EINSTEIN

D 2.6: Case study assessment of Decision Support Tool

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1. Introduction

The EU funded FP 7 EINSTEIN project is researching the Effective Integration of Seasonal Thermal Energy Storage in Existing Buildings. Scandinavian Homes, a manufacturer of low-energy houses is participating in the project as it has recently renovated a building in Lysekil Sweden and has installed a Seasonal Thermal Energy Storage (STES) in the basement of a new building. Scandinavian Homes is recording and analysing data which is being used here as a case study to validate the DST.

Figure 1.1 Refurbishment Project located at Kungsgatan 21, Lysekil, Sweden (Building 1)

This document describes the work which was carried out and led by Scandinavian Homes in Task 2.5 which uses the development in Lysekil as a case study to validate the decision support tool, the development of which was led by Acciona.

For the specific building, the retrofitting (both passive and active) which was carried out is described in this report, and a cost breakdown is provided of the passive and active measures.

It is recognised that while ideally the decision support tool would have been used to inform Scandinavian homes of the passive and active renovations deemed most appropriate, the tool was still in development when, for commercial reasons, Scandinavian homes had to proceed with the renovation. Thus the DST configuration which most closely matches that actually developed in Lysekil is selected for the comparison between the figures produced by the decision support tool and those recorded in the building. Similarities and discrepancies are highlighted, and recommendations made.

Finally, the appendix provides a financial analysis carried out on the installation to determine the payback etc.

2. Overview of Development

2.1. Description of Refurbished and New Building

Figure 2.1 Building 1 showing solar array

Scandinavian Homes purchased a city block in the town of Lysekil, Sweden for development. An existing building "Building 1" dates from 1860 and has been renovated with the aim of approaching the Passivhaus Enerphit standard. In addition, another two-storey building of similar size "building 2" to the rear of building one has also been built and a Seasonal Thermal Energy Store (STES) has been installed in the basement of building two. The STES has been integrated into the heating system for building 1 and building 2.

Figure 2.2 Building 2 (Location of STES), with building 1 in the foreground

The refurbished building being monitored "Building 1" is located at Kungsgatan 21, Lysekil, Sweden. It has a heated floor area of 381 m² and comprises:

1. four shop units (total area c. 190 m²) on the ground floor
2. two two-bedroom apartments (of total area c. 190 m²) on the first floor and
3. an attic with habitable space of 80 m² (currently unheated).

Ground floor and first floor plans are provided in the appendix.

Both passive and active measures are employed in the building in order to reduce the energy consumption.

The passive measures comprise an extensive envelope refurbishment. With respect to the active measures, the solar system which has been installed reduces the space heating and domestic hot water heating demand. The shortfall is satisfied by the district heating system and electrical heating.

3. Details of Passive Measures

3.1. Windows

Prior to the renovation, all windows were from a 1951 refurbishment consisting of a mix of double glazed openable windows and single glazed large fixed windows in the shop-fronts at street-level. All windows were replaced with 50mm thick triple-glazed glass-cassettes with double LE coatings and double argon fill plus insulated spacers. The average u-values improved from circa 4.0 to 0.92

3.2. External wall

Figure 3.1 showing the preparation for the additional external insulation

The interior of the old building was preserved and additional insulation was fitted to the exterior. Insulated beams were added to the exterior and 170mm Rockwool inserted between the beams and a new ventilated timber facade was installed. The U-value of external walls were improved from circa 0.6 W/m^{2}C to 0.146 W/m^{2}C.

It is noted that the external insulation cost considerably more than internal installation. However, the external cladding required to be changed in any event, and it was decided to retain the interior wall finishings for aesthetic reasons.

External wall 170mm stonewool with light-beam 0.6m cc external	Thermal conductivity k (W/m² °C)	Thickness (m)	Thermal resistance R (m² °C/W)			Total insulation:	170
inside air film			0.14			Tot w all (mm):	391
old wallpapers, 10 layers		0.005	0.05			Increase w all outw ard:	220
13mm ciporex light fiberboard, old	0.050	0.013	0.26			Old w all thickness:	171
5" timber	0.140	0.125	0.89	100% of surface			
old tarred paper, vaporcheck			0.05				
old 28mm timber panel	0.220	0.028	0.13				
47x170mm lightbeam vertical	0.043	0.170	0.31	7,83% of surface			
170mm Paroc stonewool	0.033	0.170	4.75	92,17% of surface			
new black permeable papper barrier			0.05				
22x45mm batten vertical		0.022	0.05				
28mm ny lockpanel spikad	0.220	0.028	0.13				
outside airfilm			0.03				
	R total:	=	6.84	m² °C/W			
Overall U-value	= 1/R total	=	0.146				
Calculation for lightbeam with 47x47mm flange and 8mm K-masonite							
flange 47mm deep	0.140	0.094	0.67	100% of surface			
8mm k-Masonite 195-47-47=101mm deep	0.220	0.101	0.08	17% of surface			
stonew ool betw een flanges	0.033	0.101	2.54	83% of surface			
flange 47mm deep	0.140	0.094	0.67	100% of surface			
	R total:	=	3.96	m² °C/W			

Figure 3.2 External Wall: Thermal Resistance and Overall U-Value Calculations

Figure 3.3 External render being applied

3.3. Foundation and floor

The interior floor of the ground floor is 40% uninsulated concrete added in the 1951 year rebuild. The remaining 60% is a double timber floor with circa 150mm layer of 150 year old sawdust for insulation with a shallow crawlspace below to the earth

The external walls rest on a simple stone foundation around the perimeter. It was decided to apply insulation around the perimeter rather than try to insulate the floor itself. The old vents of the stone perimeter were blocked and attention was paid to remove all ventilation from the crawlspace to the outside.

A mechanical extract air point was added to the little cellar in the centre of the building to control the humidity under the house. One vent in the floor in each end of the building was added to let warm interior air into the crawlspace.

A trench was dug out around the building as deep as the depth of the old stone foundation. A 200mm thick layer of expanded polystyrene insulation was added externally to the stone foundation. Depths extend to between 300 and 700mm underground depending on how deeply it was possible to excavate. This trench was filled with insulation pellets of expanded clay (LECA-balls). See figure 3.4. On top there is a sheet of 50mm expanded polystyrene sheet that is backfilled with sand up to old street level. Figure 3.5 gives the calculations for the thermal resistance and overall U-value.

Figure 3.4 showing the external insulation applied to the foundation

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Strip foundation and floor: **170mm polystyrene external with 40mm render**	**Thermal conductivity k (W/m² °C)**	**Thickness (m)**	**Thermal resistance R (m² °C/W)**		
	λ				
Around the foundation perimeter					
inside air film			0.14		
Old stone wall plastered with lime	1.20	0.500	0.42		
Polystyrene S100	0.037	0.200	5.41	100% of surface	
Sto plaster, reinforced, primer, jumboseal paint	1.5	0.02	0.01		
	R total:	=	5.98	m² °C/W	
Overall U-value	= 1/R total	=	<u>0.17</u>		
Suspended floor under 40% of bldg = 80m2 with old joisting insulated with sawdust 120mm					
Cast concrede floor under 60% of bldg =120m2 (tiled 50%, linoleum 50%					

Figure 3.5 Foundation and Floor: Thermal Resistance and Overall U-Value Calculations

3.4. Roof

Figure 3.6 application of insulation to roof

The roof was externally insulated with 250mm Rockwool inserted between new rafters spaced 1200mm apart and placed on top of the old roof. 17mm tongued and grooved timber sarking was added onto which roofing-felt, counter and tile battens were added in addition to the old clay tiles which were re-used. This resulted in an improvement of U-values from 0.35 W/m^{2}C to 0.097 W/m^{2}C.

External roof: Added externally stonewool, Paroc average 250mm between new rafters	**Thermal conductivity k (W/m² °C)**	**Thickness (m)**	**Thermal resistance R (m² °C/W)**		
old ceiling in top apartment	0.03	0.010	0.30		
old sawdust insulation at attic joists	0.08	0.150	1.88		
old wooden floorboards attic 32mm	0.14	0.032	0.23		
unheated attic			0.14		
old external roof 22mm solid timber	0.14	0.022	0.16		
old roofing felt			0.05		
45x195mm rafters vertikal 1.2m cc	0.140	0.195	0.05	3,9% of surface	
250mm stonewool Paroc (195-300mm)	0.033	0.250	7.28	96,1% of surface	
new windbarrier polypropylen			0.05		
counterbattens 23x45mm			0.02		
17mm sarking solid t&g			0.02		
Roofersfelt YAP uni			0.02		
counterbatans 23x45mm			0.02		
tilebatens 28x45mm			0.02		
clay rooftiles			0.02		
outside airfilm			0.02		
	R total:	=	10.28	m² °C/W	
Overall U-value	= 1/R total	=	0.097		

Figure 3.7 Energy efficiency improvements and their corresponding R Value

4. Active Measures

4.1. Overview

Space and domestic hot water (DHW) heating is provided by means of a district heating system in combination with a solar system. See figure 4.1 for a schematic of the wet heating system.

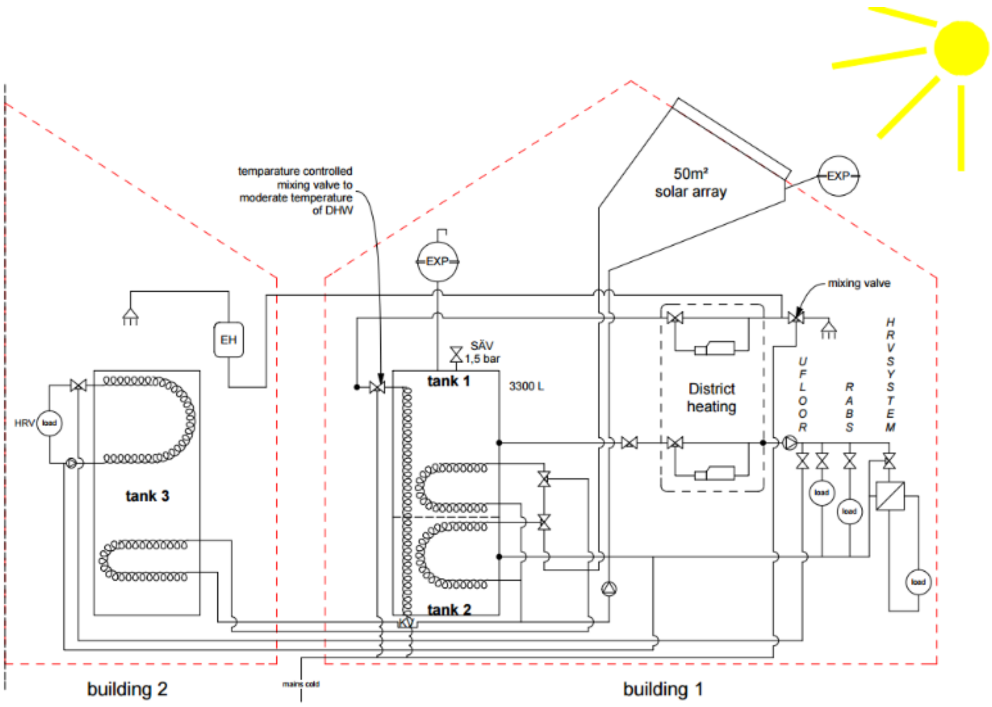


Figure 4.1 Schematic of Wet Heating System

4.2. Solar System

The 50 m² solar array comprises 10 panels of 1.8 m² aperture (totalling 18 m²) of evacuated tube collectors and 16 panels of 2 m² aperture, (totalling 32 m²) of flat plate collectors.

A 3300 L buffer tank located in building one is logically divided (although not physically) into two based on thermal stratification considerations. The solar collectors supply heat to the heat exchanger coil in the middle of the buffer tank ("tank 1") or heat exchanger coil at the bottom of the buffertank ("tank 2").

The Steca controller transfers heat to the top heat exchanger coil (located approximately 1.5 m from floor level) until the target temperature of 65°C is attained in the logical "tank one". The solar fluid is then diverted to the bottom heat exchanger coil (located 0.5 m above floor level) until the target temperature of 55°C is attained in the logical "tank two", whereupon it is diverted to tank three (the STES).

In addition a 23 m³ Seasonal Thermal Energy Store (STES) has been installed in the basement of building 2. Heat excess to the requirements of the buffer tank is fed to the Seasonal Thermal Energy Store (tank 3).

Figure 4.2 Picture of Building 1 (foreground) and Building 2 (background)

4.3. Heating System in Building One

Domestic Hot Water (DHW) is heated by the buffer tank by means of indirect heating using 6 x 15 m finned copper heat exchanger coils located at the top, middle and bottom of the buffer tank which are connected in series. Freshwater is fed to the bottom heat exchanger coil, and the DHW feed is taken from the coil located in the top of the buffer tank. If the temperature of the DHW is below 60°C, it is automatically heated to the required 60°C by means of the district heating system.

Space heating from the solar system is effected by the transfer of water from the buffer tank to the target heating systems in use in building one. If the water feed from the buffer tank is below 60°C, it is topped up automatically by the district heating system to meet the heating demand.

Figure 4.3 Buffer Tank (Comprising upper section “Tank 1” and lower section “Tank 2”)

There are three target space heating systems in use in building one, each of which is selected manually using valves located in the utility room:

1. Air heating system
   This is the primary heating system for building one. Water to air heat exchanger coils are installed in the outlet duct in each of the four HRV Systems which are located in the attic of building one. Thus heat can be transferred from the buffer tank to the air heating system by manually opening the required valve in the utility room.
2. Radiator heating system.

