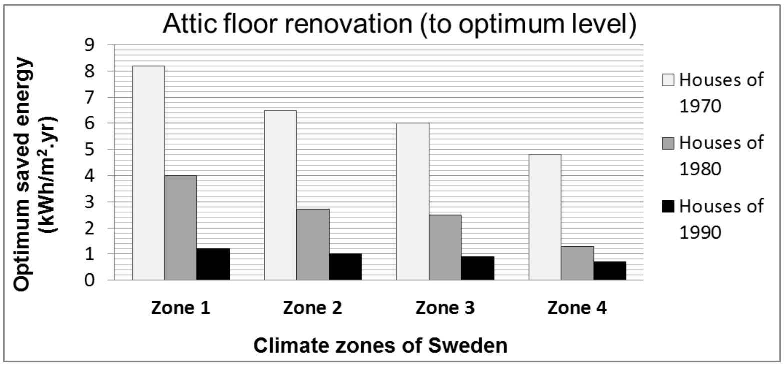

Figure 8. Space heat demand reduction due to cost-optimal level of attic floor renovation of the houses in different climate zones.

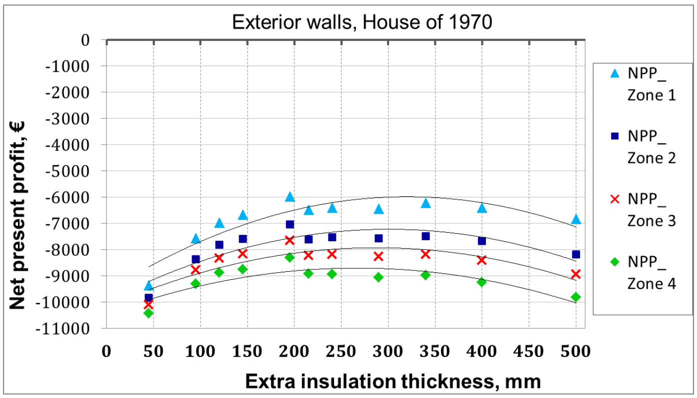

Figure 9. The trends of NPP when the extra insulation thickness of exterior walls varies for the house of 1970, considering different climate zones.

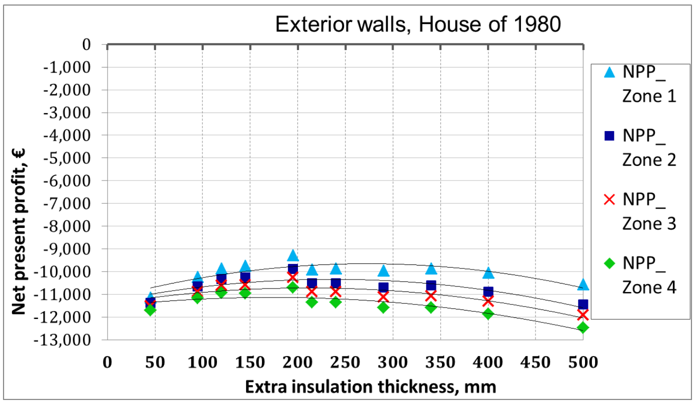

Figure 10. The trends of NPP when the extra insulation thickness of exterior walls varies for the house of 1980, considering different climate zones.

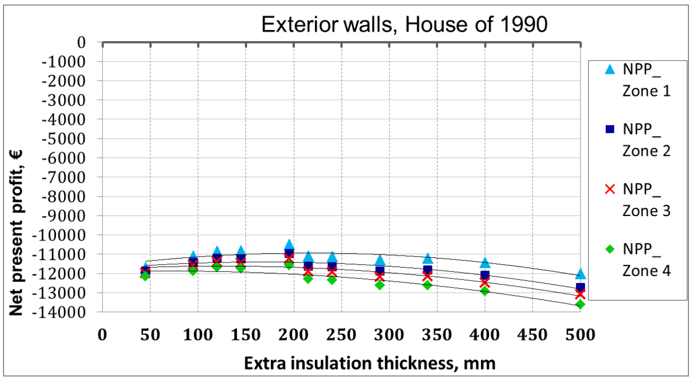

Figure 11. The trends of NPP when the extra insulation thickness of exterior walls varies for the house of 1990, considering different climate zones.

