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Passive house-concept apartments: sustainability evaluation in a case study of Stockholm, Sweden

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Abstract. The housing sector accounts for almost one-third of total energy use in Sweden; of this amount, the operation phase of a building is responsible for around 85% of its total energy use. The Swedish government aims to reduce the energy consumption in buildings by 50 % by the year 2050. One way to achieve this goal is the construction of the low-energy buildings. The purpose of the study has been to analyse the Blå Jungfrun passive house-concept, tenant occupied apartments in Stockholm, Sweden, through a blend of qualitative and quantitative research methodology. The Swedish energy-efficient buildings are considered as a platform for recommendations for improving the knowledge and practice of low-energy buildings grounded in sustainability science as the theoretical framework. The study has investigated the roles of the responsible architects and design features of the Blå Jungfrun. The economic viability of the apartments is calculated by the economic evaluation software OekoRat for a life span of 50 years. The annual energy requirements of the studied apartments are analysed in regard to their post-occupancy evaluations. The social inclusion of the Blå Jungfrun tenants is investigated considering the issue of their participation in planning stages of the apartments. The empirical findings of the study shows the inevitable correlations between the environmental, economic, and social dimensions of the passive house. The findings suggested that in order to achieve a successful sustainable system of the sustainable housing, a holistic approach in the low-energy buildings is necessary.

1. Introduction

Global warming, climate change, increasing energy costs, and decreasing resources availability are among the reasons, which have caused a focus on the building of environmentally friendly houses. The Swedish ratification of the Kyoto Protocol and the United Nations Framework Convention on Climate Change (UNFCCC) are applied as a basis for decision makings regarding the Swedish climate strategy [1]. The Swedish government agreed on 15 environmental goals in April 1999 and one additional goal was added in November 2005 [1]. The goals that are important for the building industry can be listed as *A Good Built Environment* and *Reduced Climate Impact*. In regard to the goals for the Swedish energy policy, which were provided in 1997 and consequently were confirmed in 2002 by the Swedish parliament; the Swedish energy supply should be effective and sustainable in both short and long term perspectives. In the directive for energy efficiency in the built environment, the European Union (EU) Commission declares that in order to decrease CO_2 emissions, the building sector must decrease its use of energy [2]. In June 2006, the Swedish government stated a goal, to reduce the energy consumption in buildings with 50% until the year 2050 [3]. One way to achieve this goal is the construction of the passive house-concept buildings.

1.1. Objective and methodology of the study

The analyses of the study is based on the case study of Blå Jungfrun passive house-concept project in Stockholm. The focus is on the design aspects, economic viability, and annual energy requirements of the project. The study also aims to explore the social inclusion of the users in the planning process of Blå Jungfrun in order to identify potential shortcomings.

To approach the challenge of this study, a blend of qualitative and quantitative data was needed. The qualitative data in regard to the social inclusion of the tenants of Blå Jungfrun apartments were collected through the interview sessions with the architects of the project and the environmental engineer of the construction company Skanska during years 2012-13. This qualitative data is coupled with quantitative data available from the post-occupancy evaluation of the project for the year 2011 (collected from Svenska Bostäder; the responsible housing company), the relevant statistical online databases, and Oeko-Rat software economic calculations. Hence, the sources of qualitative and quantitative data, analysis and discussion sections are not based on the marketing materials of Blå Jungfrun project but on the collected data from interviews, post-occupancy evaluations, statistical databases, and economic software calculations.

1.2. Swedish passive house definition and development

Forum för Energieffektiva Byggnader (FEBY) Passivhus defines passive houses as:
"Low energy buildings that aim to perform better than new built buildings regulated in BBR 16 (BFS 2008:20)" [4].

The earlier experiences of Swedish passive house projects were carried out in 1981 in Växjö and Färgelanda. Later, in the mid-80s, a German researcher Dr. Wolfgang Feist and a Swedish professor Dr. Bo Adamson developed the concept of present-day passive houses [1]. Ten years after the first positive experiences of passive house in Germany, the first modern passive house in Sweden was built in 2001 [1]. The Lindås project, which is a 20 terrace houses project in Göteborg (Lindås) as a part of CEPHEUS research project, became a milestone in the construction of Swedish low-energy buildings [5]. The experiences of Swedish modern passive house projects in 2001 demonstrated that this concept can be feasible in Scandinavian climate [5].