Radiators are located in both commercial unit one and commercial unit two. These are inefficient legacy radiators with thermostatic control on each.

3. Underfloor heating system

   Two 60 m pex pipes are located under the floorboards on the ground floor in building one. This compensates for the fact that the ground floor is uninsulated. In addition, electric underfloor heating is provided in the bathrooms of both apartments located on the top floor. These are 200 W elements which are individually thermostatically controlled.

It is noted that there is an element of manual control of the heating system. For example, the district heating system is turned off during the summer and the air heating system is used to heat the building via the heat recovery and ventilation heat exchanger coil.

4.4. Heating System in Building Two

The primary space heating system for building two is again predominantly based on the installed heat recovery and ventilation system. Each of the three apartments has a separate HRV System, with a water to air heat exchanger coil. The source of the heat for the air duct heat exchanger coil is the seasonal thermal energy store (i.e. tank three) or the buffer tank/district heating system located in building one. Two 15 m finned copper pipes heat exchangers located at the top of tank three enable the extraction of heat from the STES directly to the air space heating system. When the temperature of tank 3 drops below circa 28 degrees, the system switches over to take the feed from the solar/district heating in building 1.

In addition, each of the two upstairs apartments has two thermostatically controlled 300 W electric floor heat cables installed under the bathroom floor (totalling 600 W of underfloor heating per apartment). The ground floor apartment has a thermostatically controlled 500 W electric floor heat cable. These cables are not needed for space heating of the apartments, but Swedish consumers expect the floors in wetrooms to be quite warm.

Domestic hot water for building two is supplied using an insulated feed from tank 1 and 2 (the solar buffer tank) topped up by district heating domestic hot water supply in building one. To eliminate the problem of cold hot water in the morning when the first hot tap is opened, there is a 35 L tank acting as a buffer. This has a built in thermostatically controlled 1 kW immersion heater.

Figure 4.4 EPS Insulation being applied to the STES

5. Recorded Performance

5.1. Energy consumption prior to renovations

As can be seen from figure 5.1, the district heating consumption ranges from 80.424 MWh to 83.880 MWh over the three year period. The average for the three-year period is 81.959 MWh.

Prior to the renovations, the building was used as three shop units and two residential units.

värme. Förbrukningsstatistik

1 (1)

2013-12-02 15:34

RR

gning: 70 / Kungsgatan 21
hetsbeteckning: Gamlestan 1:11
SCANDINAVIEN HOMES FASTIGHETER AB

	2008			2010			2009		
inad	MWh	m3	DeltaT	MWh	m3	DeltaT	MWh	m3	DeltaT
1	11.884	0.000	0.0	13.680	0.000	0.0	11.510	0.000	0.0
2	9.816	0.000	0.0	11.310	0.000	0.0	11.148	0.000	0.0
3	10.815	0.000	0.0	13.150	0.000	0.0	10.512	0.000	0.0
4	7.590	0.000	0.0	6.550	0.000	0.0	8.256	0.000	0.0
5	4.258	0.000	0.0	4.180	0.000	0.0	4.378	0.000	0.0
6	2.235	0.000	0.0	2.140	0.000	0.0	2.865	0.000	0.0
7	1.788	0.000	0.0	1.080	0.000	0.0	1.506	0.000	0.0
8	1.788	0.000	0.0	1.700	0.000	0.0	1.911	0.000	0.0
9	4.295	0.000	0.0	3.340	0.000	0.0	3.564	0.000	0.0
10	6.386	0.000	0.0	6.250	0.000	0.0	9.226	0.000	0.0
11	8.644	0.000	0.0	10.120	0.000	0.0	8.196	0.000	0.0
12	10.924	0.000	0.0	13.340	0.000	0.0	11.332	0.000	0.0
mma	80.424	0.000	Infinity	83.880	0.000	Infinity	81.572	0.000	Infinity

Fig 5.1 LEVA District Heating Energy Consumption report 2008, 2009 and 2010

5.2. Occupancy of building

The building was purchased by Scandinavian Homes in Dec 2010. Renovations started in June 2011, and the renovated building was first occupied by tenants in October 2012.

However, it was not until the start of 2014 that the renovated building was occupied and therefore meaningful measurements could take place.

Data was gathered for a full year: from February 17, 2014 to February 17, 2015. However while the two apartments and two of the commercial units were fully occupied, the remaining two of the four commercial units were not fully occupied during this period. The occupancy of the units is given below

Shop nr 1 (delicatessen)	occupied	Feb 2014 - Aug 2014.
	unoccupied	Sep 2014 - Nov 2014.
	occupied	Dec 2014 - Feb 2015
Shop nr 2 (café)	occupied	Feb 2014 - Aug 2014
	unoccupied	Aug 2014 - Feb 2015

With respect to the second (New) building, during the period February 2014 to February 2015 the three apartments were fully occupied.

5.3. Building 1 Energy consumption following refurbishment

The table below gives the overall heating energy consumption for building one recorded by the monitoring equipment installed as part of the EINSTEIN project.

Heat load	Total {kWh}	DH {kWh}	Solar {kWh}	Electric {kWh}	Solar fraction {%}
Space heating	42,276	24,789	16,498	989	39.0%
DHW	4,179	1,471	2,708	0	64.8%
Total	46,455	26,260	19,206	989	41.3%

Fig 5.2 Heating energy consumption for Building One: 17 Feb 2014 to 17 February 2015

As can be seen from figure 5.2, the total space heating energy demand is 42,276 kWh , of which the district heating supplies 24,789 kWh , the solar installation 16,498 kWh and 988 kWh by electricity. This results in overall solar fraction of 39% for the space heating for building one.

Prior to the renovation the energy consumption of the building was 81,959 kWh on average over a three-year period.

Thus a reduction in the DHW and space heating demand from 81,959 kWh to 46,455 kWh was achieved due to passive retrofit measures, representing a reduction of 56.5%.

In addition, due to the solar installation, the overall space heating & DHW energy consumption for building one was reduced to 26,260 kWh, representing a reduction of 68% on the original district hot water and space heating demand.

5.4. Energy Consumption of Building 1 & 2 combined

The decision support tool focuses on a single building. However, in the case of the development in Lysekil, while the solar panel is located on building one, the seasonal thermal energy store is located in the basement of building two. The solar panels (located on building 1) reduce the space heating and DHW demand in building one and in building two. Furthermore, the STES (located in building 2) reduces the energy demand of building two only.

Therefore, in order to fully guage the contribution made by the solar installation including the Seasonal Thermal Energy Store, it is also necessary to consider the profile of the energy consumption in building two, and calculate effect of the solar system on the overall energy consumption.

Heat Load	Total	DH	Solar	Electric	SF
Space Htg	11145	1927	5182	4037	46.5
DHW	3238	1540	1673	25	51.7

Fig 5.3 Heating energy consumption for Building 2: 17 Feb 2014 to 17 February 2015

As can be seen from figure 5.3 above, the solar fraction for space heating in building two is above that achieved in building one, while the DHW solar fraction is significantly less.

This reflects the fact that the STES is used exclusively to feed the space heating needs of building two. The 3642 kWh contribution from the STES comprises the majority of the solar contribution for the space heating, significantly increasing the overall solar fraction for space heating.

Heat Load	Total	DH	Solar	Electric	SF
Space Htg	53422	26716	21680	5025	40.6
DHW	7417	3011	4381	25	59.1
Total	**60839**	**29727**	**26061**	**5050**	

Fig 5.4 Heating energy consumption for Building 1&2: 17 Feb 2014 to 17 February 2015

Figure 5.4 above shows the heating energy consumption for the combined building one and building two load. It shows that the space heating and DHW solar fraction have not been significantly altered compared with that previously considered for building one alone.

In addition, it is seeing that due to its smaller size and the fact that it was built to the Passive House standard, the overall energy consumption of building two is significantly below that of building one. Therefore the heat “lost” to building two does not significantly impact on the analysis of building one.

However, when considering the financial payback, the extra cost of installing the STES and the amount of heat stored in it should be considered in order to gain a full understanding of the financial viability of the STES.

It is noted that a large part of the role of the STES is to act as a heat load during the summer months, in order to avoid stagnation of the solar panels. Should the STES not be present, technical issues would arise with the installation given the excessively high temperatures which would occur for a number of months in the summer.

Given that the STES is present, the solar panel array can be sized in order to cater for a larger part of the annual space heating and DHW load.

5.5. Primary energy consumption

The primary energy conversion factor for the heat generated in the district heating network in Lysekil has been obtained from the district heating company LEVA. Reflecting the fact that the heat is waste heat from the adjacent oil refinery, the primary energy conversion factor is 0.08. It is noted that this is an atypically low figure.

The conversion factor for the electricity is more typical at 2.4.

6. Refurbishment costs

This section gives an overview of the costs associated with the refurbishment covering both the passive and the active measures.

6.1. Passive measures

	m2	€/m2	Tot €
Walls	330	300	99,000
roof slope	280	200	56,000
Floor/ circumference	195	250	48,750
			203,750

Fig 6.1 Energy efficiency refurbishment costs - passive measures

The total cost associated with the energy efficiency measures of the refurbishment of the 1860 Passive House are given in figure 6.1 above.

As can be seen from the table, the total cost for the walls is €99,000, the sloping roof €56,000 and the floor €47,750 giving a grand total of €203,750 for the passive energy efficiency measures.

The refurbishing costs for any old building are extremely high in Sweden due to a number of factors including very high taxes, detailed regulations and a lack of qualified tradesmen. In such an environment it is often less expensive to demolish the existing building and build new. In the case of the refurbishment in Lysekil, it was possible to keep elements of the old interior in some areas resulting in cost reduction compared to replacing the building.

Given the ethos of energy reduction in tandem with general refurbishment practised by Scandinavian Homes Ltd, it is very difficult to separate the costs associated with the passive upgrade from the general refurbishing costs.

Therefore, the costs above are not deemed to be definitive, but rather a best estimate of the costs associated with the energy refurbishment.

It is noted that the costs of the renovation and the walls and roof come to a grand total of €155,000. This is the specific case considered in the Decision Support Tool later.

6.2. Active measures

Figure 6.2 below gives the detail of the work carried out in Sweden on the solar heating system. Table 6.3 provides a summary of the equipment and labour costs for the solar and STES systems.

Cost of Building 1 solar Heating System Kungsgatan Lysekil								
			€ / kr rate:	9.1		15/09/2015		
Item	**Descr.**	**Suppl**	**Price €**		Amount	**Price ea Kr**	**Tot Kr**	
Collector Vacuum U-tube 1.8m2 X 10= 18m2	TZ 47/1500-20U 011-7S162_R 2,5 liter liquid	Sunking Sept 2011	5,275		10	4,800	48,000	
Collector Flat plate 2m2 x 16= 32m2		Sunking Sept 2011	7,033		16	4,000	64,000	
Controller	Steca TR 0603mc	Steca	136		1	1,242	1,242	
Pumpstation:	Steca Solar DN25 TPA-25 +TPAF-25+WILO ST25/7	Steca	270		1	2,454	2,454	
Flow Meter	Steca TA VM1 Flow Meter DS	Steca	229		4	522	2,087	
Sensor:	PT 1000		1,099		10	1,000	10,000	
VEAB ductheater 0.29 lit in pipe	CWW 160-2-2,5	VEAB	1,582		12	1,200	14,400	
Thermostatic regulating valve	Duco mixautomat	EO	44		1	400	400	
3-way motorized valve Wege-Motor-Umschaltventil		EO	396		3	1,200	3,600	
Expansionvessel solar max 10bar	80 lit	Sol & energiteknik	151		2	686	1,372	
Automatic aeriator valve for top position	LK aut airvent 740	EO	11		1	100	100	
Propylenglukol konc.	25 lit	Sol & energiteknik	182		2	828	1,656	
Internal tank (tank 1)	3300 lit w 13 coils x 15m finned cu-pipes 22mm Cuporo	Husqvarna tanksvets	7,651		1	69,625	69,625	
Labour to install tank 1, culvert, pipes, install solar panels, all inside and out +		F&G, EO	12,914		1	117,520	117,520	
Labour to install floorheat under old house + 20mm PEX 60m		F&G, EO	679		1	6,180	6,180	
Costs of Seasonal Thermal Energy Store								
Solar flexrohr twin ss insulated pipes	DN20 13mm insul 2x.75mm 25m +EPDM insul	Foamteam	1,181		50	215	10,750	
Tank 2: Steel tank in basement	23.6m3	Emils skrot Norköping April 2013	2,198		1	20,000	20,000	
Finned cupper pipes & fittings tank 2		Rinkaby rör	1,138		1	10,358	10,358	
Foam insulation of tank 2	150mm	Ecofoam AB	2,754		1	25,063	25,063	
Cupper pipes	from store	Sch Ltd	1,099		1	10,000	10,000	
New expasion vessels in attic	2x80lit expansion vessels ir	EO May 2013	1,538		1	14,000	14,000	
Upgrade to larger circulationpump EC type	Wilo Stratos 25/1-10 Can Pl	LP July 2014	440		1	4,000	4,000	
Labour to install Solar flexrohr twin ss		Åke Häggman, Niklasson	1,152		1	10,480	10,480	
Connection to existing district heating		EO	2,198		1	20,000	20,000	
Repairs of leaks and new liquid	2013	EO	1,648		1	15,000	15,000	
Repairs leaks roof new with new teflon tape	changed part liquid	EO July 2015	879		1	8,000	8,000	
Sum:			**53,878**	**€**			**490,287**	**SEK**

Figure 6.2 Solar and STES Installation costs

	Heating Bldg 1 {€}	STES {€}	Total {€}
Labour	13,593	5,877	
Equipment	24,059	10,348	
Total	37,652	16,225	53,878

Figure 6.3 Summary of costs of Solar and STES Installations

7. Validation of decision support tool

7.1. Overview of Tool

The main goal of Work Package 2 is to develop a tool that enables the evaluation of the energy performance of existing buildings, and the most profitable option to make a deep energy retrofitting, depending on the factors cited:

- Geographic location.
- Type of building
- Evaluation of existing facilities
- Application of a selection of passive refurbishment measures
- Incorporation of STES.