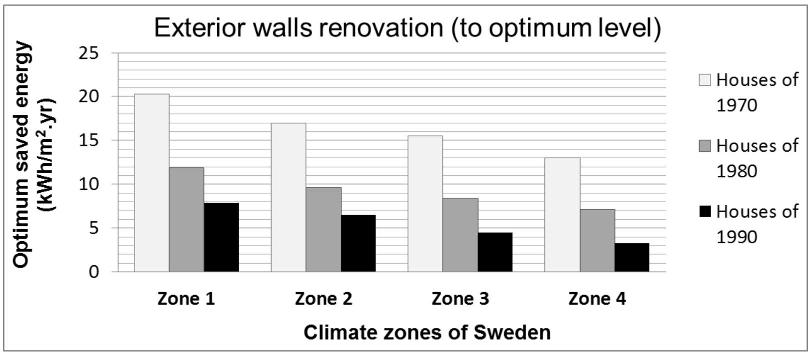

Figure 12. Space heat demand reduction due to cost-optimal level of exterior walls renovation of the houses in different climate zones.

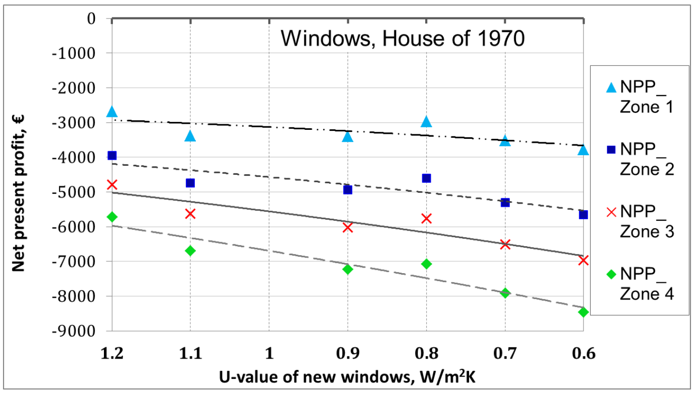

Figure 13. The trends of NPP when new windows U-value varies for the house of 1970, considering different climate zones.

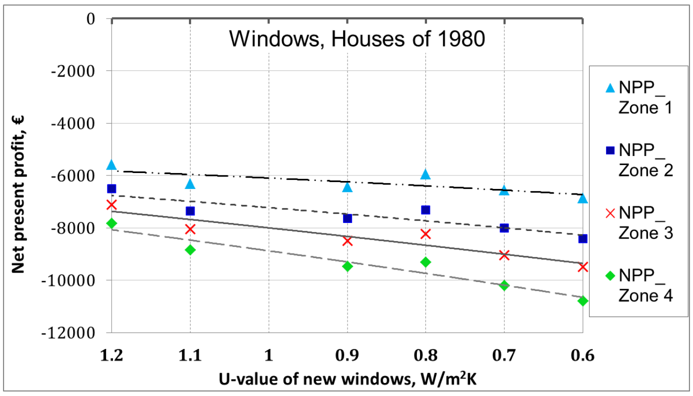

Figure 14. The trends of NPP when new windows U-value varies for the house of 1980, considering different climate zones.

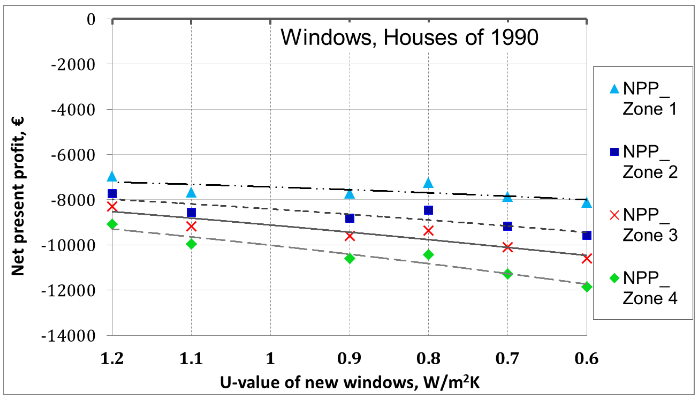

Figure 15. The trends of NPP when new windows U-value varies for the house of 1990, considering different climate zones.