1.2.1. Energy demand of the passive house in Sweden

Space heating demand, domestic hot water, electricity for mechanical systems (fans and pumps), and general electricity utilized by the building such as common lighting and electricity used for elevators are included in the Swedish criteria regarding the energy consumption [6]. However, household electricity and the energy produced at the building from installed solar cells or panels are not included in the energy consumption demand of passive houses [6]. The Swedish criteria recommend a total energy consumption of maximum 45 kWh/m^{2}a for southern climate zone and a limit of 55 kWh/m^{2}a for northern climate zone of Sweden [7]. An additional 10 kWh/m^{2}a in both regions is allowed for detached houses with less than 200 m^2 [7].

This study aims to assess not only the specific energy requirements of the case study project, but also the energy consumption patterns of the tenants of the case study. This assessment should contribute to environmental and economic aspects of the passive house. That is because the very low energy demand of the passive house contributes to fulfil the economic and environmental components [8].

1.2.2. Economic efficiency of the passive house

The specific extra costs, which are related to passive houses compared to conventional buildings, can be divided into the categories such as costs for heating, ventilation, isolation, air tightness, ground works, differentiation in net floor surface and miscellaneous costs [9]. The extra costs of passive houses are invested in energy efficiency of these buildings and are supposed to be paid back through the annual energy savings, which is provided by this obtained energy efficiency [10].

1.2.3. Social sustainability and inclusion of the residents
The social issues linked to participation of a large range of actors such as occupants are considered as a component in the making of successful sustainable building [11]. Social sustainability need to include residents in the building processes [12]. Social sustainability is an important point in the development of passive houses. The social sustainability of passive houses deals not only with the protection of human health, well-being, and indoor thermal comfort, but also the behaviour of end-users of the passive house. To achieve the goal of social sustainability several issues should be taken into consideration [12]:

- The occupants of passive houses should get included during the planning and design stages of these buildings.
- Post-occupancy evaluations of these buildings should present data “both on what energy resources residents are using and why the pattern of use looked like that”.
- Eventually, post-occupancy evaluations should yield “accurate and accessible” input to new developments.

The assessment of the social sustainability of the case study project, however, is limited. There were no studies carried out on the tenants of the case study apartments. Therefore, the effect of indoor air quality on the health and comfort of the tenants, and their views on energy consumption patterns have been not assessed.

2. Blå Jungfrun energy efficient apartment project in Stockholm

Blå Jungfrun is a pioneer passive house standard residential development with a total of 97 rental apartments, which was constructed by Skanska in 2010 first in Stockholm (see figure 1). It is located in the southeast part of Stockholm between Farsta and Hökarängen, which is about 10 km south of central Stockholm. The planning phase of the project started in October 2008 and tenants moved into the buildings during the second and final quarter of 2010 (see table 1).

Figure 1. Blå Jungfrun energy efficient apartment project in Stockholm.

Table 1. The project facts.

Project: Blå Jungfrun		
Client: Swedish housing association (Svenska Bostäder in Swedish)		
Construction company: Skanska		
Architect company: Reflex Architects		
Architects in charge: Kjell Mejhert and Pernilla Ivarsson		
Construction type: Prefabricated frame passive house		
Construction cost: (27000 SEK/m^2)* including value added tax (VAT)		
Year completed: 2010		
Location: Hökarängen, Stockholm; Sweden		
Development type: 4 blocks of 5 and 6-storeys high with 97 apartments		
Building type	Number	Area (Sqm)
2 Bedrooms apartment	21	53-55
3 Bedrooms apartment	36	73-85
4 Bedrooms apartment	20	88-105
5 Bedrooms apartment	20	111

*This amount is based on the data received from Svenska Bostäder (the responsible housing agency)

After the first year of the tenants' occupancy of the Blå Jungfrun apartments, the amount of energy consumption was calculated by Svenska Bostäder [13]. The calculations show that the energy consumption for heating has been reduced around 85% in comparison to the standard of BBR, legislation 2009 (see figure 2).

