Industrial Energy Efficient
Retrofitting of Resident
Buildings in Cold Climates

D2.5
Demonstrator Halmstad

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Executive Summary

Giganten 1 & 7 is a multifamily, multi-storey building built in 1963 and located in Halmstad, a city on the west coast of Sweden. It is eight stories high with businesses located on the first floor and residential housing on the remaining floors. The building has a heated area (heated to more than 10°C) of 6178 m^2. The building also has a parking garage located underground.

It is an early example of a “million program” building, which was a Swedish program created by the Swedish government which ran between 1965 and 1974 with the goal of producing 1 million dwellings in order to combat a severe shortage in available housing. The million program buildings are now at least 40 years old and they are in need of retrofitting and renovations. In Halmstad’s case all the water and sewer pipes needed to be changed, the kitchens and bathrooms were renovated, the windows were changed, heat pumps were added, a new heat exchanger for the district heating was installed, an advanced prognosis based control system was installed and the system was optimised for the building.

One of the challenges for renovating the million program buildings is to keep costs at levels which are affordable to the building owner while at the same time reducing the purchased energy, extending the lifetime of the building and insuring that the indoor environment is not compromised.

Partnering was used as the form of building process in this project. This form of process had several advantages over traditional building process forms. It allowed the building owner and entrepreneur to have transparency in all areas of the project, such as economy and responsibility. This meant that the project was formed by both partners together to optimise the technical solutions with the economy.

The renovation of Giganten 1 & 7 was developed within the boundaries set by both the city and building owners. Some of the limitations in this project were financial, such as the project had to fulfil certain economic parameters and others from the city who expressed that the architectural look of the building be preserved. The combination of the limitations set by the owner and city meant that there were not many options available to reduce the net energy demand. For example by insulating the façade would have been too expensive and the city expressed negative opinions about changing the look of the building. More technical solutions were needed such as prognoses control of a combination of extraction air heat pumps, outdoor air heat pumps and district heating. The result was a project which reduced the purchased energy use by 70 % with a return on investment of 18 years.

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1 Introduction

1.1 E2ReBuild Demonstrations

E2Rebuild is a European collaboration project with the vision of transforming "the retrofitting construction sector from the current craft and resource based construction towards an innovative, high-tech, energy efficient industrialised sector." (Seventh Framework Programme, Theme: EeB-ENERGY.2010.8.1-2, Demonstration of Energy Efficiency through Retrofitting of Buildings).

The demonstration projects in E2ReBuild are the core of the project. E2ReBuild is driven by the demonstration projects, whereas research activities feed into the demonstrations, and results of the demos feed into the evaluation and lessons learned in other work packages. The results and conclusions from the demonstrations will be gathered to produce an industrial platform for energy efficient retrofitting (work package 6).

The objective of the work package 2 projects is to demonstrate seven high energy efficient innovative retrofitting technologies and measures for low energy performing buildings with typologies representative for a large geographical area in Europe.

Each project establishes and demonstrates sustainable renovation solutions that will reduce the energy use to fulfil at least the national limit values for new buildings according to the applicable legislation based on the Energy Performance of Buildings Directives (for 2010) and to reduce the space heat use by about 75%.

Monitoring and follow-up: Based on recommendations given by work package 5, monitoring takes place during at least one year within this project, in some cases for a longer period (also continuing after the completion of this project).

One of the main issues in initial refurbishment discussions concerns costs. This has been treated in depth in deliverable D3.4 *Holistic Strategies for Retrofit* where costs from all demonstration projects are reported, analysed and discussed[1].

The demonstrators are supported by work carried out in work packages 1, 3, 4 and 5.

This deliverable is defined as a "demonstrator". This document is the written record of the achievement.

1.2 Demonstrator Giganten 1 & 7, Halmstad, Sweden

NCC's contribution to the E2Rebuild project is Giganten 1 & 7. Giganten 1 & 7 is a multifamily, multi-storey building located in Halmstad, a city on the west coast of Sweden. It is eight stories high with businesses located on the first floor and residential housing on the remaining floors. The building has a heated area (heated to more than 10°C) of 6178 m^2. The building also has a parking garage located underground.

This building was completed in 1963 and is an early example of a type of Swedish building commonly referred to as a "million program" building. The Swedish "million program" was a program created by the Swedish government which ran between 1965 and 1974 with the goal of producing 1 million dwellings in order to combat a severe shortage in available housing.

The million program buildings in Sweden are generally viewed as a cheap form of housing. They were not usually built in desirable areas to keep costs down, (for example outside of cities) however during

[1] As report D3.4 is restricted, public information can be found in GEIER, SONJA; EHRBAR, DORIS; SCHWEHR, PETER (2014); Holistic Strategies for the Retrofit to Achieve Energy-efficient Residential Buildings. In: Proceedings 9th International Masonry Conference 2014. Guimarães (P)

the last 50 years, the cities have expanded and many buildings from this era are now located in desirable locations. This means that the building owners have an incentive to upgrade their building stock.

Figure 1 shows a section drawing from Giganten 1 & 7. Floor 0 ("Plan 0" in Swedish) is where the parking garage is located. Floor 1 is for businesses and commercial space. Floors 2 to 8 are apartments.

Figure 2 shows a floor plan of Giganten 1 & 7. The floor plan shows the entrance (entré), baby carriage storage (barnv- frd), elevators (hiss), bed rooms (sovrum), kitchen (kök), living rooms (vardagsrum), closets (KLK) and washrooms (Bad).

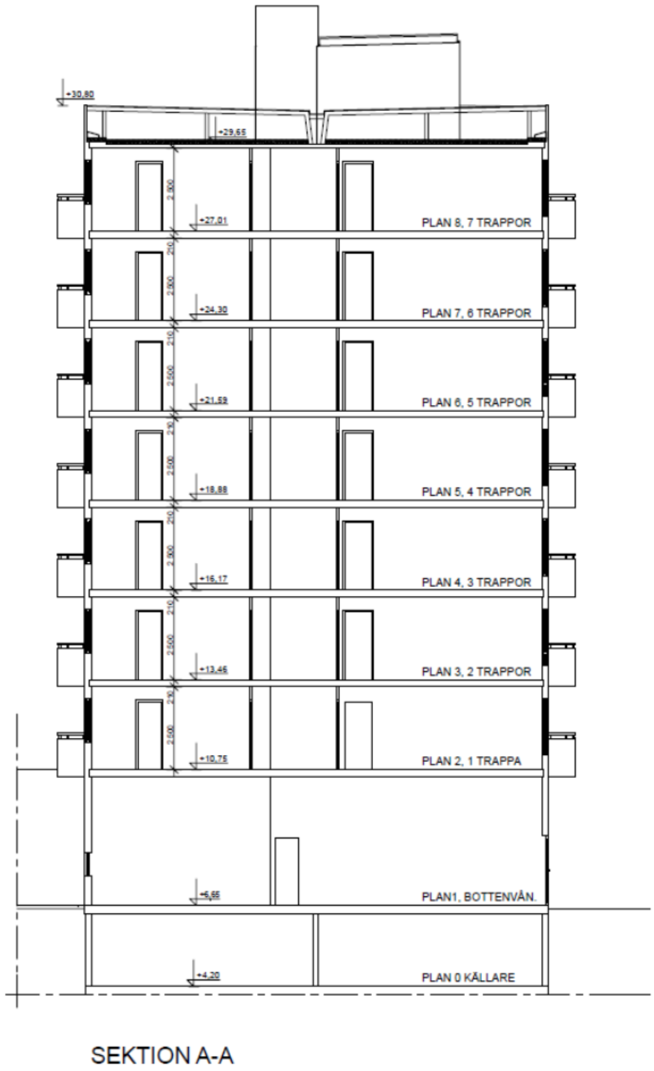

Figure 1: Section of Giganten 1 & 7.