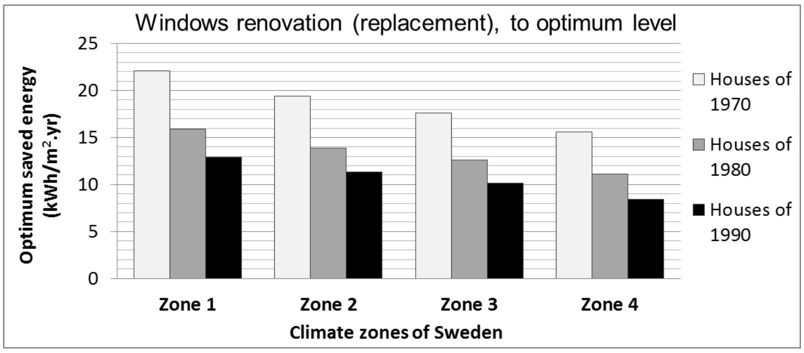

Figure 16. Space heat demand reduction due to cost-optimal level of windows renovation of the houses in different climate zones.

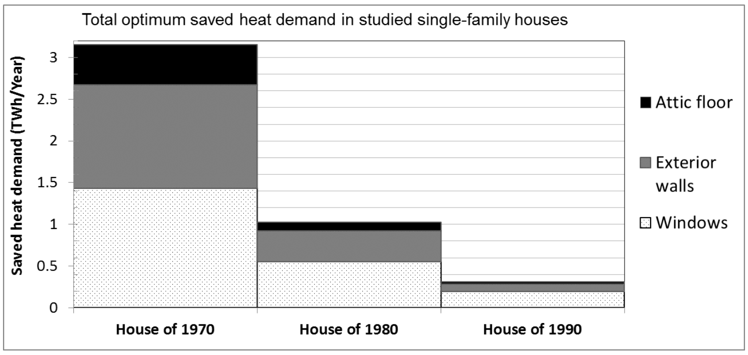

Figure 17. Total saved heat demand due to cost-optimal renovation of envelope components in the houses from three construction periods in Sweden.

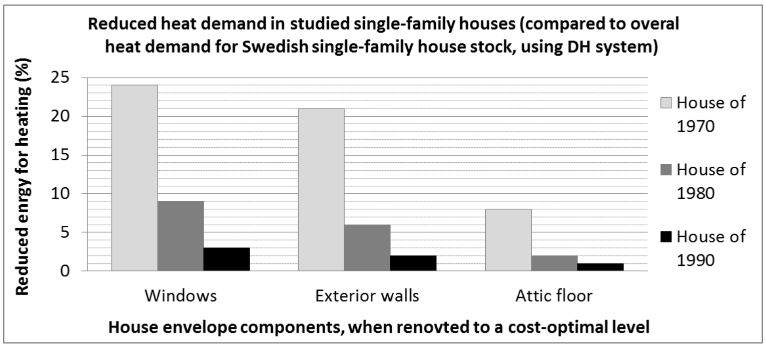

Figure 18. Reduced heat demand in single-family house stock due to cost-optimal renovation of envelope components in the houses from three construction periods in Sweden (Considering the overall final energy use of 6 TWh for heating of single-family houses in 2013).

and 1980, regardless their location in Sweden (climate zones of 1, 2, 3 and 4), considering the economic parameters assumptions, i.e. discount rate, energy price and its development over the time. However, the cost-optimal renovation of attic floor is not profitable in the houses of 1990, except those located in climate zone 1. Energy renovation of exterior walls and windows to an optimal level appear to be non-profitable regardless the age or the location of the houses. However, since changing the existing windows and using new windows with smaller thermal transmittance usually improves the airtightness of the houses and user's thermal comfort, lower energy for space heating is required to provide same level of operative temperature. This may make the measures profitable under the considered economic circumstances. This is a potential for further analysis in order to obtain a more realistic assessment for the profitability of changing windows.