The DST has been ported onto an online online version which can be accessed at:

http://einstein.dappolonia-innovation.com/sam
Username: einstein_user
Password: einstein%2015

The following figure shows the overall flow of information within the work package, in order to achieve the objective of developing a tool for assessing the most astute combination of passive and renewable energy measures from an economic perspective.

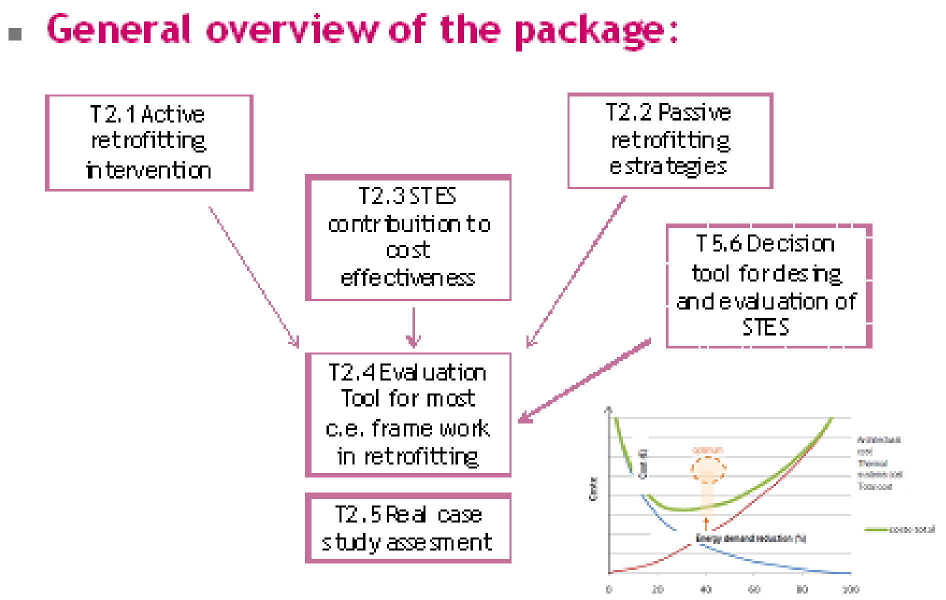


Fig. 7.1 General overview of WP2

As can be seen from figure 7.1, the tool uses inputs from a number of different tasks already carried out in work package two, including the passive retrofitting strategies of task 2.2, which enabled an analysis of the optimal combination of measures to reduce the energy demand before employing solar and/or STES. See figure 7.2.

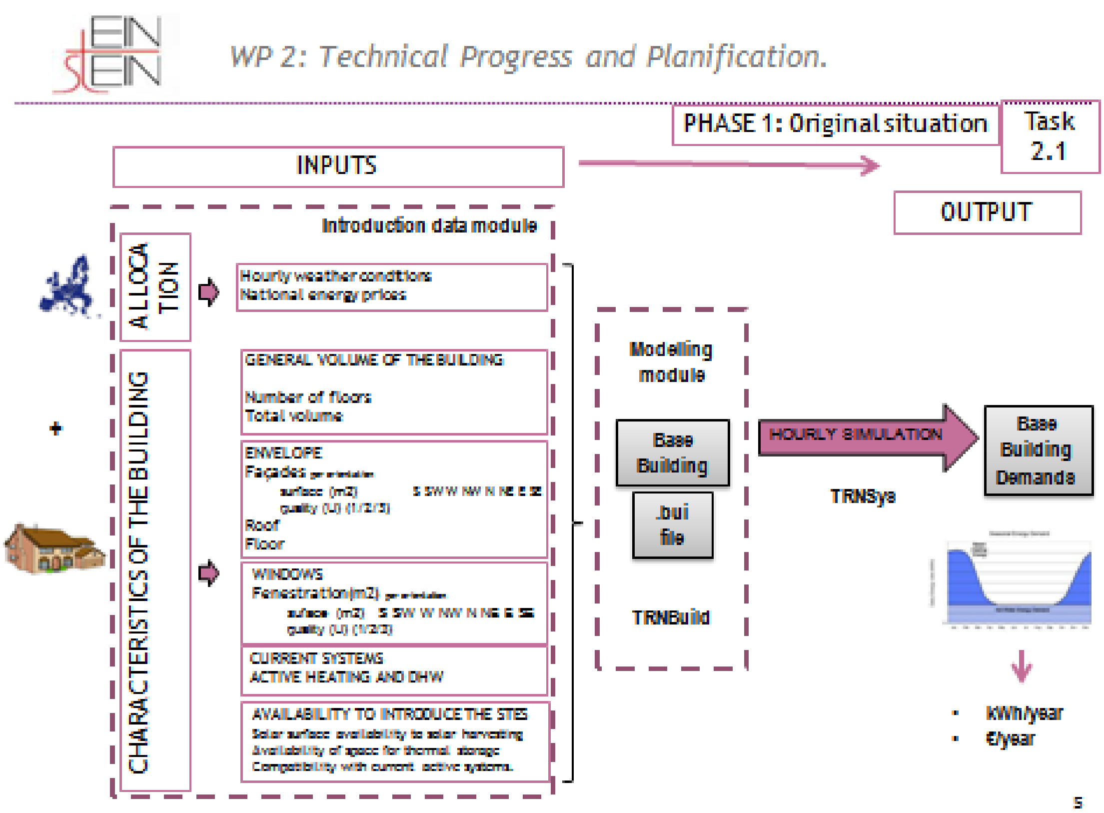


Figure 7.2 Passive retrofitting analysis: Process to evaluate best option based on energy consumption in existing buildings

Once the best passive retrofitting strategy has been identified, the active system is considered, and its influence in reducing energy consumption to meet the demand of a building is determined. Figure 7.3 below shows the flowchart of the evaluation tool, resulting in the optimal refurbishment measures proposed, the best use of renewables (including STES if deemed appropriate), and the resultant financials.

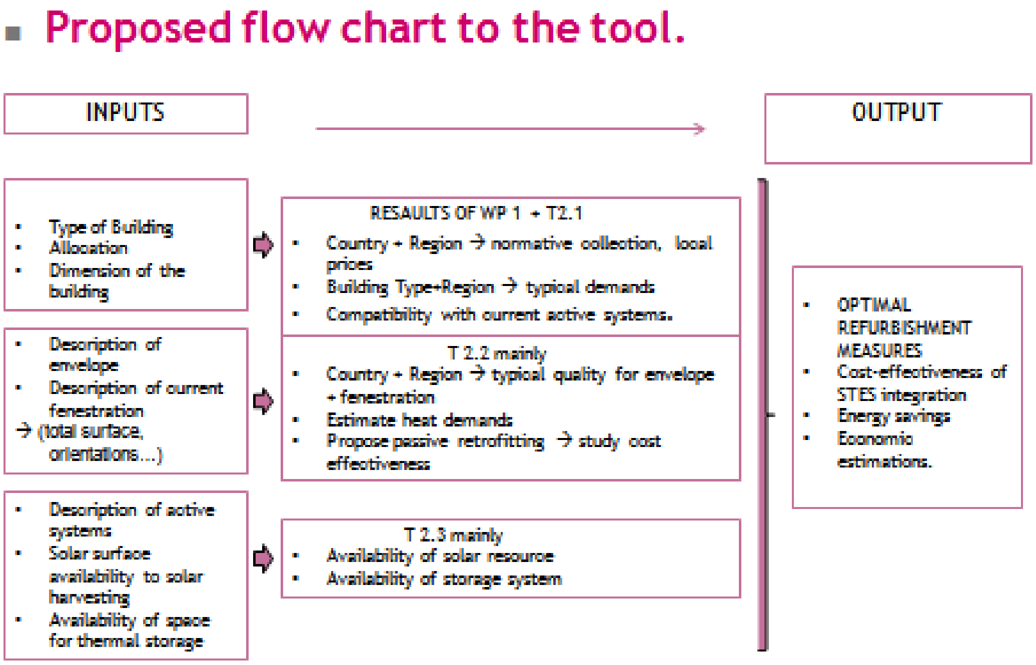


Fig. 7.3 Flow chart of the Evaluation Tool.

The tool developed uses information on the typical housing in the regions, to develop generic results to determine the best alternative for energy refurbishment.

Based on these improvements, active systems, are considered both with and without the inclusion of STES, in order to determine the optimal combination of approaches. Thus, the tool generates several alternatives for cost effective solutions in order to facilitate choosing the optimal result.

In the analysis the alternatives which most closely match those carried out in Lysekil were identified and used for validation purposes.

7.2. Validation process

The validation was carried out following a three stage process. Each successive stage looked at the validation at a lower level, identifying similarities and the similarities between the DST and the case study building.

7.2.1. Stage I: DST user interface

The first stage of the comparison is to use the DST user interface and the required variables for the case study site. This includes location, building size et cetera., As can be seen in figure 7.4, the results of the decision support tool are compared with the actual results recorded for the case study site.

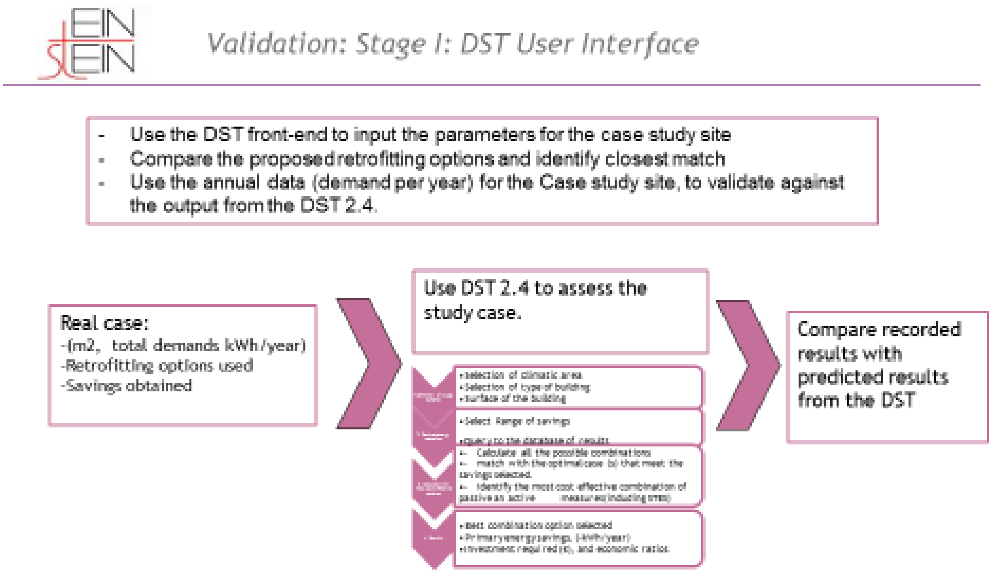


Figure 7.4 stage I validation

7.2.2. Stage II: detailed parametric analysis

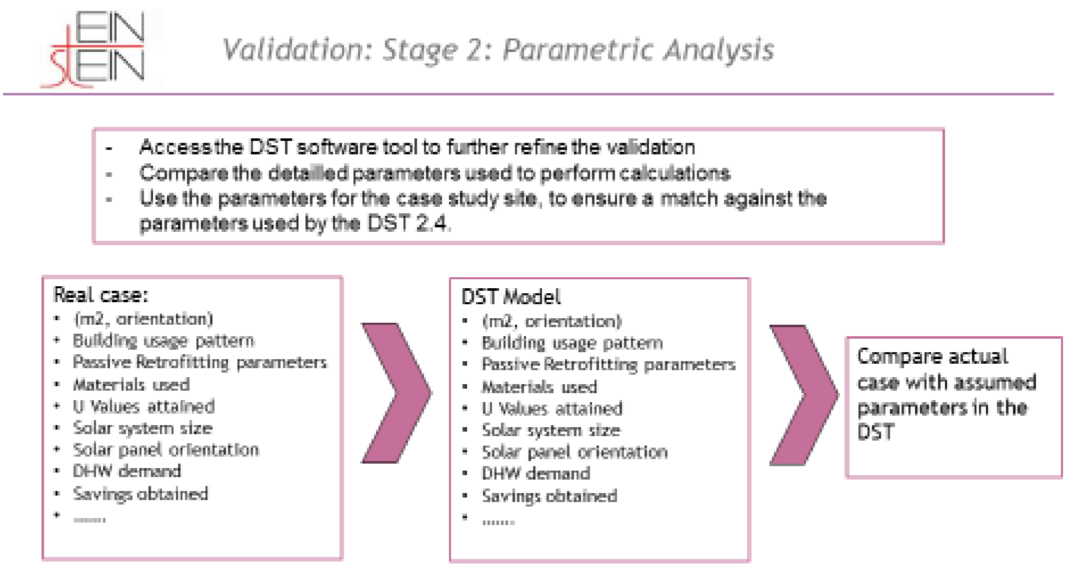


Figure 7.5: stage II validation

The second level of the validation process takes place at a parametric level. See figure 7.5. This involves access to parameters which are not available to the end-user including access to the U values assumed in the various scenarios for the roof, walls, windows, floor etc, the costs of the various measures, the DHW demand assumptions et cetera et cetera.

