CLIMA 2016 - proceedings of the 12th REHVA World Congress

Heiselberg, Per Kvols

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Heiselberg, P. K. (Ed.) (2016). CLIMA 2016 - proceedings of the 12th REHVA World Congress: volume 10. Aalborg: Aalborg University, Department of Civil Engineering.

Less than the sum of its parts – Economic and Environmental Challenges in designing Deep Energy Retrofit Concepts, the Case of Sweden

Claudio Nägeli[#1], York Ostermeyer[#2]

[#]Civil and Environmental Engineering, Chalmers University of Technology
SE-412 96 Gothenburg, Sweden

[1]claudio.naegeli@chalemrs.se

[2]york.ostermeyer@chalmers.se

Abstract

The International Energy Agency's Energy in Buildings and Communities Programme Annex 61 "Business and Technical Concepts for Deep Energy Retrofit (DER) of Public Buildings" aims at developing financially and technically feasible deep energy retrofit concepts. These concepts should consist of bundles of core technologies, which when applied in major renovations of pre 1980 buildings should yield a site energy reduction by 50% or more. The individual technological solutions to achieve this depend on national conditions such as building standards, general building practices and most importantly the climatic conditions. Retrofit solutions can be classified into three different renovation scenarios: Minor retrofit in order to achieve the national standard, major retrofit to achieve 50% reduction and advanced level retrofit to go beyond 50%. Many different studies show that individual renovation measures are economically feasible and environmental beneficial. However, when combined in deep energy retrofit bundles, certain technologies influence each other both environmentally and economically due to the interconnection in buildings. This paper demonstrates results from a simulation study of different retrofit technologies for a School building in Sweden. Technologies are assessed both individually and as part of technology bundles. The analysis highlights the differences in the impact of individual technologies compared to the application in technology bundles. We thereby demonstrate the links between different technologies in deep energy retrofit concepts. We conclude that there is a need for optimized approaches according to climatic, environmental and economic conditions.

Keywords – Deep Energy Retrofit; Public Buildings; Building Design; Optimization

1. Introduction

In Europe around 40% of total energy consumption is related to buildings [1]. The European union is addressing this among other things through the EU Directive 2010/31/EU on the energy performance of buildings, which targets that all new buildings will have to be nearly zero energy buildings (NZEB) by early 2020s an even until 2018 for public buildings [1]. What remains is the retrofit of the existing building stock. Addressing this issue, the International Energy Agency's Energy in Buildings and Communities Programme Annex 61 "Business and Technical Concepts for Deep Energy Retrofit (DER) of Public Buildings" aims at developing financially and technically feasible deep energy retrofit concepts. The Annex 61 tries to improve the decision-making process associated with achieving deep energy renovation of public buildings (e.g. office buildings, schools etc.), starting with the development of key bundles of renovation measures.

The first step in developing these bundles is to examine the effect both energetically and economically in the different participating countries of the Annex. For this purpose already other studies in different countries such Estonia, Germany, Canada, Austria and Denmark have been conducted, which examine the effect of different retrofit scenarios on representative pre- 1980s buildings [2-5]. The calculations are divided into three retrofit scenarios, corresponding to (1) Minor retrofit (i.e. the minimal intervention), (2) Major retrofit (resulting in > 50 % energy savings) and (3) Advanced retrofit: (i.e. reducing energy demand close to a NZEB).

The results presented in this paper are in line with the investigation done in these previous studies for other countries and showcase the environmental and economic effects of retrofit measures being applied individually and as part of a retrofit bundle on a representative school building in Sweden.

2. Method

Studied Building

The studied building is a generic school building with 3 stories and a basement resulting in a total of 3960m^2 heated floor area. The constructive system for this building have been chosen to correspond to the typical construction practice of the 1970s during Sweden's Million House program [6]. The building has a ventilated brick façade with a lightweight concrete structural system. Floor slabs are made from 120mm reinforced concrete. The building has an exhaust air ventilation installed and the air tightness of the building corresponds to an air change rate of 3.0 1/h at 50 Pa pressure. Heat is delivered to the building via a district heating network. The building has a length of 50 m and is 13 m wide. The window ratio of the façade is set to 22% with the long façade being southwest to northeast oriented, with almost the entire window area being distributed along the long façade and only a few windows on the short south west and northeast facades. The current state of the building is summarized in Table 1.

Table 1 Current Building State of Example Building

Parameter	Value
Number of Floors	3 + Basement
Heated Floor area	$2527m^2$
Envelope to Volume Ratio	$0.39 m^2/m^3$
Envelope to heated floor Area Ratio	$0.98 m^2/m^2$
Window Area and U-Value	$225m^2$ ($2.4 W/m^2 K$)
Exterior Wall (Ambient) Area and U-Value	$783m^2$ ($1.11 W/m^2 K$)
Exterior Wall (Ground) Area and U-Value	$252m^2$ ($3.07 W/m^2 K$)
Roof Area and U-Value	$650m^2$ ($0.69 W/m^2 K$)
Floor Slab Area and U-Value	$650m^2$ ($1.32 W/m^2 K$)

.