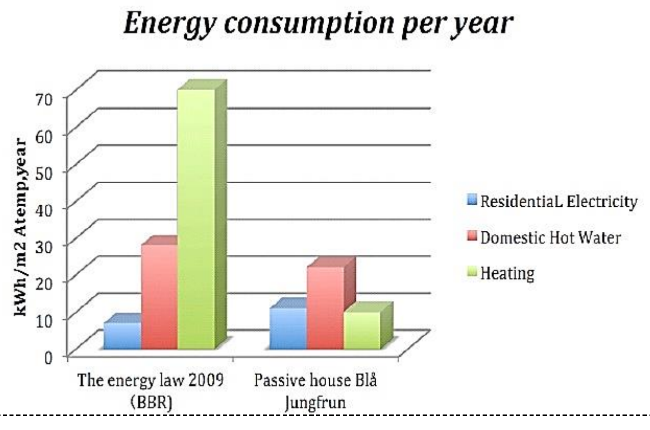

Figure 2. The comparison of energy consumption of the Blå Jungfrun with the requirements of the applicable BBR legislation 2009 [13].

3. Interview Study

From the start of the Blå Jungfrun project the architects team of the project have suggested Svenska Bostäder (the client) to develop an environmentally responsible building project. Further, Skanska as the developer and investor has entered the project and the financial comparison between conventional buildings and passive houses got calculated by Skanska. Eventually, the Blå Jungfrun project got to be constructed with passive house standards. Besides, the environmental development leader of Skanska, has explained that the driving forces for their customers of green houses have been lower energy costs during use, better in-door environment, higher value (financial benefits) of the building, and a green profile for the company.

3.1. Specific design aspects of Blå Jungfrun project

3.1.1. Architectural effect and form
Buildings have the southern orientation with most windows to the south, however, they are not the most compact buildings possible. The buildings were designed very simple in their form, while the architects could not add a lot of architectural effects to them. According to the architects, in spite of the fact that the focus of the first passive house designers has not been on architectural parts, rather on the technical parts, it is possible to design modern and attractive architectural forms for passive houses (Interview with architects).

3.1.2. Large south-facing balconies
The south-facing large balconies are designed to sunscreen the summer sun. According to architects, although, the large balconies and their connection to the buildings have been expensive to construct, they save costs in operation phase of the buildings (Interview with architects).

3.1.3. Placement of windows
There have been many calculations on the placement of windows. These buildings apply passive solar heating system through the windows for some part, thus it has been critical to decide to place the windows right in the façade (Interview with architects).

4. Economic evaluation of the Blå Jungfrun passive apartments
Construction costs of the passive house are more expensive than a conventional house, because of extra costs of a passive house such as: costs for ventilation, costs for insulation, costs for triple glazed windows and entry doors, costs for measuring air tightness, costs for ground works, etc. [10]. The additional costs of constructing passive houses are invested in energy-efficiency quality of these buildings. These extra costs are supposed to be paid back through the annual energy savings of passive house during its lifespan. The main factors that affect economic aspect of the passive house are considered as (see appendix 1) [14]:

- Initial investment costs
- Annual energy saving
- Energy costs
- Annual operation costs
- Considered period of time (Utilization of building)
- Interest rate
- General inflation rate
- Energy inflation rate

The economic efficiency of the passive house can be calculated regarding the payback time and internal interest rate of the investment [14]. The payback time of passive houses is directly dependent on the growth of the energy prices and inflation rate indirectly influences energy price and interest rate [10]. These factors are used in order to decide whether the construction of the Blå Jungfrun passive apartments is economically viable. As the first condition, the payback time must be shorter than the lifespan of the buildings [14]. Secondly, the internal interest rate, which depends on the lifespan of the buildings, has to be larger than or equal to the interest rate of the capital investment.

In order to evaluate the economic efficiency of the investment for Blå Jungfrun passive-house apartments, the software called Economic Evaluation (Oeko-Rat) is used. This software is specifically designed for economic calculations of energy savings and renewable energies and evaluates the economic efficiency of an investment in accordance with the capital value method [14].