7.2.3. Stage III: detailed data analysis

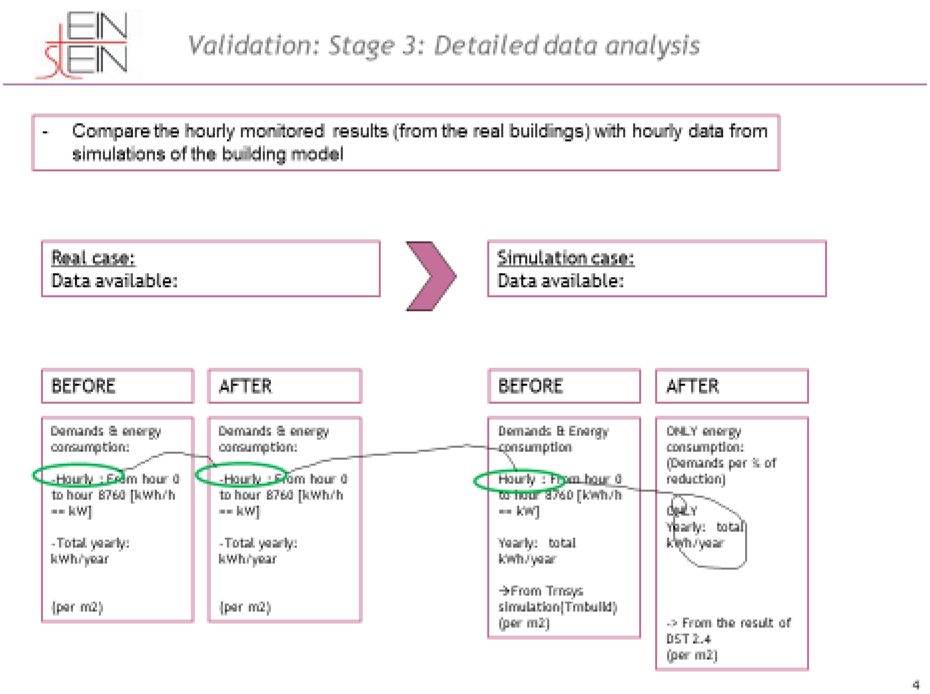


Figure 7.6: stage III validation

The third and most detailed level of the validation process looks at the recorded hourly data and compares it with the output from the TRNSYS model. At this stage any issues with underlying assumptions inherent in the TRNSYS model can be identified and corrected if necessary.

In carrying out the validation, a number of factors need to be borne in mind including:

- the energy consumption figures before the renovation was carried out were only available on a monthly basis, as they were based on the energy bills. In addition, the meter was read at infrequent intervals, making it impossible to ascribe data consumption figures to any specific month with certainty.
- The energy consumption recorded after the renovation measures were carried out was for a one-year period only, and therefore does not have the benefit of having been accrued over a longer period, with the resultant “smoothing” of DHW and space heating which is assumed by the decision support tool.
- It is noted that in the decision support tool, the domestic hot water consumption profile used is that of a residential user. For the period over which the tool has analysed the energy profile, the DST domestic hot water consumption totalled 7.04 MWh and the DST assumes that this is for the eight apartments

that are in the block. The closest approximation in Lysekil to this is the 7.4 MWh of domestic hot water consumption for building one and two and this is what is used in the analysis.

7.3. Stage I validation

The tool presents the user with a number of input variables, as can be seen from figure 7.7 below.

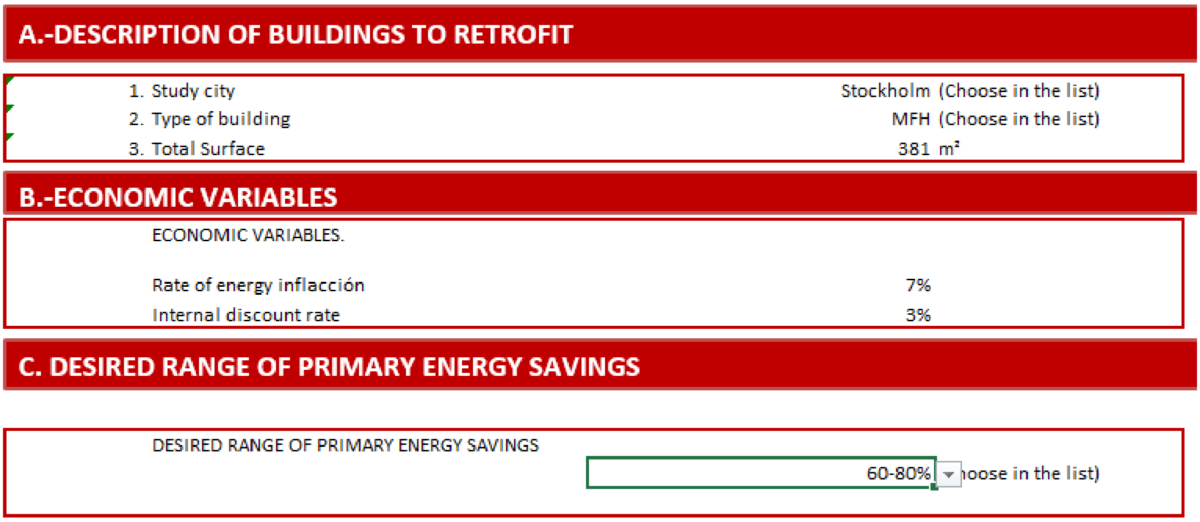


Figure 7.7 DST showing input of building parameters, economic parameters and desired range of energy-saving.

Given the comparable climates, the location of the city of Stockholm was selected and the type of building chosen was a multi-family home of 381 m². In line with the default values the rate of energy inflation chosen was 7%, and the internal discount rate 3%. There was no option to choose a consumer price index inflation rate. Reflecting the 68% reduction in space heating achieved, the desired range of primary energy savings chosen was 60 to 80%.

For the chosen inputs figures 7.8 and 7.9 represent the outputs from the decision support tool. As can be seen, the best retrofitting option proposed was the reduction in primary energy of 71.8% achieved through a medium renovation (to C13 as previously defined with insulation being added to the roof and walls), which achieves an energy saving of 18%, in combination with a seasonal thermal energy storage system designed to achieve 60% solar fraction.

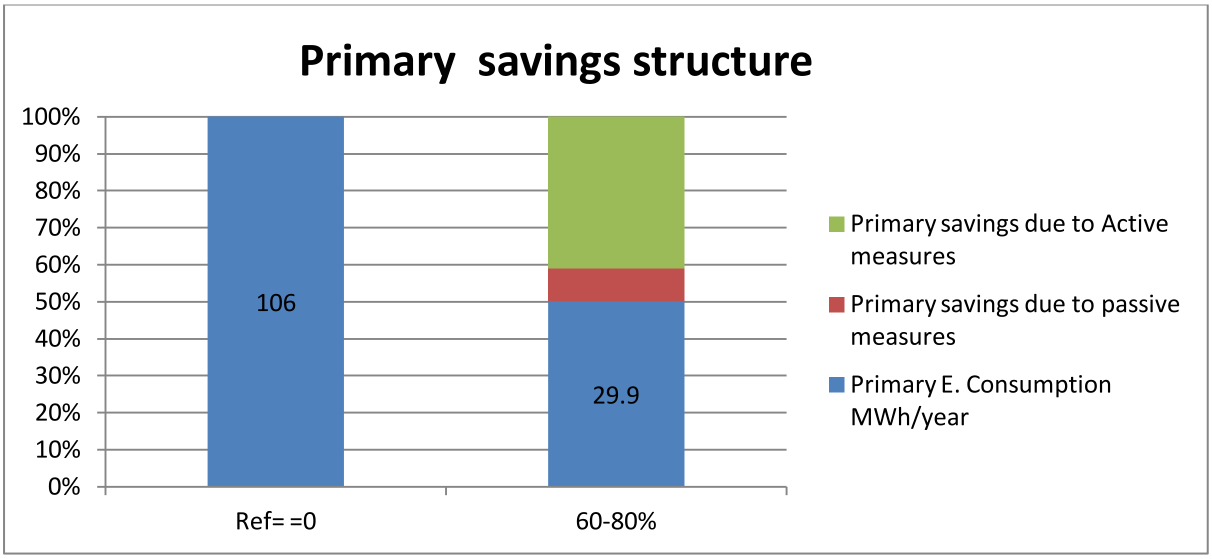


Fig 7.8 primary energy saving structure (Best retrofitting option proposed by the DST)

Best retrofitting option calculated				Energy Results			Economics
Real primary savings achieved with the options analized	Passive retrofitting applied	Reduction achieved in total heating demands	Active option	Primary E. Consumption MWh/year	Primary E. Consumption kWh/year m2	Primary E Savings MWh/year	Investment €initial(year 0)
71.8%	Add insulation on facades and roof; medium renovation (C 13)	18.0%	STES 60 SF	29.9	78.4	76.2	309,534.62 €

Figure 7.9 Best retrofitting option as proposed by the Decision Support Tool

The total cost of the proposed renovation to achieve a 71.8% reduction in primary energy amounts to €309,000.

The actual cost of the passive renovation amounted to €203,000, and the active measures cost €55,000, giving a grand total of €258,000 in order to achieve an overall energy reduction of 68%.

So, while the decision support tool proposes higher expenditure, the energy savings are also greater and in broad terms there is good agreement between the proposed cost and extent of the energy savings.

The next section delves deeper in the analysis by looking at the passive and active measures in more detail again examining the cost and performance. For this stage in the analysis, rather than look at the proposed best retrofitting option, the DST measure which most closely matches that carried out in Lysekil is examined.

7.3.1. Passive Measures

Based on the best retrofitting option proposed by the decision support tool in figure 7.9 above, a passive retrofit option of a medium renovation to the facade and roof as detailed in option C13 is to be carried out.

Madrid

	Reference Building		Medium Renovation		Deep Renovation	
	U	Rockwool thkns.	U	Rockwool thkns.	U	Rockwool thkns.
	$W/m^2 \cdot K$	cm	$W/m^2 \cdot K$	cm	$W/m^2 \cdot K$	cm
Floor	2,20	0,1	0,48	5	0,30	8,7
Facades	1,70	0,2	0,66	3	0,35	7
Roof	2,22	0,3	0,35	7,5	0,20	14
Windows	5,36	-	3	-	1,80	-

Amsterdam

	Reference Building		Medium Renovation		Deep Renovation	
	U	Rockwool thkns.	U	Rockwool thkns.	U	Rockwool thkns.
	$W/m^2 \cdot K$	cm	$W/m^2 \cdot K$	cm	$W/m^2 \cdot K$	cm
Floor	1,22	1,2	0,368	6,9	0,15	18,6
Facades	1,52	0,4	0,372	6,5	0,15	18,8
Roof	1,53	0,9	0,37	7	0,15	18,8
Windows	3,50	-	2	-	0,80	-

Stockholm

	Reference Building		Medium Renovation		Deep Renovation	
	U	Rockwool thkns.	U	Rockwool thkns.	U	Rockwool thkns.
	$W/m^2 \cdot K$	cm	$W/m^2 \cdot K$	cm	$W/m^2 \cdot K$	cm
Floor	0,50	4,7	0,15	18,7	0,11	25
Facades	0,50	4,5	0,18	15	0,15	18
Roof	0,50	5	0,13	22	0,10	29
Windows	3,00	-	2	-	1,50	-

Warszawa

	Reference Building		Medium Renovation		Deep Renovation	
	U	Rockwool thkns.	U	Rockwool thkns.	U	Rockwool thkns.
	$W/m^2 \cdot K$	cm	$W/m^2 \cdot K$	cm	$W/m^2 \cdot K$	cm
Floor	1,22	1,2	0,593	3,8	0,20	13,7
Facades	1,29	0,8	0,398	6	0,15	18,5
Roof	1,09	1,7	0,298	9	0,20	14
Windows	5,36	-	3	-	1,80	-

Figure 7.10 U Values for retrofitting measures to be carried out according to C13

As can be seen from figure 7.10 above the U values for scenario C 13 for the floor, facades, roof and windows respectively are 0.5 W/m²K, 0.18 W/m²K, 0.13 W/m²K and 3.00 W/m²K. Thus, while the decision support tool has excellent agreement with the U values for the actual renovation carried out on the facades and roof at 0.17 W/m²K, and 0.1 W/m²K respectively, the actual renovation was also carried out on the floor resulting in 0.17 W/m²K (compared with the DST value of 1.22 W/m²K) and 1.5 W/m²K for the Windows (compared with 3.00

W/m²K for the DST). Figure 7.11 summarises the U values, highlighting the areas which were carried out in Sweden but were assumed not to have been carried out by the DST.

Variable/Assumption	DST	Case Study
U Values {W/m^{2}K} prior to renovation		
Floor	0.5	
Facades	0.18	0.6
Roof	0.13	0.35
Windows	3	4
U Values {W/m^{2}K} following renovation (to C13)		
Floor	0.5	0.17
Facades	0.18	0.17
Roof	0.13	0.1
Windows	3	1.5

Figure 7.11 Summary of U Values in DST and Case Study before and after Renovation

The costs for the renovation carried out in Lysekil on the facades and roof amounted to €155,000. This is therefore the actual cost of the renovation proposed by the decision support tool under scenario C 13. Similar U values pertained in the DST and in Lysekil before and after the renovation for the facades and roof.