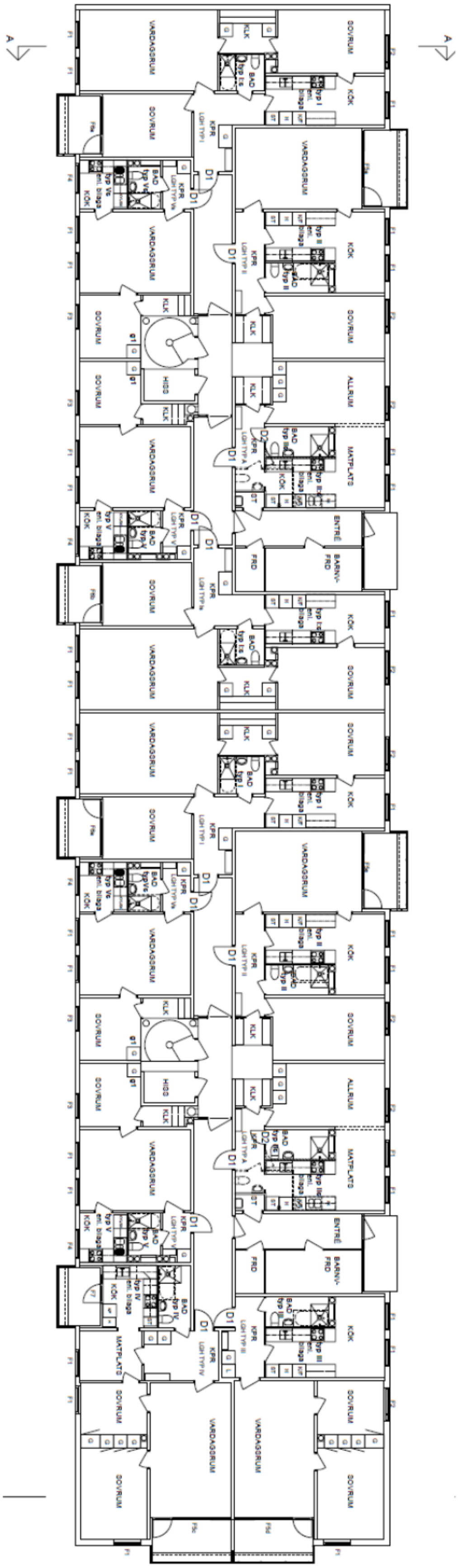

Figure 2: Floor plan of Giganten 1 & 7.

Figure 3: Giganten 1 & 7 in Halmstad, Sweden

Giganten 1&7 has a concrete load bearing frame within the building with concrete sandwich element façade. It had the original installations, including piping, ventilation (extraction system with heat pump) and electrical systems. The heating system was upgraded to use district heating, however the delivery system has not been changed (floor heating delivered to each apartment). The lifetime of the original installations were at an end and had to be changed. The façade was still structurally sound and it has a U-value of 0,4 W/m^{2}K, or 100 mm of insulation. A pre-study showed that the renovation of the façade was not within the budget of the building owner nor were the energy savings enough to justify the cost of work. Since it was not necessary to do work on the façade this option was ruled out early. However the windows were rotting. This affected the air tightness of the building, the thermal comfort experienced by the tenants as well as the energy use of the building via thermal losses, so they were changed. The building owner wanted to upgrade this building in an economically efficient way so the project was designed around this desire.

In Sweden the level of rent is strictly controlled by the government. This means that building owners cannot get a higher rent just based on location. One way to be able to increase rent is by improving the quality of living for the tenants (if the tenants association agrees to the changes). One strategy is to combine structural and energy efficiency retrofits with kitchen and bathroom retrofits. This improvement in the living area allows the building owner to increase the rent for their apartments, thereby recovering some of the investment costs for other renovations which cannot affect rent levels.

Halmstad has a warm rent. This means that there is an economic incentive for the building owner to save energy since these savings are not passed on to the tenant. As mentioned before, the level of rent is set by a combination of the size, living standard and location of the apartment. The more energy that building owner can save, the less their energy costs are. This strategy was used in the Halmstad project to calculate the return on investment. The saved energy reduces the operation costs, reducing the return on investment.

If the rent was a cold rent, the economic investment would be more difficult to justify to the building owner since they could not factor this economic savings into their calculation. Since they would not be paying for the heating, the decreased operational costs could not affect the return on investment.

Due to the age of the building, the rent levels were not considered very high. This resulted in people with a low-level income renting apartments in the building. This social group also has a high turn-over rate associated with it. This also leads to an increased cost to the building owner due to empty apartments, painting costs, and costs associated with finding new tenants.

1.3 Existing Situation and Retrofitting Targets

Giganten 1&7 needed some specific work done. This included new windows, new water and sewer pipes and maintenance on the district heating heat exchanger and extraction air heat pump. The retrofitting target was primarily a return on investment of between 10 to 15 years. This return on investment lead to the renovation of non-vital factors that could affect the financial situation, since new windows, and pipes only could not justify a rent increase or lead to a significant energy savings. These non-vital factors which could affect rent were the renovations of the kitchens and bathrooms.

E2Rebuild changed the original retrofitting targets to include a more aggressive savings in purchased energy in order to meet the E2Rebuild energy requirement of reducing the space heating use by 75 %. The specific renovations needed to meet this energy requirement are listed below and described more in depth in the following chapters of this report. The return on investment target the building owner was increased and the result of the Halmstad project was 18 years at 5 % interest, which was acceptable.

The non-vital measures which positively affected the payback time of the retrofit included improving the kitchens and bathrooms of the apartments. The energy-saving measures comprised of:

- New outdoor heat pumps
- New extraction air heat pumps
- Prognosis controlled heating system
- New heat exchanger for the district heating system
- reduced indoor temperature
- occupant controlled lighting in the garage
- new windows with a U-value of 0,9 W/m2K
- increased airtightness from 1,2 l/sm2 @ 50 Pa to 0,6 l/sm2 @ 50 Pa
- low-flow faucets
- low-energy lighting in stairwells
- extra insulation on roof.

2 Energy Efficient Retrofitting

2.1 Building Envelope, Discussion / Realization

A discussion was taken early in the project about if the facades needed any work. A pre-study of the building (done by the building owner to determine what work needed to be done) showed that the façade was still structurally sound and the façade had a U-value of 0,4 W/m^{2}K, or 100 mm of insulation. Economic calculations were done to determine if additional insulation on the facade was an economically viable part of a renovation strategy and the result was that it was not economically justifiable to modify the façade since the saved bought energy and lack of financial incentive (could not influence rent levels) resulted in a long return on investment. Since it was not necessary to do work on the façade, this option was ruled out before the tender was made.

The pre-study also showed that the windows were in very poor shape. It also showed that the installations were not functioning properly and needed to be repaired or replaced.

Since the current windows were in a poor state, they were replaced. The new windows were energy efficient windows (overall U-value = 0,9 W/m^{2}K) from Elitfönster. It was decided that the look of the building be preserved so windows similar in colour to the old windows were used, see Figure 4, Figure 5, and Figure 6.

The new windows have a low U-value and were properly sealed to reduce the air leakage through the building envelope. These two improvements reduced the heat loss from the apartments in two ways; by reducing the amount of thermal losses through the windows, and by reducing the amount of cold air leaking through the building envelope at an uncontrolled rate. This also helped to reduce the feeling of a cold draft when people are near the windows due to the higher surface temperature of the window and new air diffusers in the air intake. These modifications resulted in an increased thermal comfort level in the apartments and allowed for the reduction of the indoor air temperature from 24°C to 21°C without compromising the thermal comfort of the tenants. These three factors (better U-value, better air tightness and lower indoor temperature) decreased the heating demand by about 35 %.

Figure 4: New windows on the left and old windows on the right. The colour was chosen in order to preserve the look of the building (Stephen Burke).

Figure 5: New windows waiting to be installed (Stephen Burke).

Figure 6: Balcony window and door before installation (Stephen Burke).

2.2 Technical Equipment, Discussion / Realization

2.2.1 Infrastructure

As mentioned previously, a significant part of the renovations were not related to the energy use of the building. These renovations were deemed necessary to extend the lifetime of the building. They comprised mainly of the replacement of water and sewer piping as well as some electrical work. The old electrical system in each apartment consisted of old fuses installed in the 1960's. These were replaced with more modern circuit breakers (Figure 7).

