Innovative solution for heat recovery of ventilation air in older apartment buildings - with low intervention affecting the residents

Björn Berggren, Lund University, Energy and BuildingDesign, P.O. Box 118, 221 00 Lund, bjorn.berggren@ebd.lth.se

Henrik Davidsson, Lund University, Energy and BuildingDesign, P.O. Box 118, 221 00 Lund, henrik.davidsson@ebd.lth.se

Abstract

Buildings today account for 40% of the world's primary energy use and 24% of the greenhouse gas emissions. Reducing the energy use in buildings is an important measures to reduce energy dependency and greenhouse gas emissions. In Sweden, there are roughly 2 500 000 dwellings in multifamily houses and single family houses. There is a need to address the energy use within the existing dwellings; especially within multifamily buildings constructed 1960-1975, which accounts for almost one million dwellings or roughly 40 % of the dwelling stock in Sweden.

There are good examples of energy renovations of buildings, reducing the energy use by more than 50 %. To reach the energy savings; balanced ventilation with heat recovery was a necessary measure in all projects. However, in all projects; loss of ceiling height in parts of the apartments is a consequence of the measure. Furthermore, it required the residents to temporary move during installment in the majority of the projects.

The purpose of this study is to investigate the potential of using a heat exchanger, suitable for natural ventilation, exhaust air ventilation and hybrid ventilation, for installment in the existing building stock in Sweden.

A qualitative and quantitative comparison is carried out; comparing mechanical exhaust air ventilation, balanced mechanical ventilation with heat recovery and the heat exchanger suitable for natural ventilation, exhaust air ventilation and hybrid ventilation. The qualitative analysis compares the advantages and disadvantages of the different ventilation system. The quantitative part investigates the potential energy savings and a potential quantity of dwellings where heat recovery may be installed.

By installing heat recovery, energy used for space heating may be reduced by roughly 25%. Combining installment of heat recovery with improvement of the building envelope may reduce the energy demand for heating by roughly 75 %. Heat recovery should be able to install in roughly 80 % of the dwellings in the existing dwelling stock, built before 1980.

Keywords: Energy renovation, Heat recovery, Ventilation, Natural ventilation, Hybrid ventilation.

Introduction

Energy and environmental problems

Buildings today account for 40% of the world's primary energy use and 24% of the greenhouse gas emissions [International Energy Agency (IEA), 2013a]. The building sector is expanding. Hence, reduction of energy use and increased use of energy from renewable sources in the buildings sector; are important measures required to reduce energy dependency and greenhouse gas emissions.

Energy efficient buildings, such as Passive houses and Net Zero Energy Buildings (Net ZEBs), are two examples of necessary measures for climate change mitigation as they may reduce the energy consumption in the building sector. Today a number of buildings exist where the design principle has been to construct a Net Zero Energy Building (Net ZEB), Passive house or low energy house [International Energy Agency (IEA), 2013b; Wahlström, Jagemar, Filipsson, & Heincke, 2011]. A majority of the projects are new production.

In Sweden, there are roughly 2 500 000 dwellings in multifamily houses and single family houses [SCB, 2012a]. Available statistics show that during the last three years in Sweden new production of residential buildings has only amounted to roughly 10 000 – 20 000 dwellings per year, while demolition of dwellings has been less than 1000 dwellings per year since 2007 [SCB, 2012a, 2012b]. Hence, even if the small share of new production is built as very energy efficient buildings, the overall impact on the energy use in buildings is low.

There is a need to address the energy use within the existing dwellings; especially within multifamily buildings constructed 1960-1975, which accounts for almost one million dwellings or roughly 40 % of the dwelling stock in Sweden.

Heat recovery of exhaust air - Why should we use heat recovery?

The natural ventilation is driven by natural forces such as stack effect and wind induced pressure. The exhaust air ventilation system is mainly driven by an exhaust air fan. These techniques normally lack the possibility to recover any heat from the outgoing ventilation air. The consequences for this will be a high energy demand and a high peak power load for buildings located in cold climates. Simultaneously this might lead to a low thermal comfort due to cold draught from the incoming cold air. Furthermore, the natural ventilation technique is strongly dependent on the driving pressure due to temperature difference between the indoor and the ambient air along with the wind induced pressure to reach the desired ventilation rate.