7.3.2. Active Measures

	Retrofittin option calculated				Energy Results			Economics
Results for the range of primary energy reduction of:	Real primary savings achieved with the options analized	Passive retrofiting applied	Reduction achieved in total heating demands	Active option	Primary E. Consumption MWh/year	Primary E. Consumption kWh/year m2	Primary E Savings MWh/year	Investment €initial(year 0)
Ref. = 0	0.0%	None	0.0%	Reference	106.1	278.5	0.0	- €
0-20%	18.3%	Add insulation on facades; medium renovation (C 9)	12.5%	Biomass	86.7	227.5	19.4	11,613.70 €
20-40%	22.1%	Add insulation on facades and roof; medium renovation (C 13)	18.0%	Biomass	82.6	216.8	23.5	15,921.43 €
40-60%	57.9%	Add insulation on facades and roof; medium renovation (C 13)	18.0%	STES 40 SF	44.7	117.3	61.4	196,062.17 €
60-80%	71.8%	Add insulation on facades and roof; medium renovation (C 13)	18.0%	STES 60 SF	29.9	78.4	76.2	309,534.62 €
>80%	0	Not possible	0	Not possible	106.1	278.5	0.0	- €

Figure 7.12 Results for other retrofitting measures

In Lysekil, the solar installation achieved a solar fraction of 39 %, with an overall reduction in energy consumption of 68%.

The solar fraction proposed by the software tool of 60% does not match that actually achieved in the installation in Sweden. It would therefore be inappropriate to use this case for a comparison.

The closest approximation of the savings actually achieved are for a targeted primary energy reduction of 40% to 60%. In this case the primary energy savings achieved were 57.9% for a C13 grade medium renovation and a STES designed to achieve a solar fraction of 40%. This led to an overall primary energy reduction of 61.4MWh, at a cost of €196,062. The actual costs of the 68% energy reduction achieved in Lysekil were €155,000 for the passive energy retrofit measures and €56,000 for the solar installation including the seasonal thermal energy store, giving a grand total of €211,000.

So, at a high level, there is good agreement between the predicted overall energy savings (in percentage terms) envisaged by the decision support tool and those actually achieved in practice and also in the associated costs of achieving the energy reduction.

In order to fully validate the decision support tool, a further level of detail is required and the effect of the passive measures and active measures need to be more fully investigated. This is achieved by analysing data not available to the public via the decision support tool front-end.

7.4. Stage II Validation: Financial

7.4.1. Passive measures

The cost of the passive measures carried out in Lysekil on the roof and facades amounted to €155,000. The decision support tool proposes €9,721 as the cost for the same measures. Further analysis was carried out to determine the reason for the difference.

Cost per renovation measure (€/m2)			**DST**		**Case Study**
Floor			44.2		513
Facades			38.7		300
Roof			57.27		250
Windows			230		N/A

Figure 7.10 cost comparison of passive measures

Figure 7.10 above shows the cost per m^2 which the decision support tool uses as the basis for the calculations along with the actual figures for the renovations carried out in Sweden. Figures for the costs were obtained from IDAE (The Institute for Diversification and Energy Saving in Spain).

The cost used had two parts: material (insulation) cost and labour and other "small material". The insulation material cost is based on the prices of mineral-wool depending on density and thickness. As insulation, mineral wool with a density of 50kg/m3 was selected. The thickness to be added was specified in each simulation. In the case of the C13 renovation 150 mm of mineral wool was assumed by the decision support tool, while 170 mm of rockwool was used for the renovation itself. In both cases the U values achieved were similar.

The second part of the cost (labour and other small material) was obtained from IDAE: Guía Técnica para la Rehabilitación de la Envolvente Térmica de Edificios. Soluciones de Aislamiento con Lan Mineral (English translation: Thermal Retrofitting Technical Guide. Solutions for Mineral Wool Retrofitting). This was fixed as 12.55€/m2 + 9,53€/m2, including all the other costs apart from insulation.

Looking at the cost for the renovation which was carried out in Sweden, roughly the same thickness of insulation as was assumed in the model (170mm Vs 150mm) was applied externally, which involves the installation of vertical and horizontal beams, an airtightness layer, wind proofing layer and externally applied wooden finish.

The labour costs in the IDAE report do seem low (unfortunately especially when compared with Scandinavian rates), but perhaps the largest source of the discrepancy is the use of external insulation by Scandinavian homes compared with the assumed internal insulation in the case of the model. The use of external insulation was warranted in case of the retrofit as the external cladding needed to be replaced, and there was a desire to retain the internal wall finishes for aesthetic reasons.

It is recommended that in a future version of the DST that in addition to providing default values, the option of applying external or internal insulation is provided. Further, it would be useful to allow the input of labour and materials as cost variables. This would allow flexibility in terms of any specific requirements which may pertain for the particular building.

7.4.2. Active measures

The cost of the solar thermal installation including the seasonal thermal energy store was €56,000 in Lysekil.

The decision support tool allocates €186,341 for the solar DHW and space heating system (including STES). In order to compare the costs, it is necessary to examine the active system proposed by the decision support tool, which is based on the tool developed for the solar District heating project and is available from http://www.sdh-online.solites.de/Tool/2#.

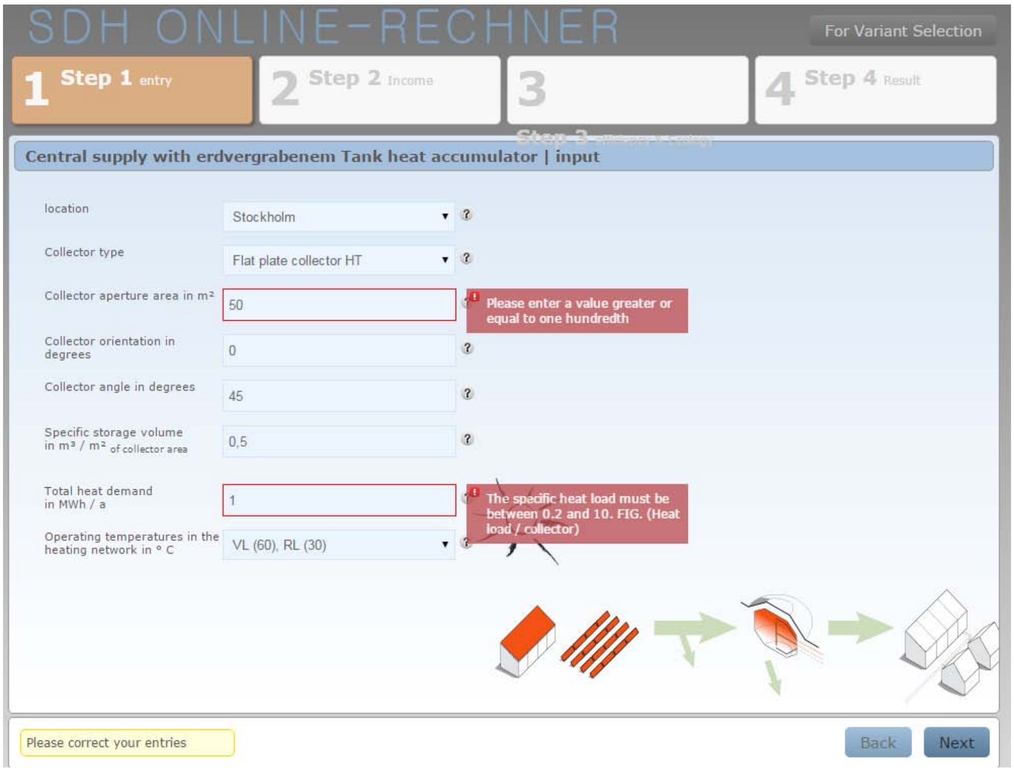


Figure 7.11 SDH online tool with Lysekil parameters.

As can be seen from figure 7.11, it is not possible to have a solar panel of less than 100 m², and when the collector area is increased to 100 m², the errors were encountered when trying to input 0.25 for the specific storage volume (reflecting 25 m³) and 0.5 for the total specific heat demand per annum (representing 50 MWh).

Investigating further, it is clear that the solar District heating design tool is not dimensioned to cater for the small multi-unit development in Lysekil. In the decision support tool the STES volume chosen was 399 m³ and the solar panels had an aperture area of 150.3 m².

Thus, it is seen that the Lysekil site does not match the conditions for which the decision support tool was constructed with respect to the active system. For this reason it is not possible to use the figures gathered from the site in Lysekil for the performance of the solar collectors, Diurnal tank and seasonal thermal energy storage tank, making a detailed analysis (using the 10 minute interval data) impossible due to the significant differences in the heating systems.

7.5. Stage II Validation: Energy

Figure 7.12 shows that while the demand for DHW & space heating energy prior to the passive renovation recorded for the premises in Lysekil exceeds that assumed by the decision support tool by 20 MWh, the recorded space heating demand of building one following renovation closely matches that predicted by the decision support tool. The lower space heating reduction predicted is due to the higher levels of refurbishment performed compared with that assumed by the decision support tool.

Variable/Assumption	DST	Case Study
Heat Demand before renovtn MWh	61.6	81.96
Space heating reduction (Passive retrofit)	20.30%	51.50%
Space Heat demand MWh (After renovation)	43.52	42.276
DHW Consumption (MWh)	7.04Mwh	7.4
Solar Fraction {%}	42	48.1
Fuel	Gas	District Htg
Fuel needed (MWh)	35.8	32.19
Solar (MWh)	20.2	23.898
Electricity (MWh)	2.1	0.989
Prim Energy conv (DH)	0.7	0.08
Prim Energy conv (Electricity)	2.56	2.4
Prim energy	44.7	4.9488

Figure 7.12 Energy related parameter comparison

There is very good agreement on the domestic hot water consumption, when the DHW demand of building one and building two are combined. (The DST model assumes a multiunit development of eight apartments, which is most closely approximated by the combined DHW load of building one and building two).

Thus when the decision support tool is calculating the fuel needed (assuming gas is used), a figure of 35.8 MWh is arrived at, while 32.2 MWh is provided by the district heating system in Lysekil

Allowing for the relatively small amount of electrical energy, using the primary energy conversion factors in the DST and provided by the energy provider in Lysekil, the primary energy consumed is seen to be 44.7 MWh in the case of the decision support tool and 4.95 MWh in the case of the actual installation.

Thus, despite relatively good agreement in the energy consumption for space heating and DHW and the solar fractions, the primary energy consumed is significantly different. This is due to the exceptionally low and atypical

primary energy conversion factor in Lysekil. Unfortunately, as a result, further comparison based on the primary energy saving per meter squared et cetera is not possible.

7.6. Stage III validation

Having carried out the stage I validation (i.e. at the user level), the stage II validation was preceded to and a parametric analysis was carried out. This identified that:

1. The specific building did not have a retrofitting scenario which matched sufficiently to the before and after situation which described the case study site in Lysekil. Therefore it was not appropriate to carry out the stage III validation at the detailed data level.
2. The relatively large district heating based solar thermal system (including STES) used in the DST was totally different in topology compared with the solar thermal system in Lysekil, again rendering detailed data level analysis impossible.

8. Summary and conclusions

The EINSTEIN decision support tool is designed to provide high level analysis and assist decision makers in assessing the viability of building retrofit and solar thermal systems including STES in four geographic regions in Europe.

This task used the specific case study of the development in Lysekil to validate the decision support tool. Extensive monitoring has been carried out and data is available on the district heating, solar, and electrical space heating and domestic hot water energy consumption in the renovated building (and the new building).

The validation of the software tool took place at successively deeper levels in order to fully validate the inputs and outputs of the model. As the analysis went deeper, differences between the DST assumptions and the actual development became more significant, and it was not possible to proceed to stage III of the validation which is the detailed validation stage.

In summary, in comparing the output of the decision support tool with the actual case study in Lysekil, the following factors impacted on the validation:

- Given that the passive and active renovation measures were carried out in advance of the development of the decision support tool, it was necessary to choose the DST options which most closely matched those implemented in Lysekil.
- The specific scenarios which were considered included the DST C13 renovation measures which assumed a subset of the actual renovation measures which were carried out on the building.
- The solar array in Sweden supplies heat not only to the renovated building, but also to another separate building. In addition, the seasonal thermal energy store supplies heat only to the new building. Of course, it is not possible to replicate this detailed configuration in the DST, and in the analysis allowances were made for this difference (e.g. w.r.t. the treatment of DHW consumption). However, it is recognised that this impinged on the ability to validate fully the energy consumption in task 2.5.
- The solar thermal installation in Lysekil is significantly below the size of that assumed by the decision support tool. Thus it is not possible to replicate the small multiunit development in the DST.

- The district heating system in Lysekil provides heat which is a byproduct of the oil refinery which is adjacent to the town. Thus the primary energy conversion factor is atypically low at 0.08, significantly affecting the primary energy consumption figures.

Despite the factors identified above, a considerable amount of analysis and validation was possible and was carried out.

It was found that at the user interface level, there is good agreement between the DST and the case study both in terms of energy and costs. The proposed optimal combination of passive and active measures closely matched the cost and the impact for the actual renovation.

At a deeper level, good agreement was found in the assumed U values of the salient renovation measures for both the before and after values. There was also good agreement on the heat demand figures both for domestic hot water and space heating and, there is good agreement in the impact of the solar system on the energy consumption figures (based on the solar fractions).