As mentioned in the previous section these renovations do not affect rent levels and it is expected that the building owner finance these costs themselves.

It was decided that while these renovations were being done (water and sewer pipes), the kitchen and bathrooms could also be renovated at the same time (Figure 8 and Figure 9). The tenants agreed to this, which meant that the rents could be adjusted according to the legal framework. (In Sweden tenants who can be affected by a renovation must agree 100 % that a renovation project goes ahead otherwise the issue goes to court. In Halmstad 95 % agreed. The case was taken to court and the courts determined there was no valid reason not to renovate.) The renovations of the bathrooms and kitchen did not have much effect on the energy use of the building (reduced domestic hot water use due to low-flow faucets), however they did have a significant impact on the economy of the project resulting in a shorter payback time.

Figure 7: On the left is the old fuse box. The right picture shows the new circuit breakers (Stephen Burke).

Figure 8: Washroom during (left) and after (right) renovations (Stephen Burke).

Figure 9: Two kitchens, one during renovations (left) and one after renovations (right) (Stephen Burke).

2.2.2 Ventilation System

Not many changes were made to the ventilation system. The building had extraction air heat pumps but they were more than 30 years old and were not fully functional. It was decided that the extraction air heat pumps be replaced with a modern high performance extraction air heat pump system with a documented Coefficient of Performance (COP) rating of about 5 compared to the old system which had a measured COP rating of about 1,5). 'Standard' extraction air heat pumps enjoy a COP of about 3,5.

New air diffusers were installed to reduce the amount of noise from the ventilation system. New kitchen fans (recirculated air with carbon filters) were installed in the kitchens. The kitchen fan air is not connected to the ventilation system as it was in the past. The air inlets for the supply air are built into the window frames. This type of air intake is known for creating thermal comfort problems in buildings because cold air comes into the building through the hole in the window frame. Air diffusers help the problem by spreading out the incoming air so that it disperses better. Otherwise there is a large risk that the cold air creates a spot which is cold due to the temperature and velocity of the outdoor air coming into the apartment. The superior ventilation system is a supply and extraction system with heat recovery. The supply air is heated to about 18ºC so the whole issue of thermal comfort is not a problem. Unfortunately this ventilation type is not possible in most million program houses because there is not enough room to run supply air ductwork through the existing ventilation shaft. This is one of the largest challenges with the million program houses in regards to available ventilation solutions. The TES Energy façade used in some of the other E2Rebuild demonstration projects can solve this issue by integrating the ductwork in the façade element; however no façade work was done to the Halmstad demo so this option was not available.

2.2.3 Heat Pumps

The primary heating system in this building was in-floor heating with heat pumps connected to the extraction air ventilation and a heat exchanger connected to the district heating system. In addition to the upgraded extraction air heat pumps, the heat exchanger on the district heating system was much less efficient then a modern heat exchanger and it was decided to upgrade this as well.

It was decided that two additional heat pumps would be installed in order to reduce the amount of bought energy. The client wanted to use bore-hole heat pumps in the early stages of the project which are very energy efficient. However, after a preliminary study showed the extreme depths and number of wells required were not economical, it was decided that two more heat pumps would be connected to four outdoor air compressors. At the time of the renovation, the outdoor air to water heat pump from Mitsubishi called ZubaDan, was the latest technology and was the most efficient outdoor air-water heat pump on the market for cold climates. Mitsubishi stated that these outdoor heat pumps gave a yearly average COP of 3 (min COP of 2,4 and max COP of 4,7) between -14ºC and +15 ºC.

This entire heating system (outdoor air heat pumps, COP 3, and extraction air heat pumps, COP 5) would work with a prognosis controller in cooperation with the district heating system. The combined Coefficient of Performance (COP) for the entire heat pump system over a year was calculated to be 4,1. The actual measured performance of the outdoor air heat pump was measured to be COP 3,7 during the measurement period. The extraction air heat pumps could not be measured due to one missing logger in the system (the total heat produced by the extraction air heat pumps).

2.2.4 Garage

Figure 10: Underground parking garage which was lit up 24 hours a day. Occupancy sensors were installed to reduce the energy use from lighting (Stephen Burke).

The garage lighting was manually controlled. In practice the lighting was on in the garage almost all day and all night. In order to reduce the energy use in the garage, new LED lights with built-in occupancy sensors were installed. These lights have a low-lighting mode so that the lights are constantly on and the lighting strength increases when a person or vehicle moves near each individual light.

3 Retrofitting Process

3.1 Organisation

This renovation project was done using Strategic Partnering between NCC Construction Sverige AB and Akelius Bostad Väst AB. Giganten 1 & 7 is one of several buildings to be renovated using this form of contracting. Giganten 1 & 7 was ABV's first Partnering project and they used the opportunity to see if this contracting form was a suitable method of doing renovations in comparison to the traditional bid-build contracting form before committing to further renovation projects. NCC, on the other hand, has a lot of experience with Strategic Partnering in new building projects and has been recognised by the International Partnering Institute as one of the world leaders in the area of Strategic Partnering[2][3].

	From	To
Brief	November 2009	October 2010
Design	November 2009	November 2010
Construction	November 2010	December 2011
Operation optimisation	January 2012	January 2013
Monitoring	July 2012	July 2013

Table 1 Time frame for demonstrator

The key players that were involved in the retrofitting project can be found in the table below.

Role	Name	Brief	Design	Construction	Monitoring
Building owner	Akelius Bostad Väst	X	X	X	X
Architect	Fredblad Arkitekter AB		X		
Energy specialist	NCC Engineering		X	X	X
Structural engineer	NCC Engineering		X		
HVAC engineer	Bravida AB		X	X	
Contractor	NCC Construction Sverige AB	X	X	X	X
Data Logging System	Kabona		X	X	X
Flooring	Golvbolaget			X	
Paint	Sanda			X	
Electricity	NEA		X	X	
District Heating	Halmstad Energi och Miljö			X	X
Tiles	Halmstad Kakelhus			X	

Table 2 Key players involved in the retrofitting demonstrator

2 http://www.partneringinstitute.org/newsletters/IPI_Newsletter_2012_06_07.html
3 http://www.byggnyheter.se/2014/05/ncc-och-telge-prisade

3.2 Partnering and Halmstad's Retrofitting Process

Partnering has a few definitions depending on which author you look at. NCC uses a modification of Nyström's definition[4] which is based on a core of trust and mutual understanding between the involved parties and puts the good of the project before the good of the individual partners[5].

Some of the additional parameters within NCC's definition, Figure 11, include common economy, common objectives (goals), common organisation, common activities, constant improvements, the right team, common economic interests and problem solving. This combination of factors allows, and even encourages, the partners to be more open in regards to technical solutions and economics. If one of the partners has a technical problem which can cost the project money, it is easy for one of the other partners to provide assistance in the form of resources or solutions since the problem will most likely affect everyone involved in the project sooner or later. Everyone loses by not cooperating.

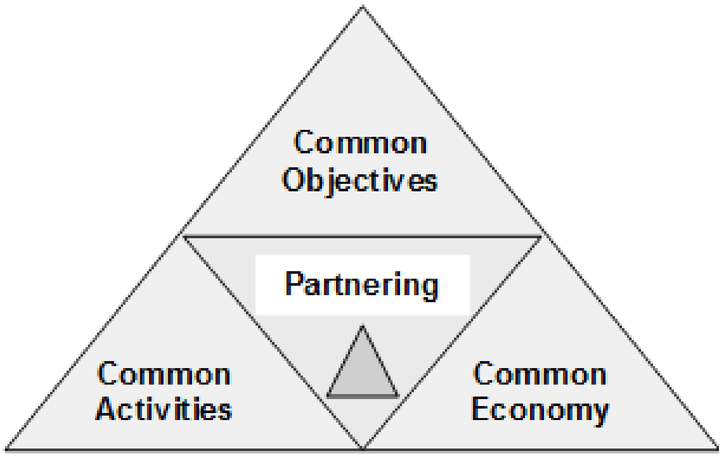

Figure 11: NCC's definition of Partnering.