The mechanical ventilation with heat recovery unit is normally made up from a heat exchanger in which the incoming air meets the outgoing air and during this passage transfers its energy. Alternatively the heat exchanger is made up of two heat exchanger separated in space connected with a brine system. In this case the brine in the heat air-to- heat exchangers is circulated with a pump. The energy recovered from the exhaust air is pumped and delivered to the air passing the supply air heat exchanger. Both of these systems reduce the energy need, the power need at the same time as the comfort is increased.

The dependence of the efficiency of the heat exchanger is substantial. Simulations have shown that the heating energy need for a passive house can more than double if the efficiency of the heat recovery unit lowered from 85% to 60% [Kildsgaard, Jarnehammar, Widheden, & Wall, 2013].

Previous projects

There are good examples of energy renovations of buildings, reducing the energy use by more than 50 % [International Energy Agency (IEA), 2010]. Some specific examples of multifamily houses built in Nordic climate, during 1961-1975; “Brogården” [Janson, 2010], “Backa Röd” [Poseidon, 2009], “Stjørdal” [Thyholt & Slagstad, 2010] and “Myhrenega” [Klinski, Dokka, & Hauge, 2011]. To reach the energy savings; balanced ventilation with heat recovery was a necessary measure in all projects.

In “Myhrenega” an effort was made to use the existing shafts and the old rubbish chute for the ventilation ducts. However, in all projects; loss of ceiling height in parts of the apartments is a consequence of the measure. Furthermore, it required the residents to temporary move during installment in the majority of the projects.

Objective

The purpose of this study is to investigate the potential of using heat exchanger, described in [Davidsson, Bernardo, & Hellström, 2013a, 2013b], for installment in the existing building stock in Sweden. The heat exchanger is suitable for natural ventilation, exhaust air ventilation and hybrid ventilation. Henceforth, it will be called IHR, “innovative solution for heat recovery”.

Method

A qualitative and quantitative comparison is carried out; comparing different ventilation systems:

- Mechanical exhaust air ventilation system, MEV (common in the existing building stock).
- Balanced, mechanical, ventilation with heat recovery, MVHR (traditional solution for recovering heat from the outgoing ventilation air).
- Innovative solution for heat recovery, IHR.

The different systems with heat recovery are also combined with measures to improve the heat resistance of the exterior walls and roofs by adding more insulation.

The qualitative comparison describes the IHR and compares the advantages and disadvantages of MEV, MVHR and IHR. E.g. complexity, space consumption, impacts on residents, etc.

The quantitative comparison is conducted in three steps. Firstly, a literature review is conducted to define common buildings and building types in the Swedish dwelling stock where the innovative solution for heat recovery may be installed. The investigation is based on data from [Boverket, 2010; SCB, 1967-1995, 2011, 2012a, 2012b] focusing on buildings built during the so called “Miljonprogrammet” 1966-1975.

Secondly, a case study is carried out for a multifamily building, representing the most common building type. Simulations are conducted using VIP Energy 2.1 [Strusoft, 2012].

Finally, the potential impact in the Swedish building stock is investigated, calculating the product of the effect for the fictive building and the potential amount of installments in the Swedish building stock. The environmental impact is calculated based on emission factors presented in Table 1.

Table 1 Emission factors for different energy sources [Fahlberg & Johansson, 2007].

Energy source	Emission factor, CO_2-eq [g/kWh]
District heating	119
Electricity	105

Results

Multifamily houses in the Swedish dwelling stock

As already mentioned in the introduction; a large share of the dwellings in multifamily buildings were completed during the 1960s. As can be seen in Figure 1, the majority of the dwellings were not built in metropolitan regions.