A finding of the validation is that the renovation costs assumed in the decision support tool appear to be atypically low, and could ideally take account of labour rate and material cost differences in the various locations modelled. It is recommended that when the tool is being upgraded that regional prices are used and a facility to override the assumed costs is provided to the user.

Another finding of the validation is that the cost associated with the solar system and seasonal thermal energy store was different to that recorded for the actual installation. This is a result of the assumed larger solar/STES system inherent in a district heating network. Again it highlights that there is an opportunity to improve the accuracy of the model by allowing the costs to be input as a variable. It is noted that energy calculations are not affected by this difference, as they are performed based on an assumed solar fraction.

In conclusion, the DST recommendations closely matched those of the case study in Lysekil, Sweden. A complete validation of the decision support tool was not possible due to the fundamental differences between the specific building (both in terms of energy retrofit measures and energy supply infrastructure) and the assumptions inherent in the DST. It is recognised that this is not a “fault” with the decision support tool, but rather highlights that there are specific idiosyncrasies in the Lysekil development which it would not be reasonable to expect a decision support tool to be able to replicate, given its objective of providing a high level tool to assist with decision-making. It is recommended that the DST could be improved in the specific area of costs for passive renovations.

Appendix Financial analysis

a. Overview - Life Cycle Cost and Savings Analysis

In order to validate the decision support tool (see later), a Life Cycle Cost (LCC) analysis using the time value of money was carried out over a 40 year period for the Solar and STES system. Life-cycle cost analysis is a tool to determine the most cost-effective option among different competing alternatives for a project, when each is equally appropriate to be implemented on technical grounds. All the costs are usually discounted and totalled to a present day value known as net present value (NPV) using a discount factor d, which bring the individual future values of money to their present day value .

A 40 year period has been chosen for the financial analysis given the significant capital investment costs required for the seasonal thermal energy store and the long service life of the STES. The investment in a STES is not expected to pay back in a short timeframe, but rather is assumed to be part of the energy infrastructure of the dwelling in the same way as appropriate orientation and insulation.

The analysis does not take into consideration the cost of financing the investment, tax incentives or annual corporate tax treatments. Emphasis is given in the life cycle analysis to the service life of the components.

b. Expected Life of the Equipment

Given that solar thermal is a mature technology, the various components carry long warranties and it is anticipated that with minimal intervention, systems will continue to operate for 15 to 40 years.

In this analysis, the cost has been allocated for scheduled maintenance (mtce) of the system every six years, in line with the maintenance schedule carried out at the installation, and it is assumed that the solar thermal system will continue to operate for 20 years without further capital investment.

Unless otherwise stated, the analysis has assumed that the value of all equipment at the end of the 20 year period is zero. This leads to the "worst-case scenario" for the financial analysis, and the approach has been to adopt this conservative financial modelling throughout the analysis.

However, while this is a reasonable assumption in the case of the DHW and space heating systems, considerable value can still be attributed to a DHW tank or a STES at the end of the 20 year period. In the case for the installation in Lysekil, the seasonal thermal energy storage tank was purchased second-hand, at a considerable discount compared with the purchase of a similar tank new.

For this reason, it is assumed that the STES tank will also require replacement at the same time as the complete system was overhauled as a cost the same as was initially incurred. In addition, in order to reduce complications

in the analysis it is assumed that the Combi system will also be required to be replaced the 20 year period. The approach of replacing all equipment 20 year period is considered a prudent but conservative financial approach.

c. Capital costs

The capital costs in the life cycle analysis are those of the Lysekil installation already outlined in figure 6.3.

In the analysis it is assumed that the capital costs of the district heating system is zero as an district heating space heating system is necessary in order to provide backup for the solar installation in respect of both space heating and DHW. Thus the capital costs of the installed district heating system are eliminated from the solar and district heating cost analyses. In addition, it is assumed in the analysis that an existing HRV System and underfloor heating system is available as a heat delivery mechanism and an extra heat transport mechanism is thus not required.

d. Operational Costs

It is assumed that a maintenance check is carried out and a glycol solution is added to the water in the solar circuit every six years. It is assumed that this costs €150 (at today's prices).

In order to estimate the costs involved in an overhaul of the system, a cost equivalent to the full system cost of the DHW and HRV System, including replacement of the solar panels, combisystem tank and STES tank is allocated to year 20, and multiplied by the appropriate inflation conversion and Net Present Value (NPV) factors, resulting in a cost allocation of €37,652 in year 20. Thereafter, the six yearly maintenance interval continues to be scheduled, with the first scheduled maintenance intervention occurring six years after system overhaul.

In analysing the costs associated with the solar heating system, the annual running costs in addition to the capital costs (which have already been considered) must be included.

From measurements conducted at the site, it is known that the underfloor/HRV System heating pump used in building one consumes 155kWh of electricity during the period of operation considered. The underfloor/HRV system heating pump in building two consumed 78 kWh of electricity when distributing heat from the district heating/solar system of building one, and 17 kWh when distributing heat from the STES located in the basement of building two.

When compared with the 60839 kWh of energy consumed in heating building one and two over the period, it is seen that the pump operation costs are negligible. Note that the main solar circulation pump was replaced in 2015 for a modern EC moter equipped low-energy pump of much highrt capacity.

In addition, the 5050 kWh electricity used for space heating and DHW heating is also relatively minor, representing less than a 10th of the overall energy consumption.

Nonetheless, the energy costs of electricity are considered separately from the energy costs of the district heating, and are considered in the overall financial analysis.

e. Treatment of the time value of money

The Life Cycle Cost and Savings analysis has been carried out with a number of different financial variables;

Annual Discount Rate d = 3%

This is based on the required IRR (Internal Rate of Return) within the company concerned at the time of the analysis.

Annual Rate of Inflation i = 3%,

This reflects the low average rates of inflation experience in Europe the last 15 years

Annual Rate of Electricity Inflation i_e = 7%

This reflects the 11 year average rate of electricity inflation in a European country (Ireland) calculated using the eurocent Unit price of Domestic Electricity in Mar 2002 at 10.71c (source ESB bills) and in March 2014 at 19.28c (source ESB). This represents an increase of 8.57c, or 80.01% in 11 years, equivalent to 8.27% on an annual basis).

f. Results of financial analysis

i. Building One

Figure 8.1 below gives a graphical representation of the Net Present Value (NPV) of the cost of the DHW and space heating for building one over the 40 year period considered. The graphical representation allows the breaking point to be readily obtained.

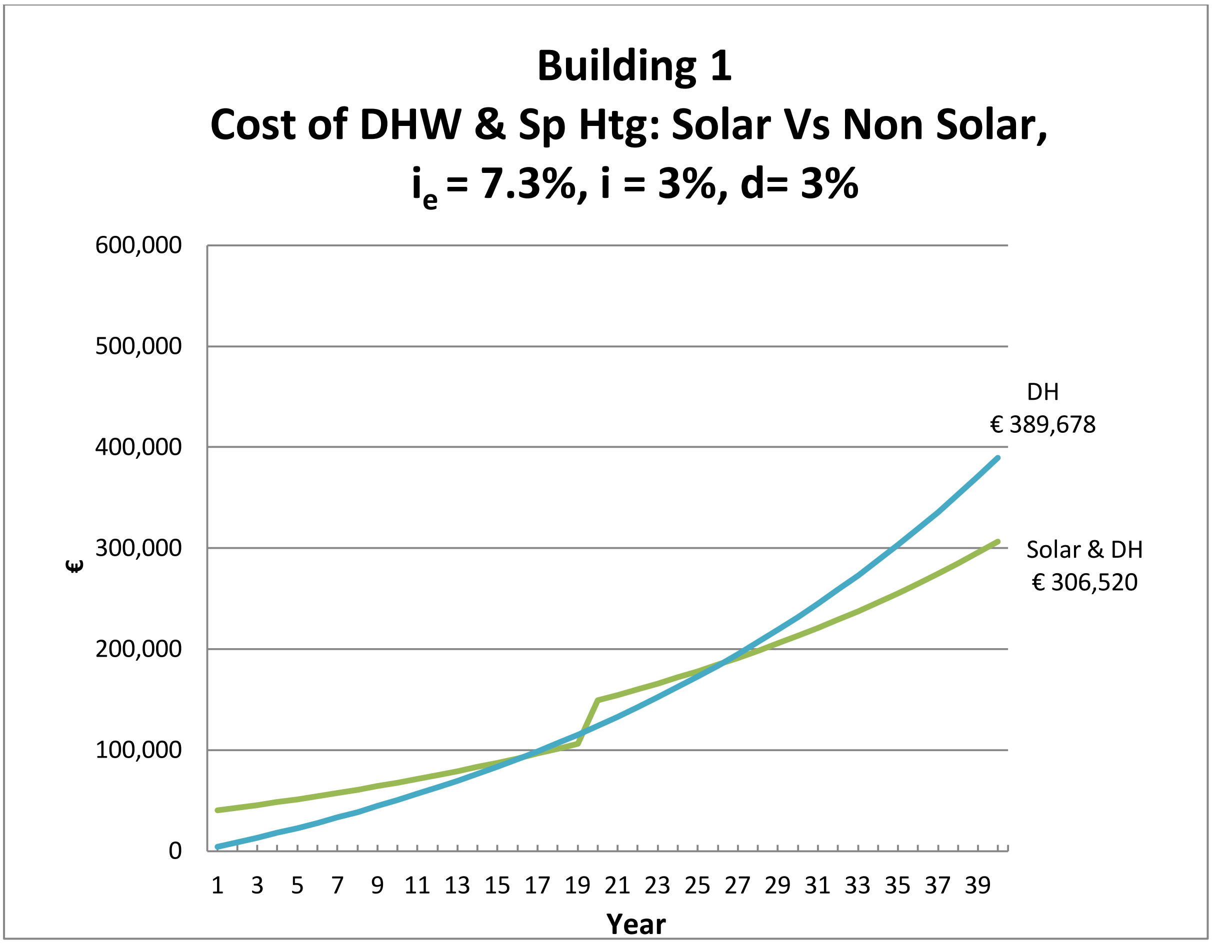


Figure 1 NPV costs for heating building one, comparing DH with solar

It shows that the overall net present value of the cost of heating building one using the district heating system option is €389,678, while the cost using the solar installation in combination with the district heating €306,520. The base case (i.e. using the district heating) clearly is least expensive initially, as no extra expenditure is required. However the NPV of the base case is €83,158 (27.1%) higher using the solar installation reflecting the higher annual running costs.

Breakeven occurs in year 16, after which the solar installation as a lower net present value than the base case. However, in year 20 it is considered that the solar equipment will have to be replaced.

Given the extra capital investment in year 20 (reflecting a replacement of all equipment), breakeven does not occur again until year 26. From year 26, the solar installation has a lower NPV compared with the base case.

It is noted that in this financial analysis, the extra cost associated with the STES is ignored given that no financial benefit will accrue in respect of heating building one. It is assumed that a heat dump will be installed at minimal cost to avoid problems associated stagnation of the solar panels. Equally, it is assumed that while the solar panels and combi system have been designed to provide heat to building one and building two, in this analysis, the extra solar heat provided to building two has not been considered a benefit. Thus while the costs are reduced (due to the exclusion of the STES), similarly the benefits of the large solar array are also reduced. The case is a necessary shortcoming of this financial analysis in respect of building one.

ii. Building two

In the same manner as the analysis conducted in respect of building one, figure 8.2 gives the net present value for space heating and DHW for the combined load of building one and building two, incorporating the cost and also the benefit of the seasonal thermal energy store.

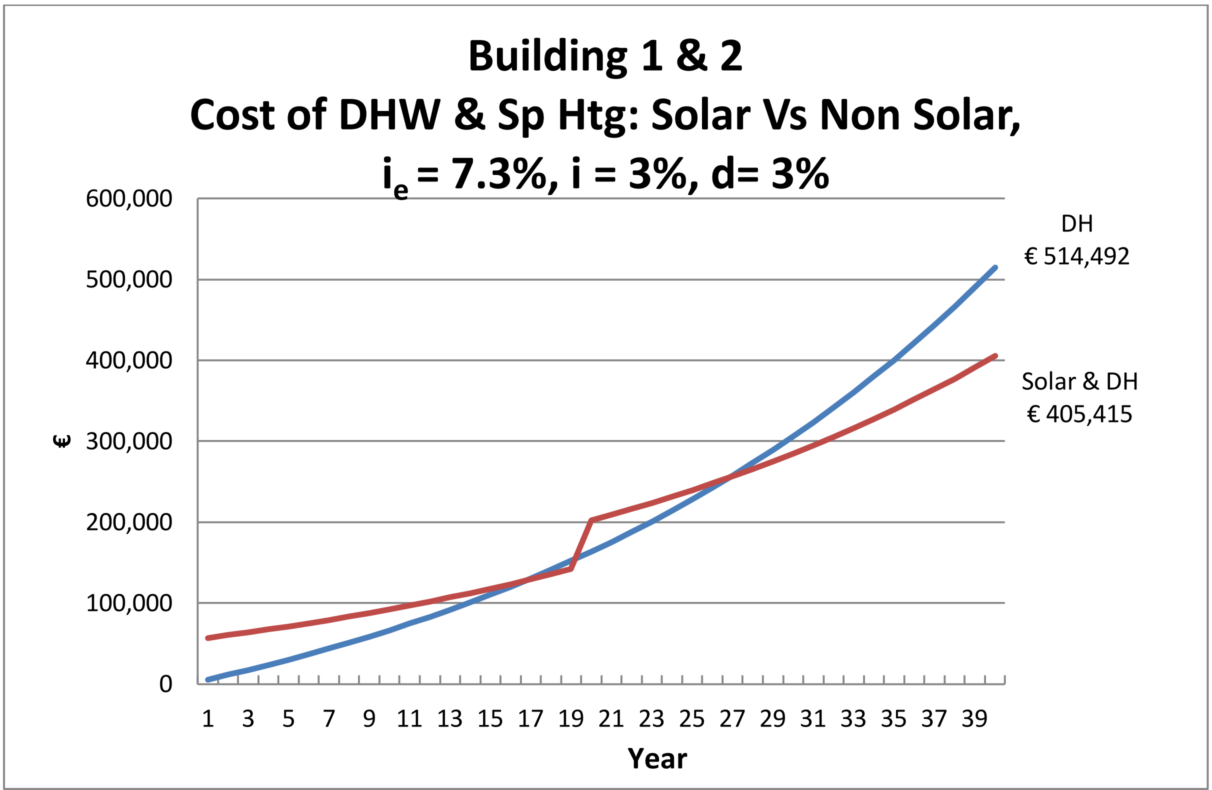


Figure 2 NPV costs for heating building one and two, comparing DH with solar

It shows that the overall net present value of the cost of heating building one and 2 using the district heating system option (in combination with electric space heating) is €514,492, while the cost using the solar installation in combination with the district heating €405,415. It is noted that the extra cost of heating building one and two over just heating building one with the solar option is only €98895 (32%), compared with €124,814 (again 32%) in the case of the DH option.