In practical terms, partnering is a method of doing business in larger and more complex projects where cost is not the focus of the project. The main goal with partnering is getting best value for your money and not necessarily the cheapest bid. This means that all parties involved in a project must sit down together at the beginning of the project and define what it is they want to accomplish with the available resources (financial, technical, competence, etc.).

The Halmstad demonstration differs from the other renovations within E2Rebuild in that it uses *Partnering* as its contract form (see Deliverable D3.1 – Collaboration Models for more information) and more advanced technical solutions than a standard renovation project. This increased the cost of the renovation project compared to the original renovation for Giganten 1&7. E2Rebuild's extra resources has allowed for this project to go ahead using the more advanced technology and evaluation methods. In a more standard project, different systems would have been installed and they would not be programmed to work together to the extent seen in the Halmstad project. The building would also not be as heavily monitored or analysed as it was for E2Rebuild. The chosen heat pumps were a significant cost (both materials and man-hours to adjust/program) since they were considered the best available technology at the time. In a standard project, the client would not be willing to pay for this technology. They would choose a cheaper, less efficient solution which has been proven on other buildings.

[4] Nyström, J, 2005, *Partnering; definition, theory and the procurement phase*, Licentiate Thesis, Report 5:64, Building and Real Estate Economics, Royal Institute of Technology, Stockholm
[5] NCC AB, 2011, *Teamplayer - a handbook in Partnering*, NCC AB, Solna

This can be verified with Giganten 6, which a renovation project that began after Giganten 1 & 7 (E2Rebuild). With Giganten 6, the building process was kept the same, with some slight improvements based on the experience from Giganten 1&7; however more standard equipment were chosen which were cheaper and less energy efficient. For example, the extraction air heat pumps chosen for Giganten 6 have a COP of 3,6 (v.s. Giganten 1&7's COP of 5) and the outdoor air heat pumps were not even installed.

3.2.1 Stage 1 - Planning

The first stage in this partnering project was to decide what to do. In this project NCC worked together with ABV to define the project and determine which technical solutions were considered economical according to ABV's definition of economical. ABV defined this as a ROI of 18 years or better (at 5,25 %). ABV also had a number of requirements that had to be taken into account. One request was that the tenants could remain in their apartments during the renovations. A second request was that the local businesses would not be affected by the renovations. A third request was that NCC handle communication with the tenants on the jobsite. The planning took into account these requests.

After a mapping of the current state of the building, a number of different technical solutions and their associated costs, limited by factors described in chapter 1.3 *Existing Situation and Retrofitting Targets*, were produced by the project team. The energy use was calculated using a 3D-model in the energy calculation program IDA-ICE, Figure 12. The results of these calculations are shown in chapter 4.3 *Energy Savings*. As mentioned before, an initial investigation showed that the façade of the building was in good shape and did not need to be repaired and that the windows were not in good shape. In some cases daylight could be seen through some of the openings in the windows and it was deemed that they needed to be replaced.

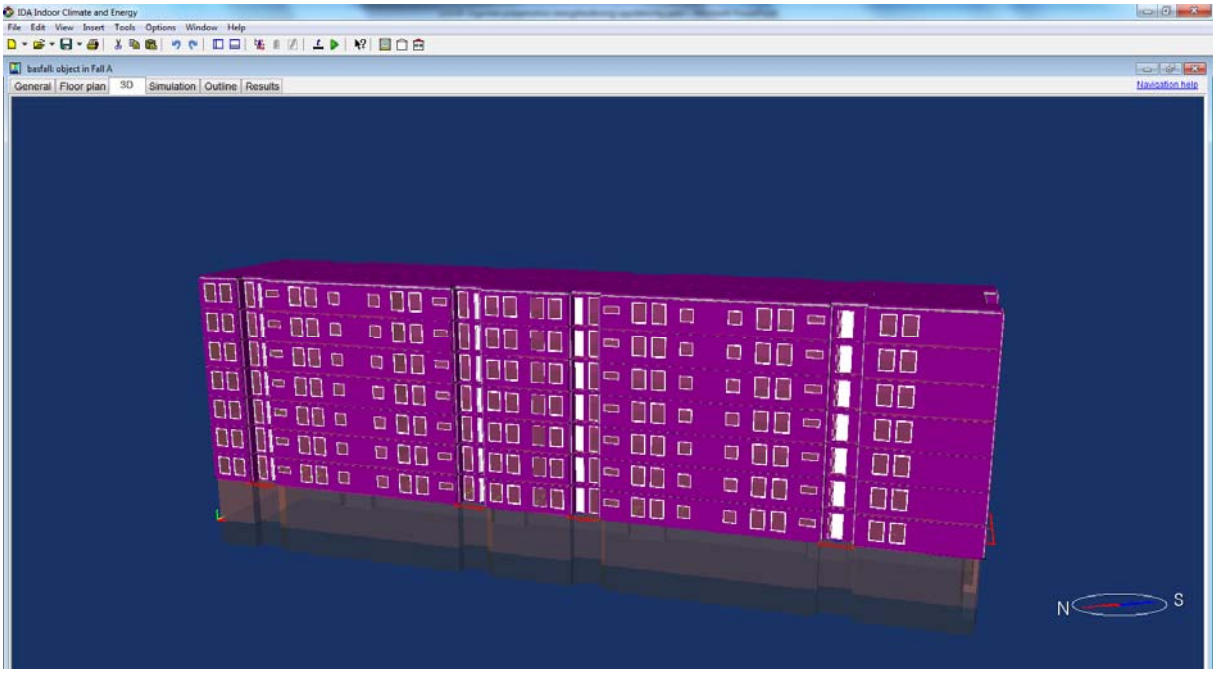

Figure 12: 3D-model of Giganten 1&7 in the indoor climate and energy program IDA.

The ventilation system in the building was old and had inefficient fans. One idea was to upgrade these fans to modern efficient fans as well as add a heat pump on the extraction air flow and put this energy into the floor heating system. In the actual project, the ventilation fans were not replaced.

The airtightness was measured and the building was found to be very leaky. Thermography results showed that most of the air leakage was unsurprisingly around the windows and balcony doors (see Figure 13and Figure 14.)

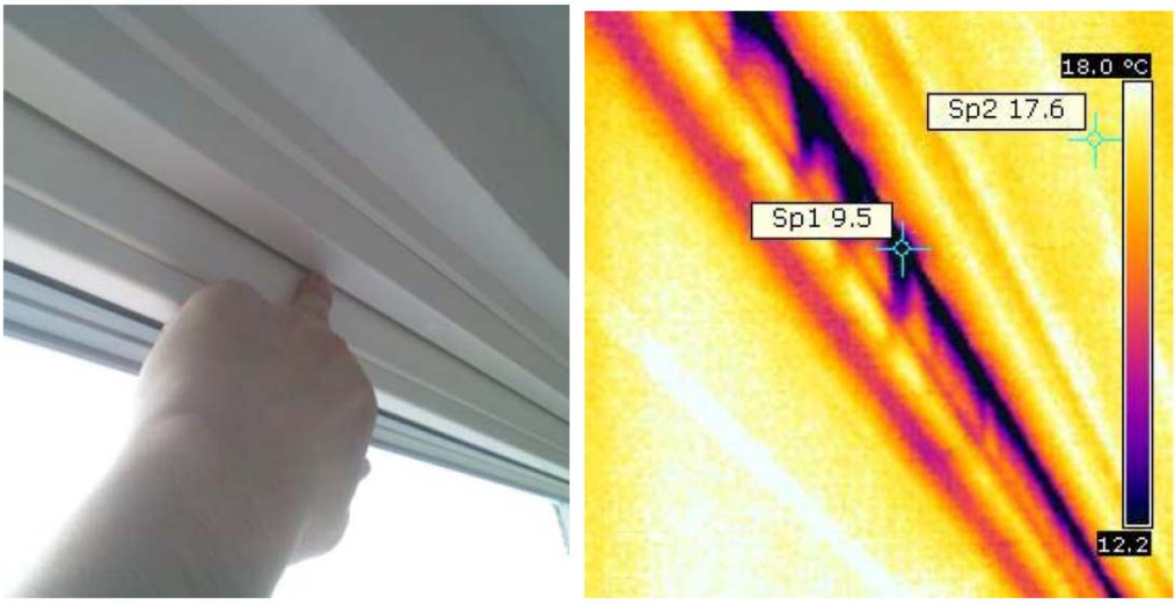

Figure 13: Air leakage through the rubber seal.