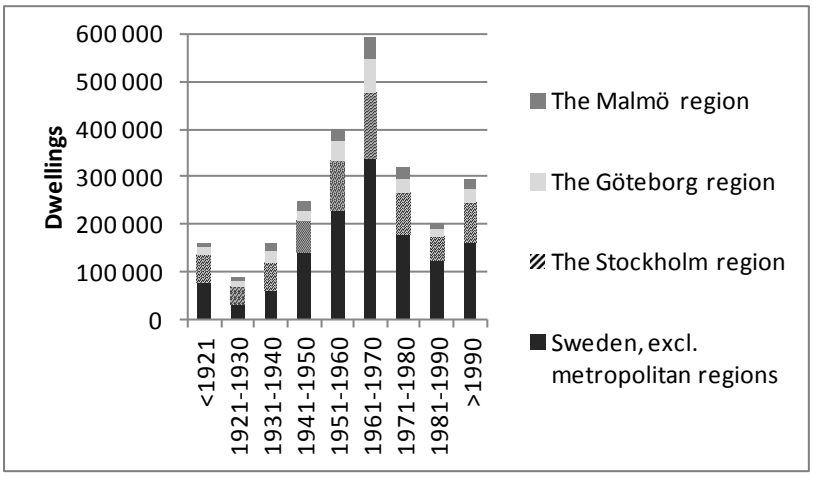


Figure 1 Dwellings in Swedish multifamily buildings by year of completion and region [SCB, 2011].

Across Sweden 83 % of the dwellings built as multi-dwelling buildings, 1966-1975, were slab block buildings. Balcony access block buildings and point block buildings are more common in the Stockholm region compared with the rest of Sweden, accounting for 21 % of all dwellings in multi-dwelling buildings. The slab block buildings and point block buildings are usually designed without an attic and have roofs with low roof fall and eaves are very small or nonexistent [Vidén, Schönning, & Nöre, 1985].

The number of floors in multi-dwelling buildings built 1968-1975 varies greatly when comparing metropolitan regions and the rest of the country. As high as 81 % of the dwellings in multi-dwelling buildings built outside metropolitan regions was four stories high or lower compared to the Stockholm region; 35 %. In the Stockholm region and Malmö region the largest share of the dwellings within multi dwelling buildings are 5 floors or higher; 65% respectively 51%. In the Göteborg region the share is 46 %. Overall, in Sweden, were three-storey buildings the most common buildings and accounted for 44 % of the dwellings built in multi-dwelling buildings within the so called “Miljonprogrammet”.

Within the gathered statistics from Statistics Sweden, SCB, data for load bearing system is only available 1968-1972. This is however the peak of production of multi dwelling buildings, thus interesting to study. During 1968-1972, 49 % of the dwellings were constructed with transverse load bearing system. The transverse load bearing system was most common in the Göteborg region where 61 % of the dwellings in multi-dwelling buildings 1968-1972 were constructed with transverse load bearing system. Load bearing pillar systems and other were not common.

Different types of buildings, number of floors and load bearing systems are presented sorted by different regions in Figure 2.