Energy and Economic Model

The building energy performance and the associated costs of the renovation measures are calculated based on the tool developed by Ostermeyer et al. [7]. The tool is based on spreadsheet which uses the calculation method of the Passive House Planning Package (PHPP) [8] for the energy simulation. The climate data of the city of Stockholm is used for this evaluation. The standard use conditions applied in the calculation are described in Table 2.

Table 2 Standard usage parameters for energy performance calculation

Parameter	Value
Usage time	24 h per day, 7 days per week
Internal heat gains	2.8 W/m2
Ventilation	Average air flow rate 1950 (m^3/h)
Infiltration:	Air exchange rate of 3 1/h @ 50Pa for status quo
Domestic hot water	12 l/Person/d

The economic analysis is carried out based on a calculated Return of Investment according to the following equation.

$$ROI = \frac{Energy\ Cost\ Savings\ per\ year}{Investment} \quad (1)$$

Efficiency measures

The different energy efficiency measures studied are described in Table 3. We limit us here to efficiency measures affecting the heating demand and do not consider any efficiency measures targeting the electricity consumption of the school building (i.e. installation of efficient lighting).

Table 3 Individual Energy Efficiency Measures studied

Component	Measure	Value
External Wall	+100mm	U-Value = 0.33 W/m2/K
	+200mm	U-Value = 0.2 W/m2/K
	+300mm	U-Value = 0.14 W/m2/K
Roof	+100mm	U-Value = 0.29 W/m2/K
	+200mm	U-Value = 0.16 W/m2/K
	+300mm	U-Value = 0.11 W/m2/K
Floor Slab	+100mm	U-Value = 0.32 W/m2/K
Perimeter	+100mm	U-Value = 0.31 W/m2/K
	+200mm	U-Value = 0.27 W/m2/K
	+300mm	U-Value = 0.11 W/m2/K
Window	Double Glazing	U-Value = 1.42 W/m2/K / g-Value = 0.65
	Triple Glazing	U-Value = 0.75 W/m2/K / g-Value = 0.55
Ventilation	Heat recovery +	Heat Recovery = 82%
Air tightness	Increase air tightness	air exchange = 1.0 1/h @ 50Pa
	Increase air tightness (Passivehouse)	air exchange = 0.6 1/h @ 50Pa
Heating System	District Heating	Efficiency = 100%
	Geothermal Heat Pump	COP = 3

Retrofit Bundles

The different measures are combined into bundles of retrofit measures according to different criteria:

- Minor Retrofit: Only simple measures in order to reach the minimum standard, which can be applied without major impact on the building. This includes exchanging the windows, insulating the roof and adding insulation along the perimeter.
- Major Retrofit: Major renovation of the complete building including technical systems in order to reach energy efficiency gains of more than 50%
- NZEB Retrofit: Major renovation in order to decrease energy efficiency to a NZEB. This includes exchanging the heating system from district heating to a geothermal heat pump.

The complete list of the different measures applied in the retrofit bundles are described in Table 4.

Table 4 Defined Retrofit Bundles

Component	Measure	Minor Retrofit	Major Retrofit	NZEB Retrofit
External Wall	Status Quo	X		
	+100mm			
	+200mm		X	
	+300mm			X
Roof	Status Quo			
	+100mm			
	+200mm	X		
	+300mm		X	X
Floor Slab	Status Quo	X	X	
	+100mm			X
Perimeter	Status Quo			
	+100mm	X	X	
	+200mm			
	+300mm			X
Window	Status Quo			
	Double Glazing	X	X	
	Triple Glazing			X
Ventilation+ air tightness	Status Quo	X		
	Heat recovery + air tightness		X	
	Heat recovery + air tightness (Passivehouse)			X
Heating System	District Heating	X	X	
	Geothermal Heat Pump			X

3. Results and dicsussion

Individual efficiency measures

Table 5 shows the effect the individual measures when applied in the studied building. While showing increasing energy savings through an increased insulation thickness, the return on investment however decreases as well. This shows, that even on a individual technology level, the economic optimal technology does not yield the highest savings. The largest savings in final energy can be achieved when switching to a geothermal heat pump, however, without any additional efficiency measures, this yields a very poor return on investment.