While the base case (i.e. using the district heating for building one and two) clearly is least expensive initially, the NPV of the base case is €109,077 (27%) higher than the NPV for using the solar installation.

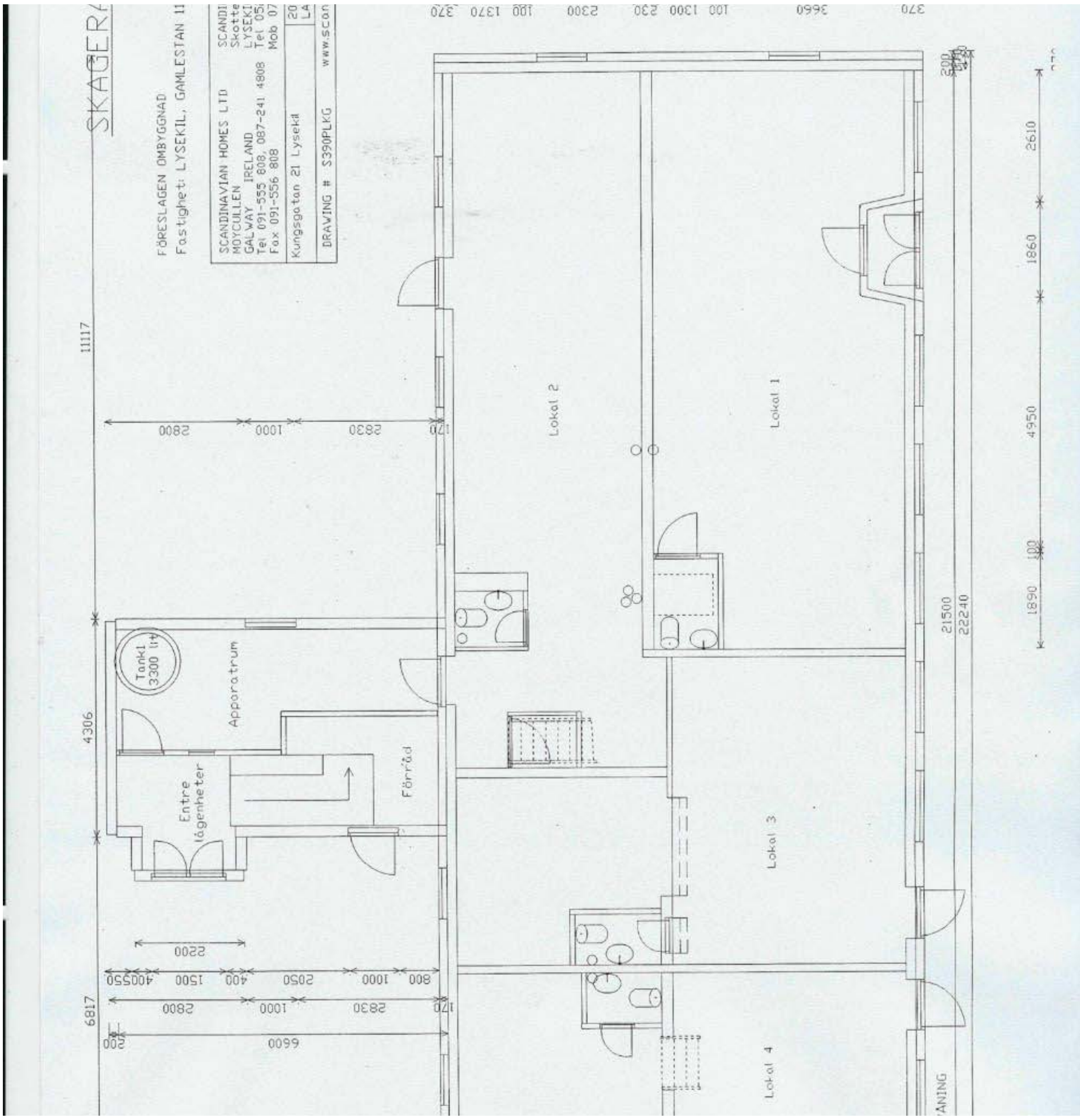
Breakeven occurs in year 17, (reflecting the extra cost associated with the installation of the STES) after which the solar installation has a lower net present value than the base case. Given the extra capital investment in year 20 (reflecting a replacement of all equipment), breakeven occurs again in year 27 after which the solar installation has a lower NPV compared with the base case.

Coincidentally the solar option provides a 27% saving for building one (ignoring the STES) and a 27% saving for building one and two (incorporating the STES)

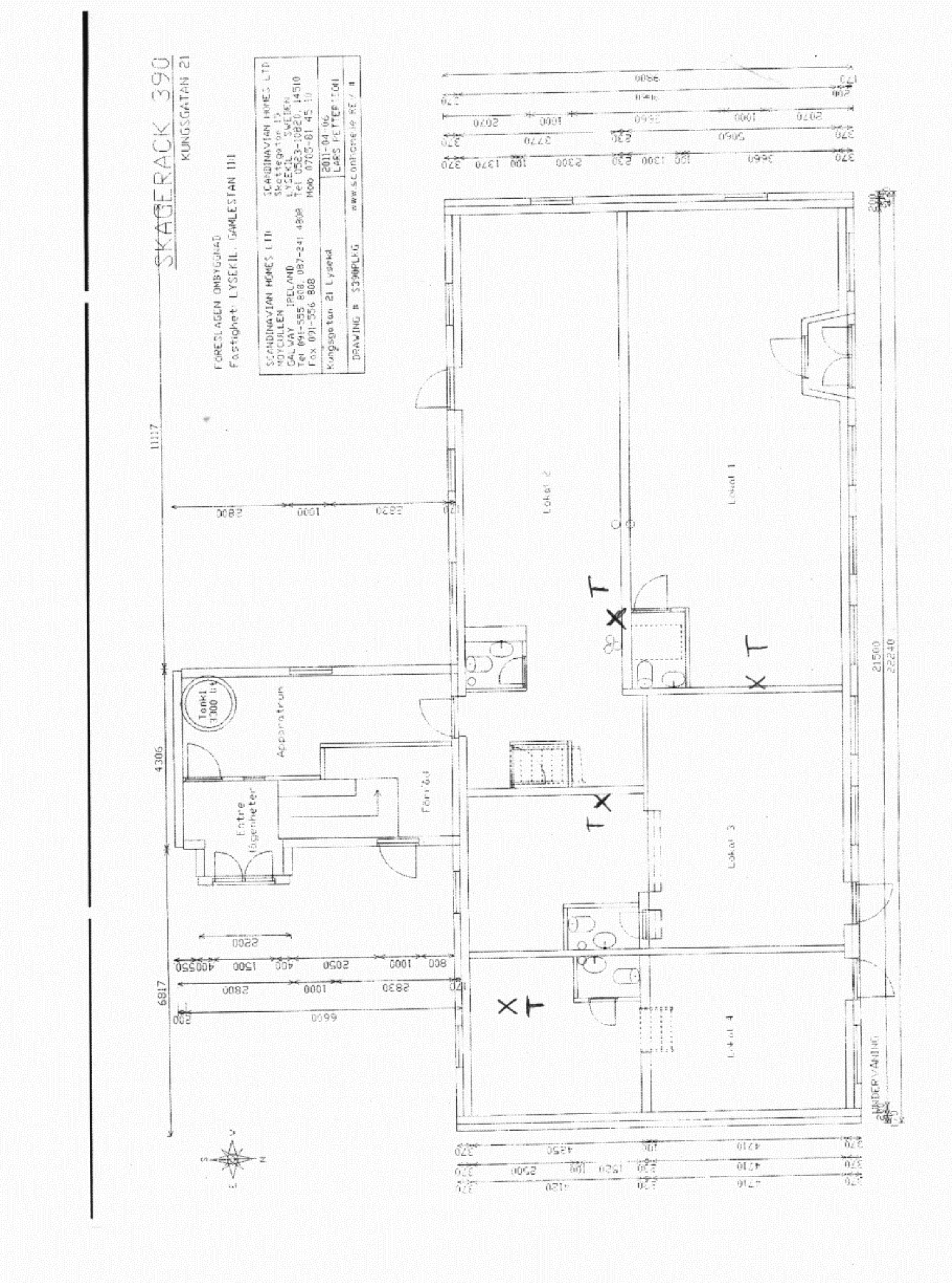
Description

	Checked & FOK on 04/01/2013	Type	Omega Product	DT85 Channel	Description	Notes
ure/F=Flow/E=Electric)						
lar Fluid/Room)						
low, Rtn= Return, Buf=Buffer tank						
	y	In flow PT100	P1-M-A-6-60-M10-P-5	DT1 Ch 3	Solar Fluid Flow at equipment room	Solar fluid Flow in
	y	In flow PT100	P1-M-A-6-60-M10-P-5	DT1 Ch 4	solar fluid return at equipment room	Solar fluid Return i
	y	Surface RTD	SA1-RTD-4W-120	DT1 Ch 5	Solar Fluid Flow at equipment room	Back-up solar fluid
	y	Surface RTD	SA1-RTD-4W-120	DT1 Ch 6	solar fluid return at equipment room	back-up solar fluid
	y	Probe PT100	P1-M-A-6-60-M10-P-5	DT1 Ch 7	Top of buffer tank (2.8 m height)	
	y	Probe PT100	P1-M-A-6-60-M10-P-5	DT1 Ch 8	Middle of buffer tank (2.16m height)	
	y	Probe PT100	P1-M-A-6-60-M10-P-5	DT1 Ch 9	Bottom of buffer tank (0.43m height)	
	y	Surface RTD	SA1-RTD-4W-120	DT1 Ch 11	DHW - temperature supplied to Buffer Tank	Surface sensor loca
	y	Surface RTD	SA1-RTD-4W-120	DT1 Ch 13	DHW - temperature supplied from Buffer Tank	Temp of DHW fron
	y	Surface RTD	SA1-RTD-4W-120	DT1 Ch 14	DHW - Temperature supplied to house after DH input	
	y	Surface RTD	SA1-RTD-4W-120	DT2 Ch TBC	Space Heating O/p from Buffer Tank - Flow Temp	
	y	Surface RTD	SA1-RTD-4W-120	DT2 Ch TBC	Space Heating O/p from Buffer Tank - Return Temp	
	y	Surface RTD	SA1-RTD-4W-120	DT2 Ch TBC	District Heating (DH) Flow Temperature	Surface RTD
	y	Surface RTD	SA1-RTD-4W-120	DT2 Ch TBC	District Heating (DH) Return Temperature	Surface RTD
	y	Wall Mount Temp	EWS-RTD	DT1 Ch 113	Temp apartment 1	Requires a power s
	y	Wall Mount Temp	EWS-RTD	DT1 Ch 111	Temp App2	Requires a power s
	y	Wall Mount Temp	EWS-RTD	DT1 Ch 104	Room temperature Lars Office	Requires a power s
	y	Wall Mount Temp	EWS-RTD	DT1 Ch 109	Room temperature shop 2	Requires a power s
	y	Wall Mount Temp	EWS-RTD	DT1 Ch 105	Temp Shop 3	Requires a power s
	y	Wall Mount Temp	EWS-RTD	DT1 Ch 110	Temp Shop 4	Requires a power s
	y	RTD Air Temp	RTD-805	DT1 Ch 106	External Air 1	Requires to be mo
	y	RTD Air Temp	RTD-805	DT1 Ch 107	External Air 2	Requires to be mo
	n	Probe PT100	HSRTD-3-100-A-5M	DT1 Ch 108	Soil Temp location 1	**Connection proble**
	y	Flowmeter	Steca TA VM1	DT1 Counter 1	Tank 1 flowmeter (buffer tank)	Solar fluid flow to
	y	Flowmeter	Steca TA VM1	DT1 Counter 2	Tank 2 flowmeter (buffer tank)	Solar fluid flow to
	y	Flowmeter	Steca TA VM1	DT1 Counter 3	STES flowmeter	Solar Fluid flow to
	y	Flowmeter	Steca TA VM1	DT1 Counter 4	Domestic hot water flowmeter	DHW consumption
	y	Flowmeter	Steca TA VM2	DT2 Counter TBC		
	y	Flowmeter	Steca TA VM3	DT2 Counter TBC		
	y	Flowmeter	Steca TA VM4	DT2 Counter TBC		
	n	El power consumption	Landis	DT1 Counter 5	Electricity consumption of solar pump	**Connection proble**
	y	El power consumption	Landis	DT1 Counter 6	El of Pump for HRV and wet underfloor & rads	
	n	El power consumption	Landis	Indept counter	Electricity consumption of apt 1 u/f: not connecte toDT	
	n	El power consumption	Landis	Indept counter	Electricity consumption of apt 2 u/f: not connected to DT	
n from District Heating	y	Open collector output	N/A	DT 2 Ch TBC	Counter recording kWh from DH each 5 mins	
operational following installation of Seasonal Energy Store						
		Probe PT100	*TBC - HSRTD-3-100-A-5M*	*DT 2 Ch TBC*	*Tank 3 Bottom Temp location 1*	
		Probe PT100	*TBC - HSRTD-3-100-A-5M*	*DT 2 Ch TBC*	*Tank 3 Bottom Temp location 2*	
		Probe PT100	*TBC - HSRTD-3-100-A-5M*	*DT 2 Ch TBC*	*Tank 3 Bottom Temp location 3*	
		Probe PT100	*TBC - HSRTD-3-100-A-5M*	*DT 2 Ch TBC*	*Tank 3 Middle Temp location 1*	
		Probe PT100	*TBC - HSRTD-3-100-A-5M*	*DT 2 Ch TBC*	*Tank 3 Middle Temp location 2*	
		Probe PT100	*TBC - HSRTD-3-100-A-5M*	*DT 2 Ch TBC*	*Tank 3 Middle Temp location 3*	
		Probe PT100	*TBC - HSRTD-3-100-A-5M*	*DT 2 Ch TBC*	*Tank 3 Top Temp location 1*	
		Probe PT100	*TBC - HSRTD-3-100-A-5M*	*DT 2 Ch TBC*	*Tank 3 Top Temp location 2*	
		Probe PT100	*TBC - HSRTD-3-100-A-5M*	*DT 2 Ch TBC*	*Tank 3 Top Temp location 3*	