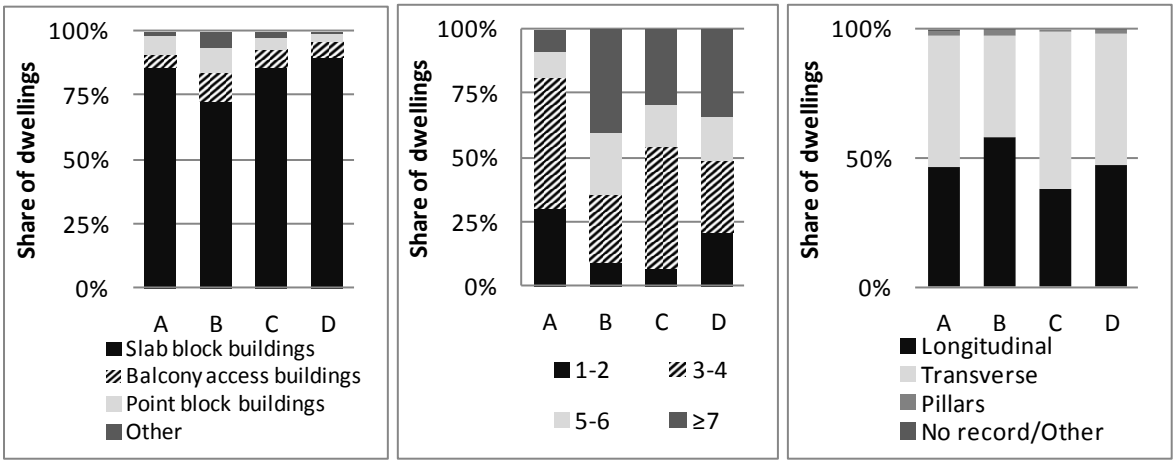


Figure 2 Left: Distribution of dwellings in different types of multifamily houses in different regions 1966-1975. Middle: Distribution of number of floors in dwellings in multifamily houses in different regions 1968-1975. Right: Distribution of load bearing systems in dwellings in multifamily houses in different regions 1968-1972. A: Sweden, excluding metropolitan regions B: Stockholm region C: Göteborg region D: Malmö region [SCB, 1967-1995].

As can be seen in Figure 3, in multifamily buildings built before 1961; almost 50 % are ventilated using natural ventilation and almost 50 % uses exhaust air ventilation system. In multifamily buildings built 1961-1975; roughly 70 % uses exhaust air ventilation system and roughly 10 % uses balanced ventilation with heat recovery [Boverket, 2010]. Comparing requirements for U-values in building regulations and results from field studies [Boverket, 2010], named BETSI in Figure 3, the U-values for exterior walls are roughly 20 % lower for multifamily buildings completed 1961-75. Comparing roof constructions the difference is larger. The U-value of roof constructions are roughly 50 % lower compared to regulations for multifamily buildings completed 1961-75. Roof constructions and exterior walls in multifamily buildings completed 1976-85 are roughly the same.

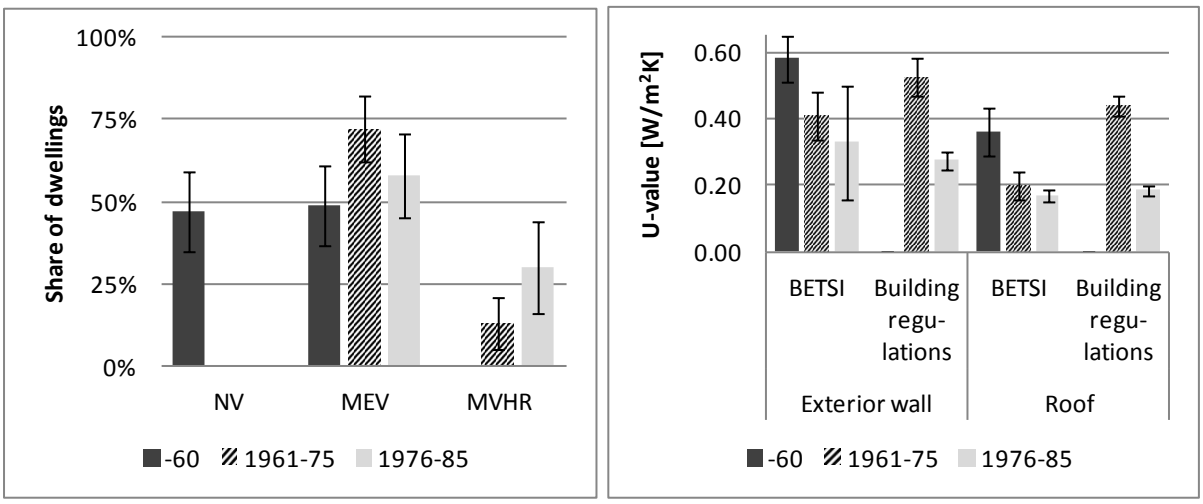


Figure 3 Left: Distribution of dwellings with different types of ventilation [Boverket, 2010]. Right U-values for exterior walls and roofs, comparing requirements in building regulations and results from field studies; BETSI [Boverket 2010].