The saved energy for space heating of the houses varies, significantly, between the houses that are located in zone 1 compared to zone 4, when they are renovated to an optimal level. The saved heat demand for the houses in climate zone 1 is 120 % higher than the houses in zone 4, when attic floor is renovated to an optimal level. This figure is about 88 % and 46 % for optimum renovation of exterior walls and windows, respectively.

Taking total heated floor area of the existing single-family houses in Sweden into account, the results of this study indicate that energy renovation of the house of 1970 (to an optimal level) could save space heat demand by about 950 % more than renovation of the house of 1990 and about 210 % more than the house of 1980. This suggests the crucial contribution of the house of 1970 (i.e. built from 1961 to 1975) to final energy saving for space heating. They require immediate action for energy renovation, which can be followed by the house of 1980 and then 1990, if necessary. Among the considered envelope components, replacing the existing windows appear to be way more effective for energy saving. Whilst the attic floor optimum renovation has the smallest share of energy saving, it yet is the most profitable measure. The renovation is assumed to be for reducing the space heating energy demand and no need for repair or maintenance are assumed during the lifespan of the houses. The cost of renovation may be partly compensated by the maintenance or repair cost, when it is considered at the same time. In such cases, the cost-effectiveness of the renovation measures can be improved.

The results of this study can be used to obtain energy and economic efficient renovation strategy for single-family houses in Swedish building stock, as the analysis is based on the representative houses characteristics in all climate zones of Sweden. Since the study is microeconomic-based, the findings can be used by the house owners to design and prioritise the renovation projects. It can also be used as a base to set renovation strategies by building sector and financial organisations.

References

Aggerholm, S., H. Erhorn, et al. (2011). Cost-optimal levels for energy performance requirements. Luxembourg, Energy performance of buildings.

Andreas Hermelink, et, et al. (2011). Cost optimal building performance requirements, European Council for an Energy Efficient Economy (eceee).

Arumägi, E. and T. Kalamees (2014). "Analysis of energy economic renovation for historic wooden apartment buildings in cold climates." *Applied energy* 115: 540–548.

Ballarini, I., S. P. Corgnati, et al. (2014). "Use of reference buildings to assess the energy saving potentials of the residential building stock: The experience of TABULA project." *Energy Policy* 68: 273–284.

Bonakdar, F., A. Dodoo, et al. (2014). "Cost-optimum analysis of building fabric renovation in a Swedish multi-story residential building." *Energy and Buildings* 84 (0): 662–673.

Bonakdar, F., L. Gustavsson, et al. (2013). *Implications of energy efficiency renovation measures for a Swedish residential building on cost, primary energy use and carbon dioxide emission*. eceee Summer Study Proceedings, France, European Commission for Economic Energy Efficiency.

Boverket (2010). Teknisk status i den svenska bebyggelsen – resultat från projektet BETSI. Karlskrona.

Boverket (2013). Optimala kostnader för energieffektivisering – underlag enligt Europaparlamentets och rådets direktiv 2010/31/EU om byggnaders energiprestanda. Karlskrona, Sweden, Boverket.

Boverket (2015). Konsekvensutredning BBR: Ändring av Boverkets byggregler (BBR) – avsnitt 9 Energihushållning.

BPIE (2013). IMPLEMENTING THE COST-OPTIMAL METHODOLOGY IN EU COUNTRIES. I. Nolte, O. Rapf, D. Staniaszek and M. Faber. Brussel, BPIE.

Cetiner, I. and E. Edis (2014). "An environmental and economic sustainability assessment method for the retrofitting of residential buildings." *Energy and Buildings* 74: 132–140.