The total cost difference of normal houses and the Blå Jungfrun passive apartments is used as initial investment costs. The annual energy saving is the annual difference of energy consumption of normal houses of Svenska Bostäder and the Blå Jungfrun passive apartments (see table 2; see appendix A for calculations). According to Nordic conditions, the basic lifespan of the buildings is considered to be 50 years and can be then renovated and used for another 50 years [15].

Table 2. Amount of factors used for economic evaluation of the Blå Jungfrun passive apartments

Factor	**Blå Jungfrun project passive house apartments**
Initial investment costs (SEK)	16065000 SEK= (160650 hSEK*)
Annual energy saving (kWh)	943500
Energy cost (Electricity) (SEK/ kWh)	1.6833= (0.016833 hSEK/kWh)
Annual operation costs (%)	2
Considered period of time (utilization) (Years)	50
Interest rate in 2011 (%)	1.625
Inflation rate in 2011 (general) (%)	3.0
Annual inflation rate of energy in 2011 (%)	6.1

*the unit h stands for Hecta (hundred) in calculations.

Sources of table 2:
Row 1: Based on data from Svenska Bostäder.
Row 2: Based on data from post-occupancy evaluations of Svenska Bostäder.
Row 3: Based on data from European statistics (Eurostat, 2012).
Row 4: [14].
Row 5: [15].
Row 6: Swedish central bank's interest rate (global-rates, 2012).
Rows 7 and 8: Based on data from Organization for Economic Co-operation and Development (see appendix B).

The economic evaluation with the energy price in Sweden shows that the investment for building the Blå Jungfrun passive apartments is economically viable, since the payback time for this investment is less than the lifespan (utilization time) of the houses. The internal interest rate of this investment is 14.4 %, which is more than the general interest rate in Sweden (see table 3).

Table 3. Factors of economic efficiency for the Blå Jungfrun passive apartments.

Considered period of time	Payback time	Interest rate	Internal interest rate of the investment	Result
50 years	**10.1 years**	1.65 %	**14.4 %**	**Economic**

The economic evaluation for all the 2 bedrooms apartments, 3 bedrooms apartments, 4 bedrooms apartments, and 5 bedrooms apartments of the Blå Jungfrun passive-house concept apartments has carried out, separately. The results for all calculations are the same with payback time of 10.1 years and internal interest rate of the investment, which is 14.4 %. This estimated payback period of 10.1 years could have been shorter, if the annual energy consumption of the project would have been lower than the measured requirement of 2011.

5. Energy requirements of the Blå Jungfrun passive apartments

According to the post-occupancy evaluation, which is carried out by Svenska Bostäder, the measured energy requirements of the Blå Jungfrun passive apartments for the year 2011 has been 59 kWh/m^{2}a for residential electricity, space heating and, hot water and 92 kWh/m^{2}a including tenant electricity (see table 4) (see appendix C).

Table 4. The measured energy requirement of Blå Jungfrun passive houses for 2011.

Residential electricity	9 kWh/m^{2}a
Heating ventilation and VVC (district heating) & Dehydration of concrete (electricity or district heating)	19 kWh/m^{2}a
The heating electric radiators	4 kWh/m^{2}a
The warm water (apartments and laundry)	27 kWh/m^{2}a
The household and laundry electricity	33 kWh/m^{2}a

Considering the Swedish criteria for energy consumption, the maximum amount of energy demand for passive apartments (excluding household electricity) is recommended not to exceed 45 kWh/m^{2}a in Southern climate zone of Sweden [7]. Therefore, the measured value of 59 kWh/m^{2}a for Blå Jungfrun in 2011 is not within the Swedish criteria of the passive houses.

On the other hand, it has been argued that the energy use, especially for space heating, can be higher during the first heating season in comparison to later during the continuous operation. Generally, this situation is caused by additional energy used for structural drying and also the phase when the occupants are learning how the system works might take more or less time [1].