Comparison of different systems for heat recovery

The MEV and the MVHR are well know ventilation techniques. The IHR is a ventilation system driven by natural forces when these are available. During wind still periods with an ambient temperature close to the indoor temperature the driving forces will be close to zero. During such periods a fan can be used to assure the ventilation rate. This type of technology combining natural ventilation with a fan is known as hybrid ventilation. The heat recovery system is a run-around system with brine-to-air heat exchangers placed at roof level to recover parts of the heat that would otherwise leave the building. The heat is transported in the brine to the incoming air at ground level or alternatively at floor level for single apartment air intakes. Figure 4 shows illustrations of the brine-to-air heat exchanger that was investigated and discussed in two articles [Davidsson, Bernardo, & Hellström, 2013a, 2013b]. The heat exchanger is made up from solar collector absorbers soldered to a manifold. To the left in the figure is a drawing of the exchanger showing the cold air meeting the hot water and to the right is a photograph where one side of the cover has been removed. In table 2 MEV, MVHR and IHR are compared.

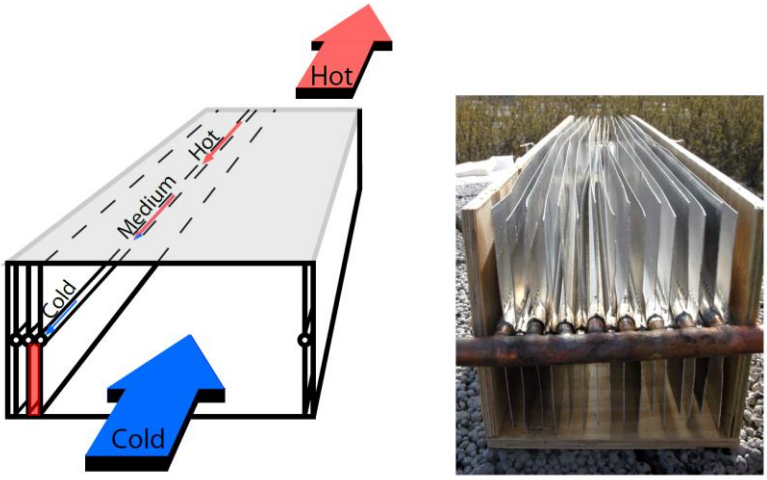


Figure 4. The heat exchanger for the ventilation heat recovery system.

Table 2 Summary of Strengths and weaknesses.

	Strengths	Weaknesses
MEV	Low volume needed for ducts Well known technology	No heat recovery No preheating of inlet air
MVHR	Well known technology High thermal comfort Reduced space heating demand	High electricity consumption for fans Increased need for ducts Increased maintenance
IHR	Low volume needed for ducts Low electricity consumption	New technology Hard to combine with noise dampers and filters

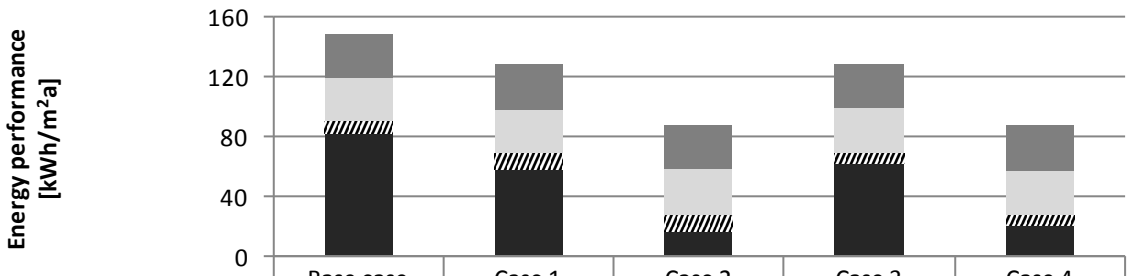
Case study

The case study is based on the most common building type; a three floor slab block building, heated with district heating. Characteristics' and input data for the case study are given in Table 3. For both MVHR and IHR simulations are conducted with and without improvement of the building envelope. It is assumed that the air tightness is rather poor and that this may only be improved if the building envelope is improved. Occupancy loads are according to Swedish guidelines [Levin, 2009].