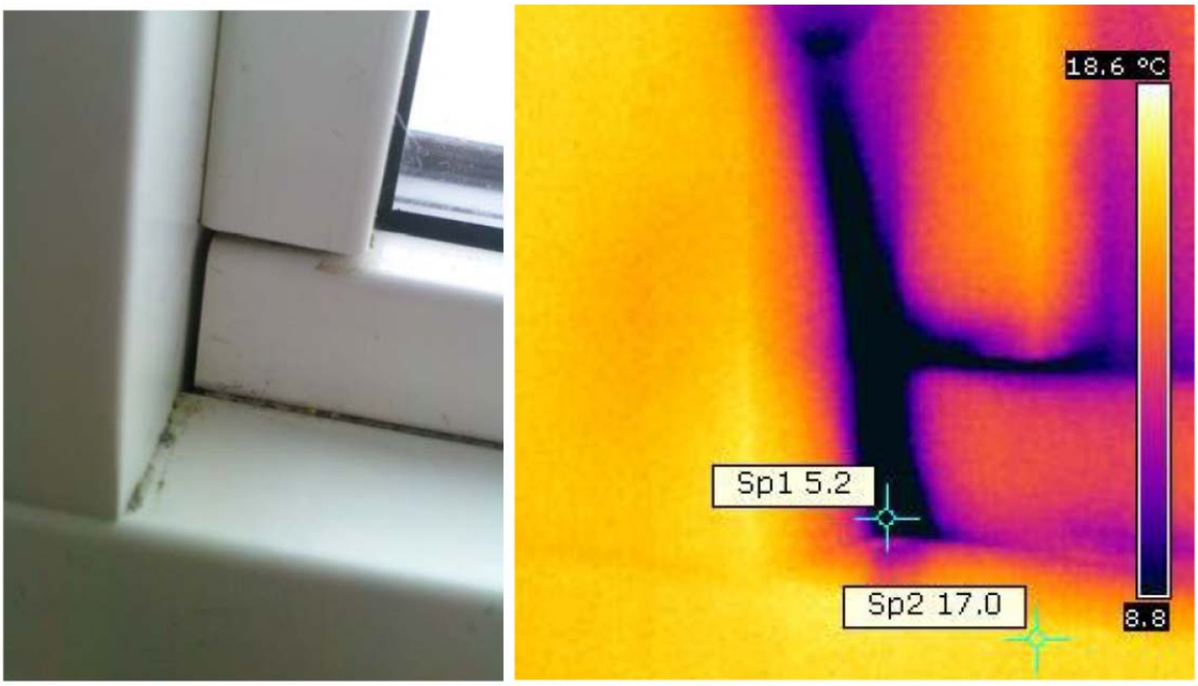

Figure 14: Air leakage through the window frame.

Because of these leaks, the tenants had the heating system on full, resulting in an indoor temperature in the building of around 24-25 °C. Tenants who found this to be too warm opened the windows to cool their apartment. About 6-7 % energy per degree Celsius could be saved by reducing the indoor temperature needed to maintain a good thermal comfort in the apartments.

The existing floor heating system with a liquid carrier was heated by a heat pump on the district heating system. The installed heat pump was found to be non-functional. It was thought that the installation of a bore-hole based heat pump system would be most efficient however the return on investment study showed that the bore-hole based heat pump was too expensive due to the depth of the wells. It was not deemed to be a cost effective solution and was instead replaced with a new outdoor air heat pump system.

The final aspect of the technical solution was to control and optimise the new systems using smart control systems. By monitoring all the systems in real time, an advanced control system using a Prognoses Control System for climate prediction, could optimise the heating systems of the building at any given time. For example, the system could determine if it was more energy efficient to heat hot water using either the outdoor air heat pumps, or heat from the district heating system and implement this. It could also determine that the next day will be cold and begin heating the building before the temperature change, reducing the peak power needed. It can also determine that the heating system needs to use a combination of the available systems because one system is not enough to meet the demand.

The results of the cost and energy analysis resulted in three possible options, the cheapest being Package A and the most expensive being Package C. All the Packages included essential renovations such as water and sewer pipes, renovation of kitchens and bathrooms. The differences were only related to energy savings potential of the building system.

3.2.1.1 Energy Savings Package A

Energy savings package A comprised of new windows (total U-value 1,1), increased air tightness of the building, and a reduction of the indoor air temperature by about 2 ºC. In this case, the original installations would be repaired but not upgraded.

3.2.1.2 Energy Savings Package B

Energy savings package B included new windows (total U-value of 1,1), increased air tightness, reduction of the indoor temperature by about 2 ºC, low-flow faucets, prognosis control, occupancy controlled lighting in the stairwells, and new extraction air heat pumps.

3.2.1.3 Energy Savings Package C

Energy savings package C included new windows (total U-value of 0,9), increased air tightness, reduction of the indoor temperature by about 2 ºC, low-flow faucets, prognosis control, occupancy controlled lighting in the stairwells, occupancy controlled lighting in the garage, new extraction air heat pumps, and new outdoor air ZubaDan heat pumps from Mitsubishi.

At the end of stage 1, ABV had three different scenarios to choose from. They choose the second scenario at first, however when the project became a part of E2Rebuild, they switched to the scenario with the most energy savings.

3.2.2 Stage 2 – Stop or Go?

A small but very important stage in the project was the stop or go stage. At this point, the initial investigation, financed by ABV, was finished. ABV could now stop the project or even switch contractors if they wanted too. ABV was satisfied with the results and level of cooperation in stage 1 and decided to go ahead with stage 3 with NCC as their Partner.

3.2.3 Stage 3 – Renovations

Stage 3 began after a go was given and the Partnering contract was approved between NCC and ABV. A more detailed planning of work began according to the energy savings scenario which was chosen by ABV. Some of the work was subcontracted out, as per Table 2 (see D3,1 Collaboration Models for more information) however much of the work was done within NCC.

It was decided that the building would be renovated one stairwell at a time to keep the disturbance to the tenants to a minimum. This meant that each stairwell would be subject to about 4 weeks of renovation work. The tenants could choose to stay in the apartments for free during this time, or re-locate to another of ABV's buildings. Since the kitchens and bathrooms were to be renovated, water was provided to each floor by running water hoses and grey water pipes through the old garbage shoots. Temporary sinks were installed at each garbage shoot so the tenants had easy access to water. To replace the kitchens and washrooms, temporary cooking and bathroom facilities were built on the ground floor.

Another issue was that fact that elevators were refurbished limiting access to the apartments to the stairs. Elderly and disabled people had access to people who could help them and alternatively, a temporary apartment was available that they could move into during the elevator shutdown if they thought it was too difficult to take the stairs. A few people made use of these offers.

One of the NCC employees was assigned the task of "Renovation Host", the official person that the tenants could go to with questions, concerns and problems. This person worked on the project and also helped facilitate communication between the tenants, housing company (ABV) and entrepreneur (NCC).

3.2.4 Stage 4 – Optimisation and Monitoring

Stage 4 started during stage 3 and continued for two years after the completion of the project. Stage 4 was about the optimisation of the building as a system and verifying the energy savings. A part of the Partnering agreement was that NCC guaranteed the energy savings 2 years after completion (with a risk margin of 15%). Some problems were discovered, see chapter 4 – Results and Conclusions, and corrected during this stage. The E2Rebuild measurement data was collected beginning seven months after the optimisation stage began and continued for one year.