6. Discussion

The vision of sustainability has been the driving force for constructing the Blå Jungfrun passive-concept apartments. The energy efficiency awareness of the residents is achieved by installing Smart box for each apartment unit in order to provide energy consumption feedback to tenants of the Blå Jungfrun passive apartments. However, the post-occupancy evaluations that have been carried out by Svenska Bostäder demonstrate that the tenants have not reduced their energy consumption patterns. In the Blå Jungfrun apartments, the rents are reduced and tenants have to pay for warm water and extra heating that they consume, separate from the rent amounts of the apartments. According to the architects of the project, when one reads about what tenants have answered to evaluation questions of the project, they have declared that they are more concerned now and they think more about environmental questions. However, when these answers and results are compared with the post occupancy energy statistics, it is seen that tenants have not reduced the energy consumption. Moreover, from interviews, it has been recognized that tenants of Blå Jungfrun apartments have received a lot of information about the buildings being passive house before signing their contracts. Since the tenants pay for their own use of hot and cold water, electricity and some of the heat, the hope has been that they would use less energy. One issue is that he residents of Blå Jungfrun project have got their apartments in Blå Jungfrun apartments through the regular Stockholm apartment queue. In this manner, Svenska Bostäder has no right to favour people who are environmentally interested and responsible and hence few of the tenants choose the apartments due to the house being passive.

According to Palm (2011), in low-energy buildings tenants and tenant/owners often identify actors other than themselves as responsible for energy efficiency [16]. For example, householders rely on the construction company regarding the energy efficiency issues [16]. The research by Pyrko and Darby on conditions of energy efficient behaviour identifies that citizens in Sweden trust their government and often expect that someone does something and that decisions are made for the society’s best, thus people should be informed about the right and rational way to be effectively involved in the process [17]. Their research emphasizes the shortage of face-to-face advice in the home on the issue of energy efficiency, which is more effective but more expensive than normal procedures [17]. Likewise, Palm and Ellegård suggest “time diaries and visulaization tools” as useful tools for approaching inhabitants to target their energy behaviour [18].

The first modern passive house, which was built in 2001 in Sweden, was Lindås project. However, involving end-users was never an option in Lindås project [19]. Isaksson & Karlsson has conducted an interdisciplinary investigation on the thermal environment and space heating of low-energy terraced houses of Lindås project [20]. They have concluded that in developing the next generation of low-energy buildings, an interdisciplinary planning that takes the experiences of occupants as well as measurements into consideration is very important [20].

However, nine years after the completion of the Lindås project in south of Gothenburg in 2001, the Blå Jungfrun passive apartments are constructed in Stockholm in 2010 and still the residents are disconnected from the planning phase of the project. Moreover, the interview materials of this study revealed that Svenska Bostäder has compared the results of the post-occupancy evaluation forms of the tenants and the results of the energy statistics. The tenants have expressed their sustainability awareness intentions; however they have not acted in an environmentally sustainable manner. The reason for this disagreement can be that households want to answer for example survey questions in a way that is politically correct, but it may be difficult to translate that desire into practical action. One major problem with housing policies can be that the housing sector is dominated by a “techno-centric (top-down policy recommendations)” approach, while the “eco-centric (public participation and community involvement)” approach can result in more beneficial outcome [21].

7. Conclusion

The findings of this study show that the environmental, economic, and social aspects of the passive house are closely intertwined. The deficiency in each aspect affects the whole system of the passive house. Fifty percent energy consumption reductions in buildings to year 2050 in Sweden mean substantial changes in patterns of energy consumption in buildings with improvements in all environmental, economic, and social aspects of sustainable buildings. In order to achieve a sustainable system of the passive house, the government or public authorities at the national and local levels need to inform the public of such projects, mediate the involvement of the public, and provide support for the community involvement. The energy-saving behaviours of the passive house tenants can be facilitated by their early participation.

As the result of the increase in the world population from 7.0 billion to 9.3 billion by 2050, 70% of people will be living in urban areas [22]. Cities considered responsible for about 60-80% of global energy consumption and for 75% of global greenhouse gas emissions [22] are increasingly perceived as being crucial in addressing climate change and environmental problems. Accordingly, urban housing as a major component of the city has turned to the centre of attention with the potential to attain the essential strategies to achieve greater sustainability. Housing design that does not take into consideration the participation of its inhabitants, cannot be sustainable in long-term. The results of this study highlight that the of UN`s Agenda 2030 and Sustainable Development Goals (SDGs) [23] would not be achieved, when bottom-up approaches are not applied to urban housing development and planning.