Table 3 Input data for simulations

	Base case	Case 1	Case 2	Case 3	Case 4
Conditioned area [m^2]			1200		
Window-wall-ratio [%]			20		
Air exchange rate [h^{-1}]			0.5		
Geographic location			Stockholm, Sweden		
Ventilation system	MEV	MVHR	MVHR	IHR	IHR
Heat recover/SFP [%, kW/m^3s]	-/0.5	80/1.75	80/1.75	75/0.5	75/0.5
Exterior walls, U-value [W/m^2K]	0.35	0.35	0.10	0.35	0.10
Roof construction, U-value [W/m^2K]	0.20	0.20	0.10	0.20	0.10
Windows, U-value [W/m^2K]	2.00	2.00	0.90	2.00	0.90
Air tightness (EN 13829) q_{50} [$l/s, m^2$]	1.0	1.0	0.3	1.0	0.3
Slab on ground, U-value [W/m^2K]			0.30		
Thermal bridges			Included in U-values		
Interior floor slabs			200 mm reinforced concrete		

The results from the simulations are presented in Figure 5. As can be seen, comparing Case 1 and Case 3 with the Base case, installing heat recovery roughly reduces the energy demand for space heating by 25-30%. The reduction is lower when using IHV. However the increased auxiliary energy is less. The overall effect on the energy performance (including all energy use) is a decrease in energy use by 14-15 percent for Case 1 and Case 3 compared with the Base case. Comparing Case 2 and Case 4 with the Base case, energy demand for space heating is reduced by 75-79 %. The large reduction is mainly due to reduced transmission heat transfer losses, but also due to reduced infiltration losses. Reductions of CO_2-equivalents are roughly 2.5 kg/m^2a if heat recovery is installed. If installment of heat recovery is combined with measures to improve the building envelope; reductions of CO_2-equivalents are roughly 7.5 kg/m^2a. There are today roughly 60 million square meters of conditioned area in multifamily houses built before 1960 in Sweden. Roughly 40 million square meters in multifamily houses completed 1961-70 and roughly 20 million square meters in multifamily houses completed 1971-80 [Energimyndigheten, 2012]. Based on the statistics for different ventilation systems it may be assumed that these measures may be possible to apply on 80 % of the dwellings. I.e. roughly 100 million square meters.



	Base case	Case 1	Case 2	Case 3	Case 4
Plug loads & Lighting	30	30	30	30	30
Domestic hot water	30	30	30	30	30
Auxiliary energy	7	11	11	7	7
Space heating	83	58	17	62	20

Figure 5 Energy performance for different cases

Discussion and conclusions

It should be noted that the available statistics and results from field studies differ regarding how they choose to divide/sort the existing building stock by year of completion. However, it is possible to conclude that the most common multifamily building type within the existing building stock in Sweden has the following characteristics:

- Built outside of metropolitan areas.
- 3-4 stories high.
- Slab block building, ~50/50 % with longitudinal/transverse load bearing systems respectively.
- Natural ventilation or Mechanical exhaust air ventilation.

The energy savings, for space heating, achieved by installing IHR i slightly lower compared to traditional MVHR. However, the increased electricity consumption for MVHR is roughly as high as the difference in energy savings. If a building owner would consider electricity as a more valuable energy carrier compared to heat, the IHR would be the preferred system.

The IHR has the benefits of requiring no extra ducts compared to the existing ventilation system already within the building. The piping's for the brine requires little volume. The piping's could be mounted on the exterior side of an exterior wall if the wall is to be improved by adding more insulation.

This case study indicates that it is possible to achieve large energy savings within existing buildings, by improving the building envelope and recovering the heat in the ventilation air. However, these measures should be combined with measures for reducing the energy demand for domestic hot water, plug loads and lighting in order to achieve even higher energy savings.

This study focuses on energy savings. Moisture related problems which may occur when more insulation is used, indoor air quality, fire safety etc. has not been investigated.