Table 5 Effect on energy use of different individual energy efficiency measures in kWh/m^2 year

Component	**Measure**	**Heating [kWh/m2 a]**	**Appliances [kWh/m2 a]**	**Total [kWh/ m2 a]**	**Savings [%]**	**ROI [%/a]**
Status Quo		110	25	134	-	
External Wall	+100mm	91	25	116	14%	1.6%
	+200mm	87	25	111	17%	1.6%
	+300mm	85	25	110	19%	1.5%
Roof	+100mm	98	25	123	9%	0.7%
	+200mm	95	25	123	12%	0.7%
	+300mm	93	25	119	13%	0.7%
Floor Slab	+100mm	108	25	132	2%	0.3%
Perimeter	+100mm	97	25	121	10%	4.1%
	+200mm	95	25	120	11%	3.1%
	+300mm	95	25	119	11%	2.5%
Window	Double Glazing	101	25	126	7%	1.2%
	Triple Glazing	96	25	121	10%	1.1%
Ventilation	Heat recovery + air tightness	86	25	110	18%	0.9%
	Heat recovery + air tightness (Passive house)	85	25	110	19%	1.3%
Heating System	Geothermal Heat Pump	38	25	62	54%	0.8%

Retrofit Bundles

The effect the retrofit bundles described in Table 4 are shown in Table 6. While yielding increased efficiency gains through the an increased extent of the retrofit measures applied, the results of the different bundles shown that increased savings do not yield an increase economic feasibility. Contrary, the results show, that going beyond a major refurbishment with efficiency gains of more than 58% result in a significant decrease of the return of investment.

Table 6 Effect on energy use of different retrofit bundles in kWh/m^2 year

Retrofit bundle	Heating [kWh/m2 a]	Appliances [kWh/m2 a]	Total [kWh/m2 a]	Savings [%]	ROI [%/a]
Status Quo	110	25	135	-	-
Minor Retrofit	74	25	98	27%	1.2%
Major Retrofit	32	25	56	58%	1.1%
NZEB Retrofit	9	25	33	75%	0.79%

4. Conclusion

The results of this study show measures in order to achieve deep energy retrofit for a School building in Sweden. The energy savings measures considered mainly focus on reduction of transmission and ventilation losses such as insulation, new windows and heat recovery in the ventilation. These measures are the most common in Sweden, which due to its climate has high heating demand. A geothermal heat pump was also considered, however, as the building is connected to the district heating network its application is not very likely and is therefore only considered as part of the NZEB-scenario. The results show, that the all the retrofit options do not yield a high ROI. However, as the analysis uses the status quo as a reference and does not consider anyway costs as part of this simplified calculation, the return of the energy savings part of the investment might be higher. However, the results do indicate the going beyond the DER scenario decreases the ROI significantly. Therefore, in order to reduce site energy demand further, renewable energy generation options such as PV or solar collectors might be considered.

Moreover, while it is commonly known that the energy efficiency gain often exceeds the corresponding economic gain, the systematic effect of different measures when applied together or subsequently in a building is often not explicitly discussed. The fact that retrofit measures decrease the effect of any subsequent measure makes such measures less likely to be implemented. This could result in sub-optimal solution and lock-in effects in case of a step-wise retrofit of a building. This highlights the need for systemic solutions and combined approaches aiming for deep energy retrofits instead of a step-wise measures. However, such interactive effects also need to be considered within deep energy retrofit concepts, as some measures effect each other (e.g. passive demand reduction and active technologies). This is calling for integrated and optimized retrofit concepts taking into account all building components together and not looking at individual building parts separately. Moreover, in order to reach European targets for NZEB, retrofit concepts should take into account both the energy demand reduction as well as on site energy supply options in order to be more cost-effective.

References

[1] European Comission. 2010. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings. June.

[2] M. Case (ERDC, USA), A. Zhivov (ERDC, USA), R. Liesen, (ERDC, USA) and M. Zhivov (UIUC, USA). 2016. Building envelope optimization with US Army barracks and office building renovation in 15 DOE climate zones for deep energy retrofit. ASHRAE Transactions. Vol. 122, Part 1
[3] J. Rose (DBRI-AAU, Denmark), K.E. Thomsen (DBRI-AAU, Denmark), O. C. Mørck (Cenergia, Denmark), Kalle Kuusk (TUT, Estonia), Targo Kalamees (TUT, Estonia), Tõnu Mauring (University of Tartu, Estonia). 2016. Economic challenges of deep energy renovation – differences, similarities and possible solutions for northern Europe – Estonia and Denmark. ASHRAE Transactions. Vol. 122, Part 1
[4] J.M. Riel and R. Lohse (KEA, Germany), H. Staller (AEE, Austria). 2016. Building envelope parameters optimization for deep energy retrofit of public buildings in Germany and Austria. ASHRAE Transactions. Vol 122, Part 1
[5] R. Yao (University of Reading, UK), X. Li(Chongqing University, China), B. Li (Chongqing University, China), M. Shahrestani (University of Reading, UK), S. Han(University of Reading, UK). 2016. Building envelope parameters optimization for deep energy retrofit of public buildings for different climate zones in UK and China. ASHRAE Transactions. Vol 122, Part 1.
[6] Johansson, Birgitta, ed. 2012. Miljonprogrammet - utveckla eller avveckla?. Stockholm: Formas.
[7] Ostermeyer, Y., Wallbaum, H. & Reuter, F., 2013. Multidimensional Pareto optimization as an approach for site-specific building refurbishment solutions applicable for life cycle sustainability assessment. The International Journal of Life Cycle Assessment, 18(9), pp.1762–1779.
[8] Passive House Institute. 2013. Passive House Planning Package (PHPP) v8. Passive House Institute, Darmstadt, Germany