An integrated approach can contribute to achieving the successful sustainable system of the passive house concept, which needs to be user-centred rather than just selling the technology. The purpose of this study has been to contribute to the development of knowledge regarding the best practices by which, a balanced sustainable system of the passive house can be achieved. Findings show that with the changes in both the housing company governance structure and community involvement, reductions in energy usage of the residents would be expected.

Appendix A

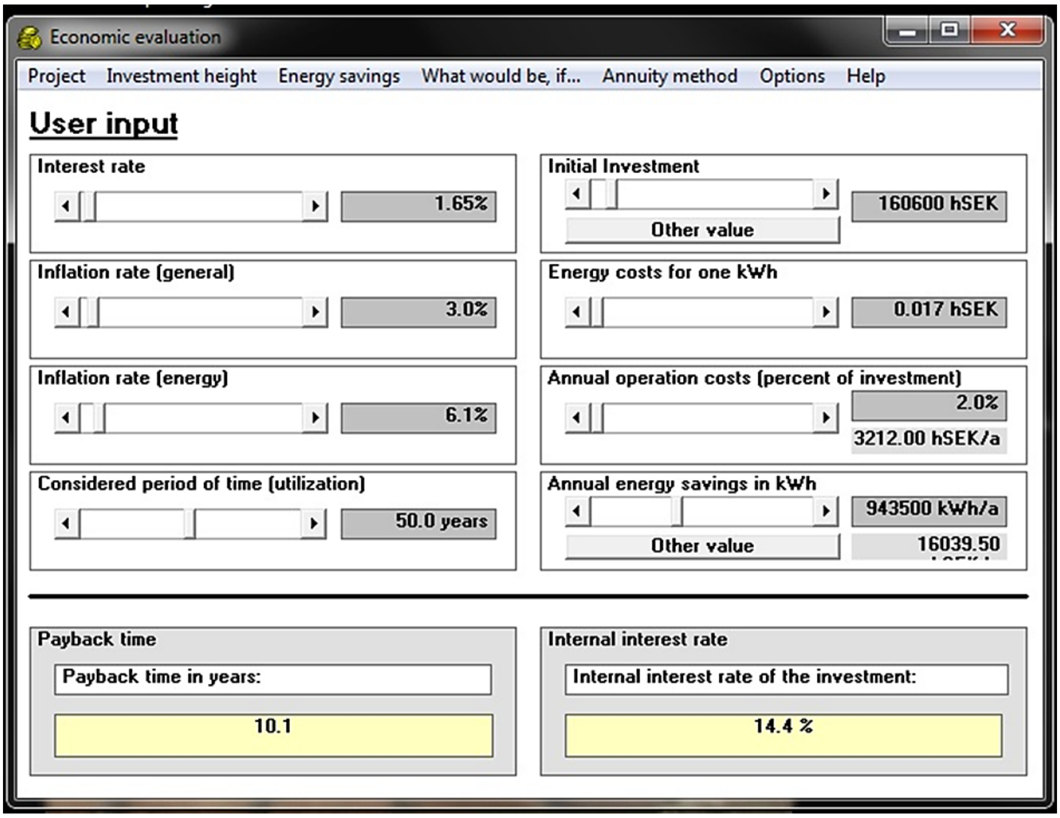

figure A1. The economic evaluation of Blå Jungfrun passive houses in software Oeko-Rat.

The input & output data and factors for the Blå Jungfrun passive apartments are summarized as below (see figure A 2):

Economic Evaluation

Input data

Interest rate:	1.65%
Inflation:	3.0%
Energy infaltion	6.1%
Period of using:	50.0 years
Costs of investment:	160600 hSEK
Costs of energy pro kWh:	0.017 hSEK
Savings of energy:	943500 kWh/a - 16039.50 hSEK/a
Operating costs per year:	2.0% - 3212.00 hSEK/a

Output data

Period of amortization:	10.1
Internal interest rate:	14.4 %

Figure A 2. the input & output data for economic evaluation of the Blå Jungfrun passive apartments [Oeko-Rat[1]]