Constantinescu, T. (2010). Cost Optimality, Discussion methodology and challenges within the recast energy performance of buildings directive. Brussel, Belgium, BPIE**:** 40.

Dodoo, A., L. Gustavsson, et al. (2010). "Life cycle primary energy implication of retrofitting a wood-framed apartment building to passive house standard." *Resources, Conservation and Recycling* 54 (12): 1152–1160.

Dol, K. and M. Haffner (2010). Housing Statistics in the European Union. Delft University of Technology, OTB Research Institute for the Built Environment.

EEFIG (2015). Energy Efficiency – the first fuel for the EU Economy. How to drive new finance for energy efficiency investments, Energy Efficiency Financial Institution Group

Érika Mata, Angela Sasic Kalagasidis, et al. (2014). "Cost-effective retrofitting of Swedish residential buildings: effects of energy price developments and discount rates." *Energy efficiency* 28 (286).

European Commission (2012). "Notices from European Union institutions, bodies, offices and agencies on the energy performance of the buildings (2012/C 115/01)." *Official journal of the European Union.*

European parliament (2010). "Directive 2010/31/EU of the European parliament and of the council on the energy performance of buildings (recast)." *Official journal of the European Union*.

European parliament (2012). Directive 2012/27/EU of the European parliament and of the council of 25 October 2012 on energy efficiency. *Official journal of the European Union*.

Farsäter, K., Wahlström, Å, Mjörnell, K & Johansson, D. (2015). A synthesis of studies on renovation profitability, Lund University.

Ferrari, S. and F. Zagarella (2015). "Costs assessment for building renovation cost-optimal analysis." *Energy Procedia* 78: 7.

Gustafsson, S.-I. and B. G. Karlsson (1989). "Life-cycle cost minimization considering retrofits in multi-family residences." *Energy and Buildings* 14 (1): 9–17.

Hall, T. and S. Viden (2005). "The Million Homes Programme: a review of the great Swedish planning project." *Planning Perspectives* 20: 27.

IEA (2013). "Transition to sustainable buildings, Strategies and Opportunities to 2050."

Institute for Housing and Environment (IWU) and Mälardalens University Sweden (MDH) (2012). Typology Approach for Building Stock Energy Assessment – Tabula Project.

Investopedia-LLC. (2016). from http://www.investopedia.com/.

Kauko, H., M. J. Alonso, et al. (2014). "Case Study on Residential Building Renovation and its Impact on the Energy Use and Thermal Comfort." *Energy Procedia* 58: 160–165.

Kuusk, K., T. Kalamees, et al. (2014). "Cost effectiveness of energy performance improvements in Estonian brick apartment buildings." *Energy and Buildings* 77: 313–322.

Mata, E., A. S. Kalagasidis, et al. (2010). Retrofitting Measures for Energy Savings in the Swedish Residential Building Stock Assessing Methodology. *ASHRAE Buildings XI*, ASHRAE.

Niemelä, T., R. Kosonen, et al. (2016). "Cost-optimal energy performance renovation measures of educational buildings in cold climate." *Applied energy* 183: 1005–1020.

Sköldberg, H. and B. Rydén (2014). The heating market in Sweden - an overall picture, Värmemarknad Sverige.

Stocker, E., M. Tschurtschenthaler, et al. (2015). "Cost-optimal renovation and energy performance: Evidence from existing school buildings in the Alps." *Energy and Buildings* 100: 20–26.

StruSoft (2016). VIP-Energy. Sweden, StruSoft AB.

Swedish Energy Agency (2015). Energy Efficiency trends and policies in Sweden.

Swedish Energy Agency (2015). Energy in Sweden 2015.

Wahlström, Å., P. Filipsson, et al. (2013). *Cost optimal energy efficiency in multifamily houses*. Passivhus Norden 2013, Göteborg, Sweden.

Wikells-Byggberäkningar-AB (2013-2014). *Sektionsfakta – ROT 4.14*, Wikells Byggberäkningar AB.