References

Boverket. Energi i bebyggelsen – tekniska egenskaper och beräkningar, pp. 210 (2010).

Davidsson, H., Bernardo, R., & Hellström, B. (2013a). Hybrid Ventilation with Innovative Heat Recovery—A System Analysis. Buildings, 3(1), 245-257, pp. 13 (2013a).

Davidsson, H., Bernardo, R., & Hellström, B. (2013b). Theoretical and Experimental Investigation of a Heat Exchanger Suitable for a Hybrid Ventilation System. Buildings, 3(1), 18-38, pp. 21 (2013b).

Energimyndigheten. Energistatistik för flerbostadshus 2011 (ES 2012:05), pp. 62 (2012).

Fahlberg, K., & Johansson, S. Emmisionsfaktorer - Sammanställning av tillgänglig data och statistik, pp. 23 (2007). Retrieved 2013-04-11 from http://www.ima.kth.se/klimatswe/dokument/CO2e%20Statistik%20Inkl%20LCA%20V%C3%A4rden.pdf.

International Energy Agency (IEA). Advanced Housing Renovation with Solar and Conservation (2010). Retrieved 2013-04-11 from http://task37.iea-shc.org/.

International Energy Agency (IEA). Towards Net Zero Energy Solar Buildings, (2013a). Retrieved 2013-04-02 from http://task40.iea-shc.org/.

International Energy Agency (IEA), SHC Task40/ECBCS Annex52 IEA Net Zero energy Buildings database (2013b). Retrieved 2013-04-11 from http://iea40.buildinggreen.com/index.cfm

Janson, U. Passive houses in Sweden. From design to evaluation of four demonstration projects. Doctroral Thesis, Lund University, Lund, pp 390 (2010).

Kildsgaard, I., Jarnehammar, A., Widheden, A., & Wall, M. Energy and Environmental Performance of Multi-Story Apartment Buildings Built in Timber Construction Using Passive House Principles. Buildings, 3(1), 258-277, pp. 20 (2013).

Klinski, M., Dokka, T. H., & Hauge, Å. Practical experience from the first apartment house renovation with Passive House components in Norway. Proceedings from 4th Nordic Passive House Conference, Helsinki, pp. 8 (2011).

Levin, P. Brukarindata för energiberäkningar i bostäder, pp. 36 (2009). Retrieved 2013-04-11 from http://www.sveby.org/wp-content/uploads/2012/01/brukarindata_bostader.pdf.

Poseidon. Renovering med fokus på energi och inne miljö, pp. 6 (2009). Retrieved 2013-04-11 from http://poseidon.goteborg.se/Documents/Broschyr%20i%20r%C3%A4tt%20ordning%20f%C3%B6r%20digital%20l%C3%A4sning.pdf.

SCB. Statistics of State Loan Projects (1967-1995). Gathered 2010-09-20 – 2010-12-16 from Lund University Library.

SCB. Kalkylerat bostadsbestånd (2011). Uppdragsbearbetning från SCB 2011-01-26.

SCB. Bostads- och byggnadsstatistisk årsbok 2012 pp. 240 (2012a).

SCB. New construction of residential buildings (2012b). Retrieved 2013-04-11 from http://www.scb.se/Pages/TableAndChart____19985.aspx.

Strusoft. VIP Energy, Version 2.1 (2013). Retrieved 2013-04-11 from http://strusoft.com/index.php/sv/produkter/vip-energy.

Thyholt, M., & Slagstad, H. Terrasse apartments Husby, Stjørdal, NO, pp. 4 (2010). Retrieved 2013-04-11 from http://archive.iea-shc.org/publications/downloads/task37-910-Husby.pdf

Wahlström, Å., Jagemar, L., Filipsson, P., & Heincke, C. LÅGAN Rapport 2011:01 Marknadsöversikt av uppförda lågenergibyggnader, pp. 64 (2011).

Vidén, S., Schönning, K., & Nöre, K. Flerbostadshusen i Sverige : kvaliteter och brister, ombyggnadsbehov och möjligheter. Stockholm: Statens råd för byggnadsforskning, pp. 594 (1985).