Giganten had around 470 logged measurement points per hour. Most were not related to E2Rebuild. Some of the most important measurement points for the E2Rebuild project included the hot water flow, the district heating energy, the heating to the apartments, the heating to the stairwells, electricity to the various heat pumps, produced heat from the heat pumps, room temperatures (2 apartments per floor), and commercial energy use (which was outside of E2Rebuild). Outdoor climate data was bought from the Swedish Meteorological Institute during the measured period.

Task 5.1 in Work Package 5 was charged with defining the measurement parameters to be used within the E2Rebuild projects. NCC has contributed to this task and NCC's measurement strategy is based on the results from this task. For more information on the measurements and results please see 4.3 Energy Savings and the final reports from Work Package 5.

4 Results

4.1 The Upside of High-tech Solutions

The Halmstad retrofit was approached as an economical optimisation of one system. The goal was not to improve a number of individual components independent of each other to reduce the purchased energy use, but to use components that could work together to optimise the operation of the building for the building owner resulting in the maximum purchased energy savings while providing tenants with a better indoor environment for a reasonable cost, return on investment, to the building owner.

This was achieved through the E2Rebuild project by allowing the project to try new heat pump technology together with a customized control system which uses old and new technology to realise a purchased energy savings of about 70% (120 kWh/m^2 year) for heating, hot water and building electricity (excluding household energy use). This purchased energy savings was realised without modifying the external walls or changing the look of the building.

This idea in combination with a project using Partnering as its organisational form, makes it unique. Since it is considered economically sustainable, the technical solutions and method of working have a high replication potential for other Million Program buildings. As mentioned before, since E2Rebuild began, the lessons from the Halmstad project (Giganten 1 & 7) have been applied on Giganten 6, which is next door.

4.2 The Downside of High-tech Solutions

The road to the planned energy savings was not a smooth one. During the course of the project, several problems occurred. As mentioned before, the original idea of bore-hole heat pumps had to be discarded because of the high cost. A more detailed geological analysis showed that the bore-holes would have to be drilled deep for this technology to work with the Halmstad project. The costs of these wells were too much for the building owner and not cost effective over the long-term. The project decided to switch to a combination of heat pumps and district heating instead.

Another problem which arose with the technical solutions was that the old power lines into the building were a fire hazard. This was only discovered when connecting the heat pump system for operation. The project was delayed for over a month because all the electricity cables from the main line to the building had to be changed by the electricity supplier before the heat pumps could be taken on line. This was also in December so the tenants were not able to maintain more than 20 degrees indoors.

After the heating system was connected and powered up the heating functioned. However, as with all buildings with high tech solutions, there is usually a period where the systems do not function optimally and they need to be adjusted. The largest problem with Giganten 1 & 7 was that the control system was not optimally programed in the beginning.

Since this system is a customised and complex system, it is dependent on people to make the different systems work together. It is not easy to create an optimised system from the start so the project needed about a year of operation before it could finally be optimised for the building. The result of this was that some of the heat pumps would shut down too quickly and then have to wait their minimum cool-down time before starting up again. During the down-time, the heating system had to switch to more expensive district heating until the heat pumps came on-line again. Once on-line again, the heat pumps quickly provided a lot of heat then shut down again. The problem ended up being a wrong number in the source code.

Another problem which occurred was that the top floors were not getting enough heat (all other floors have both heated floors and ceilings, but the top floor only has a heated floor). The temperature of the heating system was raised and lowered but whenever the top floor was warm enough, the bottom floors were too hot. The final solution was to change the flow controls for the top floor so that it received more warm water quicker than the bottom floors. According to the indoor temperatures this seems to have solved the problem.

The last problem with technical solutions is that you do not actually reduce the heating demand. The amount of bought energy is reduced but real energy demand is still there. One indication of this is when the building's primary energy is analysed. Changing technical solutions do not necessarily reduce the primary energy use. This was shown to be the case in Deliverable3.4 Holistic Strategies, Figure 21.

The building is very dependent on the technology and if the technology fails the energy costs can be high again. This is in comparison to measures which reduce the heat loss through the building envelope such as insulation. When heat loss through the building envelope is physically reduced, the dependency of technical solutions is reduced, thus lowering the risk that the building will use more purchase energy in the future when the technical solutions become less efficient or break.

4.3 Energy Savings

4.3.1 Purchased Energy

According to the measured energy use, the Halmstad project performed as calculated within the calculated economic frame. The measured energy use matched the calculated energy use very well, see Figure 15 and Figure 16, and the technology is operating as it should. See Work Package 5 for more information regarding the measured energy use.

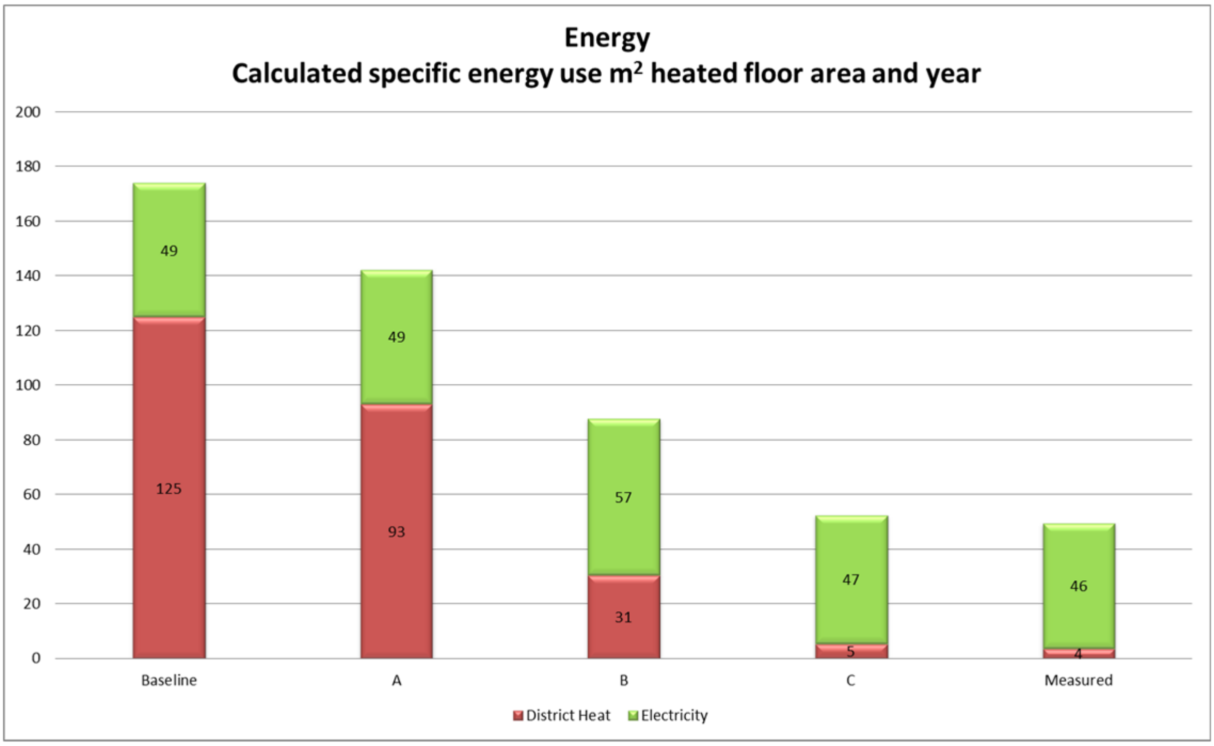

Figure 15: The calculated specific energy use (purchased) for the actual building (baseline) compared to savings packages A, B, C and measured.