1 Oeko-Rat. Economic Evaluation Software. Available at: http://nesa1.uni-siegen.de/index.htm?/projekte/OekoRat/Oeko-Rat.htm

The calculations procedure for economic evaluation of Blå Jungfrun passive houses:

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In order to calculate the initial investment costs:
Construction cost of Blå Jungfrun passive houses including VAT = 27 000 SEK/m^2
This amount is 7 % more than construction costs of conventional buildings.
27 000 – 7 % = 25 110 SEK/m^2
Construction cost of conventional houses including VAT = 25 110 SEK/m^2
Living area of Blå Jungfrun passive houses = 8 500 m^2
27 000 SEK/m^2 - 25 110 SEK/m^2= 1890 SEK/m^2
1890 SEK/m^2 × 8500 m^2 = 16065000 SEK = 160650 hSEK = Initial investment costs

In order to calculate the annual energy saving:
The average energy requirements in conventional buildings of Svenska Bostäder (excluding household electricity) = 171 kWh/m^2.year
The measured energy requirements of Blå Jungfrun passive houses (excluding household electricity) = 60 kWh/m^2.year
171 KWh/m^2.year - 60 kWh/m^2.year = 111 KWh/m^2.year
111 KWh/m^2.year × 8500 m^2 = 943500 kWh/year = Annual energy saving

Energy costs:
0.204 Euro per kWh (in the year 2011) = 1.6833 SEK = 0.016833 hSEK ≈ 0.017 hSEK

Appendix B

figure B 1. General inflation rate in 2011 in Sweden

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Figure B 2. Energy inflation rate in 2011 in Sweden

Appendix C

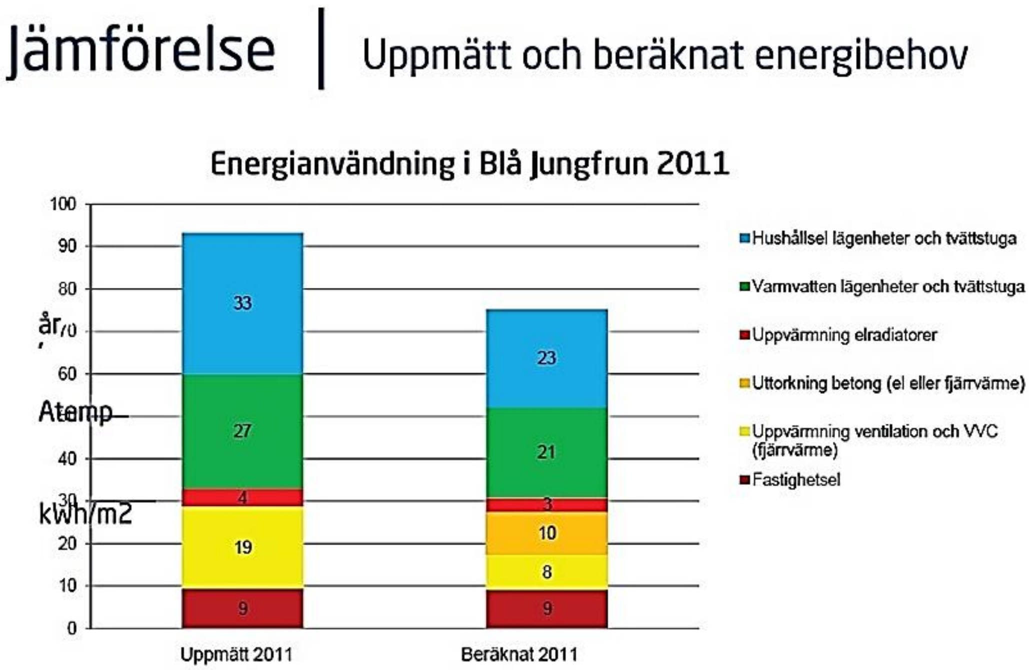

figure C 1. The comparison of the annual calculated energy requirement (right column) & annual measured energy requirement (left column) of Blå Jungfrun passive apartments in 2011 (data gather from Svenska Bostäder in 2012)

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