Energy type			Baseline (Calibrated Model)		Calculated Energi (IDA-ICE)		Measured	
			[kWh/år]	[kWh/m2 Atemp, yr]	[kWh/år]	[kWh/m2 Atemp, yr]	[kWh/år]	[kWh/m2 Atemp, yr]
	District Heating							
Heating demand								
	Space Heating		619629	100	402286	65	448725	73
	Heating losses (10 %)		25524	4	40229	7		
	Opening Windows		49424	8	24712	4		
	Domestic Hot Water		185340	30	148272	24	125701	20
	DHW losses (distribution)		23915	4	23915	4		
	Savings Prognoses Control				-37068	-6		
	Electricity							
Heat Pumps								
	Outdoor Air Heat pump	Heat energy			-255360	-41	-302511	-49
		Electricity			84943	14	79594	13
	Extraction heat pump	Heat energy	-131489	-21	-313680	-51	-247825	-40
		Electricity	87659	14	52280	8	49565	8
Ventilation								
	Electricity to the fans		38106	6	25404	4		
Other real estate energy			96387	16	96387	16	153368	25
	Heat exchanger electricity				1836	0		
	Stairwell lighting		12264	2	4088	1		
	Elevators		18200	3	18200	3		
	Garage		50458	8	8541	1		
	Other							
	Total		**1075417**	**174**	**324984**	**53**	**306617**	**50**

Figure 16: Energy figures showing the baseline calculation based on measured data, the calculated energy use for the E2Rebuild energy savings package and the measured energy use between July 2012 and July 2013. Note that some of the calculated types are integrated in the measurements (for example, opening windows cannot be measured separately but is a part of the space heating).

4.3.2 Primary Energy

As mentioned in the previous section, The Downside of High-tech Solutions, technical solutions can reduce the purchased energy while not having any impact on the primary energy. This was the case with the Halmstad project and it is interesting to look at how this can occur. Please note that it is not possible to compare primary energy with purchased energy in this section.

Halmstad Before		Calibrated calculation in IDA/ICE				
	Energy Demand Before [kWh/m2 NFA]	Source	PE conv. fact. fp [kWh PE / kWh S] national /local	PE national [kWh/m2 NFA]	PE conv. fact. fp [kWh PE / kWh S] acc. EN 15603	PE based on EN 15603 fp [kWh/m2 NFA]
Heating Source 1	108,0	District Heating	0,17	18	1,3	140
Heating Source 2	-16,7	HP	0,17	-3	1,3	-22
DHW Source 1	30,0	District Heating	0,17	5	1,3	39
DHW Source 2	-4,6	HP	0,17	-1	1,3	-6
Auxiliary	14,2	Electricity	1,5	21	3,31	47
Losses Source 1	7,9	DHC	0,17	1	1,3	10
Losses Source 2				0		0
Total	**138,8**			**42**		**209**

Figure 17: Calculated primary energy before renovation.

Halmstad Afterwards		Calibrated calculation in IDA/ICE				
	Energy Demand Afterwards [kWh/m2 NFA]	Source	PE conv. fact. fp [kWh PE / kWh S] national /local	PE national [kWh/m2 NFA]	PE conv. fact. fp [kWh PE / kWh S] acc. EN 15603	PE based on 15603 fp [kWh/m2 NFA]
Heating Source 1	73,5	District Heating	0,17	12	1,3	96
Heating Source 2	-66,7	HP	0,17	-11	1,3	-87
DHW Source 1	24,0	District Heating	0,17	4	1,3	31
DHW Source 2	-25,4	HP	0,17	-4	1,3	-33
Auxiliary	26,3	Electricity	1,5	39	3,31	87
Losses Source 1	10,4	DHC	0,17	2	1,3	14
Losses Source 2				0		0
Total	**42,1**			**42**		**108**

Figure 18: Calculated primary energy after renovation.

In Figure 17 and Figure 18, the primary energy (PE) is presented both with local conversion factors and European conversion factors. Before the renovations, the heat pump was not functioning well and most heat was purchased from the local district heating supplier, Halmstad Energi. This supplier has a low PE conversion rate because much of their heat is waste heat from industries. Electricity is also low, however even renewable electricity has a PE factor that is 9 times higher than the district heating! In the Halmstad case the main heating energy comes from the heat pumps. The cost of electricity is about twice that of district heating so by purchasing electricity for heat pumps you purchase much less district heating. This brings down the purchased energy. However, the additional purchased electricity affects the total primary energy by such a large factor that the saved PE from the district heating is nullified by the small increase in purchased electricity!

4.4 Partnering

By becoming partners, both companies had a financial stake in the project. If a project goes well, both share the benefits; if a project goes bad, both share the costs. In a traditional bid-build project, the building owner takes all of the risks. Even if a project goes bad the entrepreneur(s) can still make a profit at the expense of the building owner. The entrepreneur(s) are not necessarily interested in the success of the project to the extent that they would be in a Partnering project where they could lose both time and capital.

Using partnering allowed NCC and ABV to develop a renovation strategy which was win-win for both partners. ABV received prices for the minimum amount of work they needed for their building plus various ways of reducing their energy use with suggestions on how to finance these extra renovation costs within their defined ROI. They could also choose to get prices from other companies after this and even switch construction companies if they preferred with no penalty.

NCC was able to show ABV alternative sources of funding which allowed for the project to be larger while still falling within ABV’s ROI requirements. NCC also kept communication open with the tenants, which helped the renovation process by making the tenants positive towards the work. They were shown a demonstration apartment before work began and they were allowed to choose some of the colours. They could live in their apartments during the retrofit and were given one month rent-free. They felt more involved and were kept up-to-date about what the current status was. This resulted in tenants who were positive about the renovations and did not cause any problems.

ABV thought that the partnering process was better than a traditional process and saw many advantages with using partnering. Some of the advantages they stated were:

- Smoother process since everything was planned in advance.
- They were more involved in the planning of work.
- They were better informed.
- They did not need to define every detail of the project in advance.
- They did not have to solve all the problems they normally have in a traditional project, it was OK to ask NCC to solve some of them instead.
- They could make use of NCC's experience and knowledge to improve the project without significantly increasing their costs.
- They did not have to deal with tenants during the retrofit because NCC had a representative on-site to deal with inquires and complaints.
- No problems with tenants at all in this project.
- They felt that they got a more energy efficient building for their money than if they had used external consultants to help define the project and technical solutions.

ABV also liked the open process. The project was much more transparent to them and because they were a partner, they became more involved in the building process. They also said that this involvement also required less effort from them compared to a traditional project because they did not have to create a project description where they dictate all the conditions of the project in advance. The partners agree on the project conditions as a part of the project.

ABV thought that one of the biggest advantages with partnering was that they could ask NCC to solve problems that ABV usually had to solve within a traditional project (for example dealing with tenants). This helped ABV free up time that was spent on other areas of the project.

ABV also felt that NCC had better communication with them and their tenants compared to the entrepreneur in a traditional construction project. The improved communication between client and entrepreneur is due to the fact that ABV is also a partner in the project and it is expected that they contribute just as much as any other partner. The improved communication with the tenants was a result of ABV's desire that the tenants be informed directly from NCC so that they get real information from the people who know what is going on instead of second-hand information.

NCC fulfilled this wish by appointing a tenant representative who had the job of informing, dealing with complaints, organising extra help, and dealing with inquiries from curious tenants who were interested in the project. In this way ABV saved a lot of time answering phone calls about complaints and from tenants wondering what NCC was doing, when they would be working in their apartment, etc.

ABV also benefitted from knowledge transfer from NCC. Since all the problems affected both parties, this information became more open to ABV, including the solutions. ABV stated that if this project would have been a traditional project (where they defined the project in advance) their building would not have achieved the energy savings that they realised because they lacked knowledge about newer technical solutions. They also could make use of NCC's experience with different systems and how they have functioned in the past so that the whole building could be optimised instead of just parts of the building. ABV also said that, based on their experience, they could not have had a better project through external consultants.

Both parties stated that they experienced a smoother process and a good working climate. ABV said that they liked that the process was defined and worked through by the partners before work was even started. Everyone knew what had to be done and how long it should take, including the tenants.

However, partnering is not the perfect solution for all projects. One of the main disadvantages with partnering that could be seen with the Halmstad renovation is that the project can cost more than a traditional project. The principle of developing the project together takes more time during the design stage. Late changes, or items missing from the drawings, can also result in extra costs later in the project.

4.5 Replication Potential

The replication potential of the Partnering process and technology used in this renovation project is very high. The million program houses are at the end of their life and they need to be renovated/refurbished. The largest challenge the building owners are facing is how to finance the renovation costs, and the largest challenge for the construction companies is how to deliver a cost-effective, energy efficient renovation solution which does not sacrifice the indoor environment or the building’s durability. This process allows for the customization of any project and it not constrained by limited options for renovations. It can be adapted to the wishes of any client. If the client wants to prolong a building with a poor envelope, then envelope improvements can be designed to reduce the thermal losses through the building envelope while at the same time optimizing the technical systems within the building. Technical systems can be chosen based on the new thermal properties and each individual building can be adjusted and monitored after the renovation is completed to guarantee the calculated energy savings.

The replication potential should also be high in other parts of Europe as well, since the most important part of the renovation work is based on communication between the building owner and contractor (engineer, architect, etc.) through the use of Partnering. The largest problem which must be dealt with is that Partnering is not a common form of collaboration in Europe (quite common in North America) so all parties will need to be educated on this contracting form before its full potential can be realized.

4.6 Final Conclusions

The purpose behind the Halmstad demonstration was to have a cost efficient renovation of a million program building which reduced the purchased energy by 75 % using Strategic Partnering as the contract form of work, while having the tenants live in their apartments during the renovation work. The energy savings guaranteed by NCC and was later verified by monitoring the various energy flows in the building after the renovation. The Halmstad project fulfilled all their goals (economic, process and energy) set by the project team.

This project has shown that each object to be renovated is different, and a pre-defined list of energy saving measures cannot economically be applied to all buildings. The best solutions can be found when all stakeholders have an interest in the success of the project and all stakeholders openly share their past experience, benefits and risks. Strategic Partnering allows this and the project’s success depends to a great extent on the communication between the building owner and the construction company. It is vital that the stakeholders sit down together early in the project and discuss what it is the building owner wants, and how much they are willing to spend or what return on investment is acceptable. In this manner, all parties can discuss possible solutions and their associated costs openly until an acceptable plan is formed. The result is an economically sustainable renovation project.

It is important to remember that the technical solutions shown for the Giganten 1&7 demo are not necessarily the best solutions for other buildings. All the solutions developed within this project are a result of this specific building's needs as well as the building owner's desires. The results from this project have already been applied to the neighbouring building, Giganten 6, in Halmstad where the building process was almost identical to Giganten 1&7 but the technical solutions were adjusted for the specific building's, and building owner's specifications. The fact that this process is already being implemented before the publication of results shows the replication potential of the work method used in Giganten 1&7.

Appendix A Original BEST Sheet

Building Energy Specification Table (BEST)

Community / site	Halmstad/Sweden	Giganten	BEST no. 5

1,1	Building Category	residential retrofitted	total area / category / BEST sheet [2]	5720 m^2
	[1]			

1,2	Local Climate		January average outside temperature	°C	-2
			August average outside temperature	°C	15
	Climatic Zone	3	Average global horizontal radiation	kWh/m^2 yr	930
	(national definition)	Climatic zone III	Annual heating degree days [3]	°Cd/yr	3007

1,3	Maximum requirements of building fabric			Existing building [5]	National regulation for new built [6]	suggested specification [7]	Energy savings [%] [8]
	Façade/wall	U	W / m2K	0,375	-		
	Roof	U	W / m2K	0,24	-		
	Ground floor	U	W / m2K		-		
	Glazing	U_g	W / m2K	3	-	0,9	
	Average U-value	U_{av}	W / m2K	1,13	0,5	0,5	0
	Glazing	g	total solar energy transmittance of glazing [%]		-		
	Shading	Fs	Shading correction factor		-		
	Ventilation rate [4]		air changes/hr		-		

2 Building Energy Performance

2,1 Energy demand per m2 of total used conditioned floor area (kWh / m2yr) incl. system losses

energy carrier existing building	suggested energy carrier		specify energy efficiency measures [13]	Existing building [5]	National regulation / normal practice	suggested specification [7]	% Energy savings [8]
Heating + ventilation							
Distric heating	Exhaust vent.	kWh/m^2yr	Balancing of temperature, new windows, improved airtightness	123		72	
Cooling + ventilation							
		kWh/m^2yr					
Ventilation (if separate from heating/cooling)							
Exhaust vent		kWh/m^2yr	New fans	5		2	
Lighting							
	electricity	kWh/m^2yr	Attendance controlled strategy	3		2	
Domestic Hot Water (DHW)							
		kWh/m^2yr	Individual measure, low-flow fittings	35		18	
Other energy demand							
heat pump, elevator		kWh/m^2yr		23		15	
		kWh/m^2yr	Subtotal sum of energy demand	189	110	109	1
	Appliances (please indicate, but costs are not eligible)						
	electricity	kWh/m^2yr					

2,2 RES contribution per m2 of total used conditioned area (kWh / m2 yr)

total production kWh/yr	m^2 installed	kW installed	specify RES measures	Existing building [5]	National regulation / normal practice	suggested specification [7]	RES contribution [%] [8]
		53,1	Change: exhaust heat pumps to borehole-	15		64	
			Green electricity through own PVs			19	
		kWh/m^2yr	Subtotal sum of RES contribution	15	0	83	

3 Building Energy Use

per m^2 of total used/heated floor area (kWh/m2 yr)

		Existing building	National regulation	suggested specification	
kWh/m^2yr	Subtotal sum of energy demand	189	110	109	
kWh/m^2yr	Subtotal sum of RES contribution	15	0	83	
kWh/m^2yr	Total Building Energy Use	174	110	26	76%

4 Other national overall energy performance targets or criteria (additional information, mandatory if existing)

	Units [9]	explain content and scale [10]	Existing building	National regulation for new built (2006)*	suggested specification

Appendix B Energy Data

Halmstad Before

Calibrated calculation in IDA/ICE

	Energy Demand Before [kWh/m2 NFA]	Source	PE conv. fact. fp [kWh PE / kWh S] national /local	PE national [kWh/m2 NFA]	PE conv. fact. fp [kWh PE / kWh S] acc. EN 15603	PE based on EN 15603 fp [kWh/m2 NFA]
Heating Source 1	108,0	District Heating	0,17	18	1,3	140
Heating Source 2	-16,7	HP	0,17	-3	1,3	-22
DHW Source 1	30,0	District Heating	0,17	5	1,3	39
DHW Source 2	-4,6	HP	0,17	-1	1,3	-6
Auxiliary	14,2	Electricity	1,5	21	3,31	47
Losses Source 1	7,9	DHC	0,17	1	1,3	10
Losses Source 2				0		0
Total	**138,8**			**42**		**209**
Delivered to the grid			0	0		0

Halmstad Afterwards

Calibrated calculation in IDA/ICE

	Energy Demand Afterwards [kWh/m2 NFA]	Source	PE conv. fact. fp [kWh PE / kWh S] national /local	PE national [kWh/m2 NFA]	PE conv. fact. fp [kWh PE / kWh S] acc. EN 15603	PE based on EN 15603 fp [kWh/m2 NFA]
Heating Source 1	73,5	District Heating	0,17	12	1,3	96
Heating Source 2	-66,7	HP	0,17	-11	1,3	-87
DHW Source 1	24,0	District Heating	0,17	4	1,3	31
DHW Source 2	-25,4	HP	0,17	-4	1,3	-33
Auxiliary	26,3	Electricity	1,5	39	3,31	87
Losses Source 1	10,4	DHC	0,17	2	1,3	14
Losses Source 2				0		0
Total	**42,1**			**42**		**108**
Delivered to the grid			0	0		0

Conversion factors fp (total) acc. EN 15603:2008* Table E1 - Annex E		
Electricity (UCTE Mix)	3,31	[kWh PE / kWh S]
Local-/District heating	1,3	[kWh PE / kWh S]
Electricity, Nordic mix.	1,5	SOU 2008:25
District heating, Halmstad	0,17	Lokala miljövärden 2012