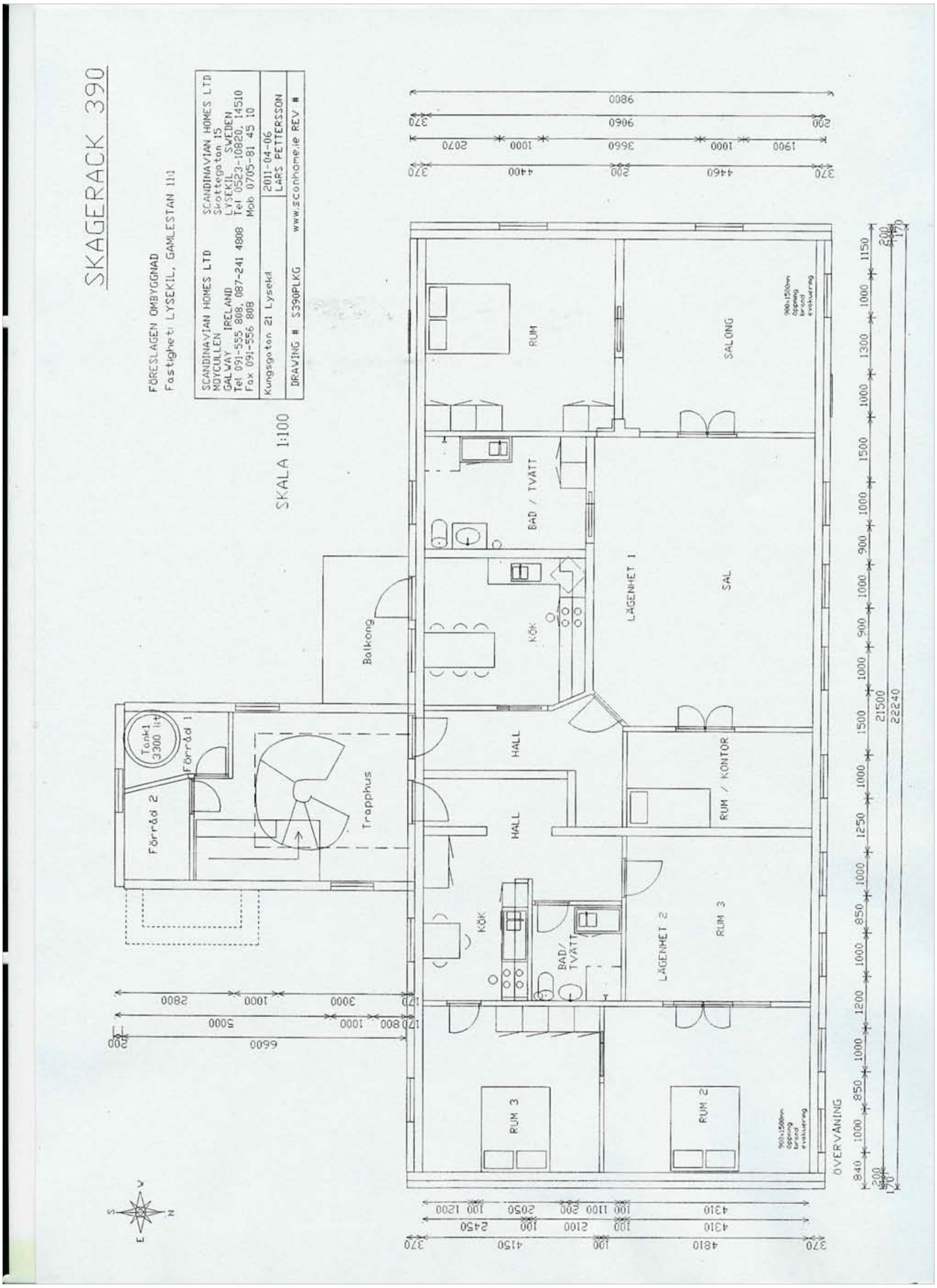
Kungsgatan, Building 1, Ground Floor Plan



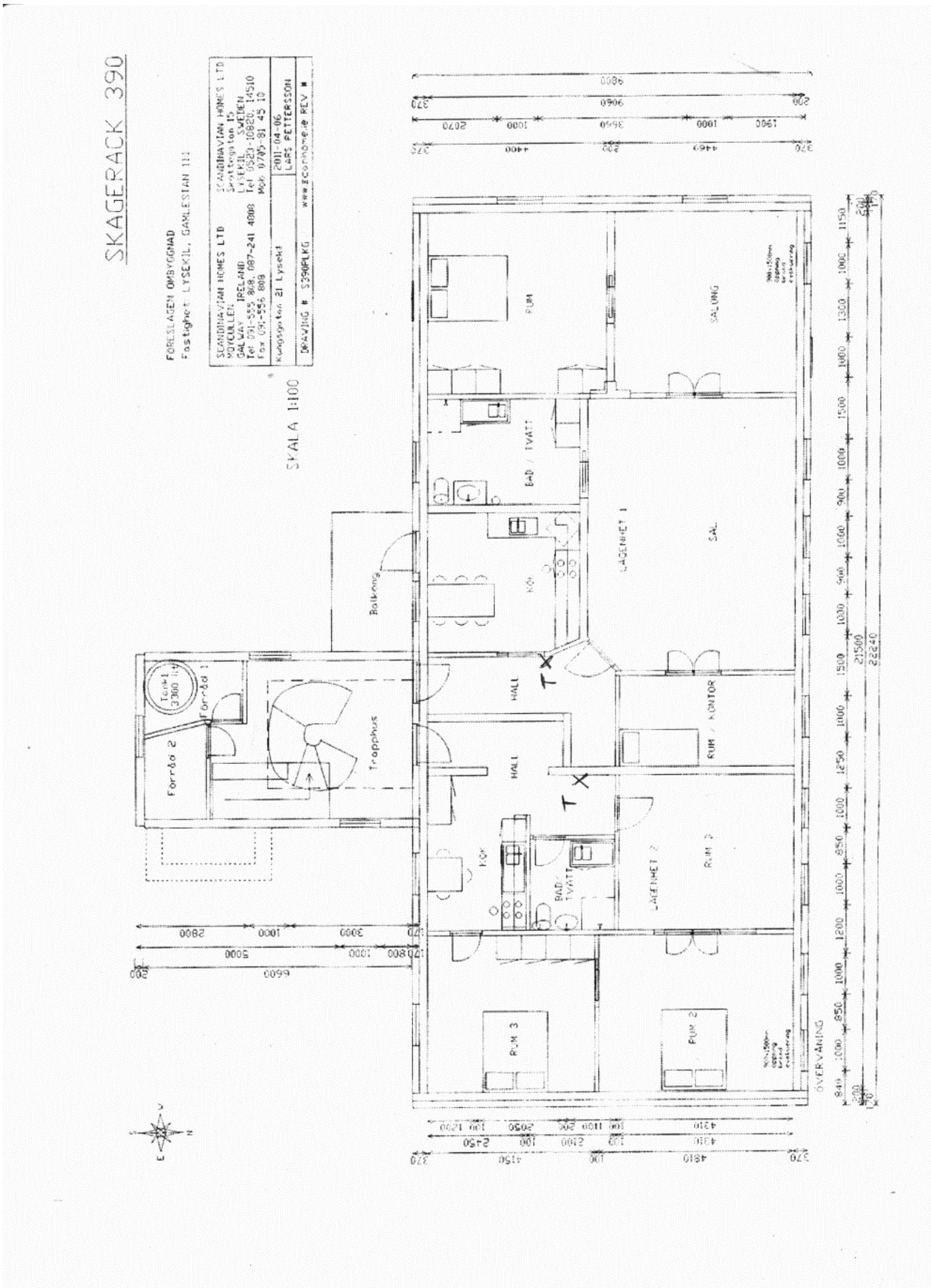
Kungsgatan, Building 1, Ground Floor Plan, showing position of Temperature sensors



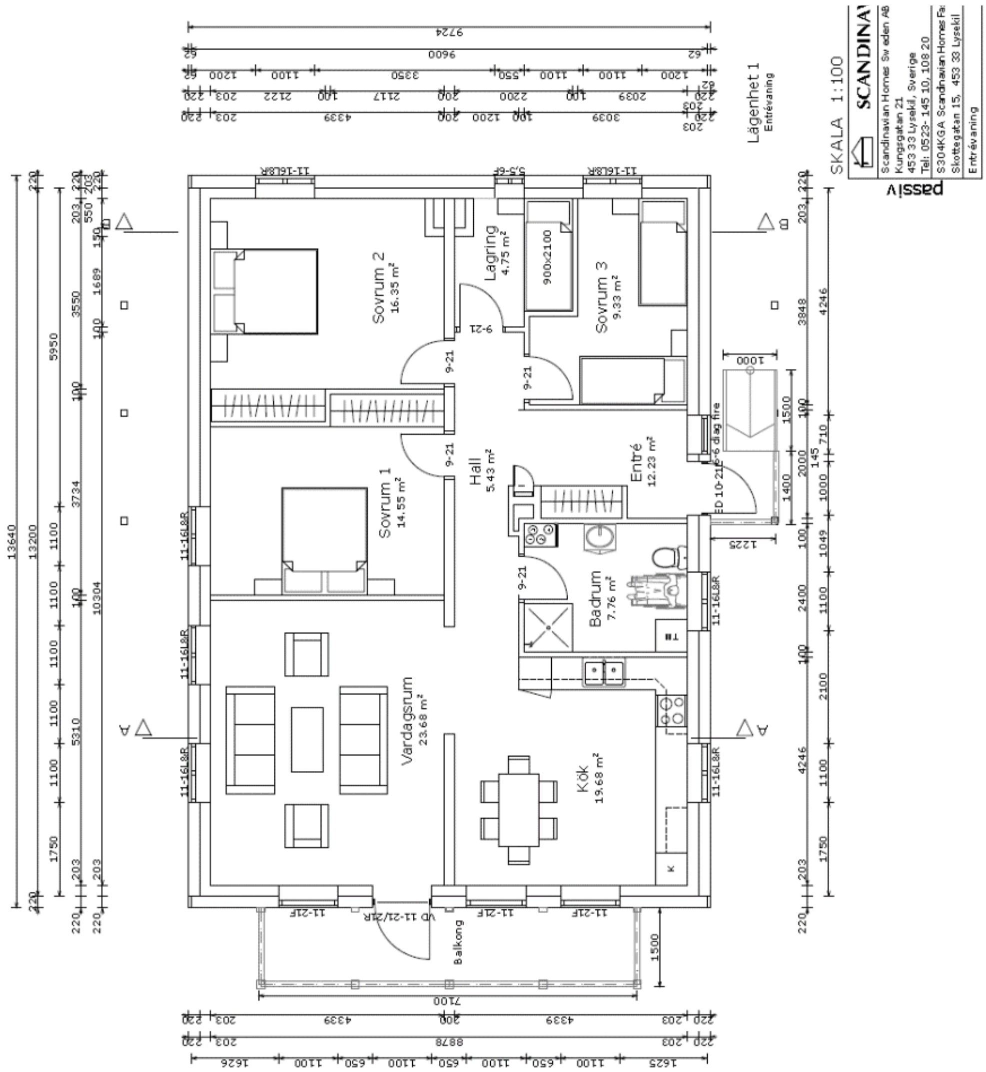
Kungsgatan, Building 1, First Floor Plan



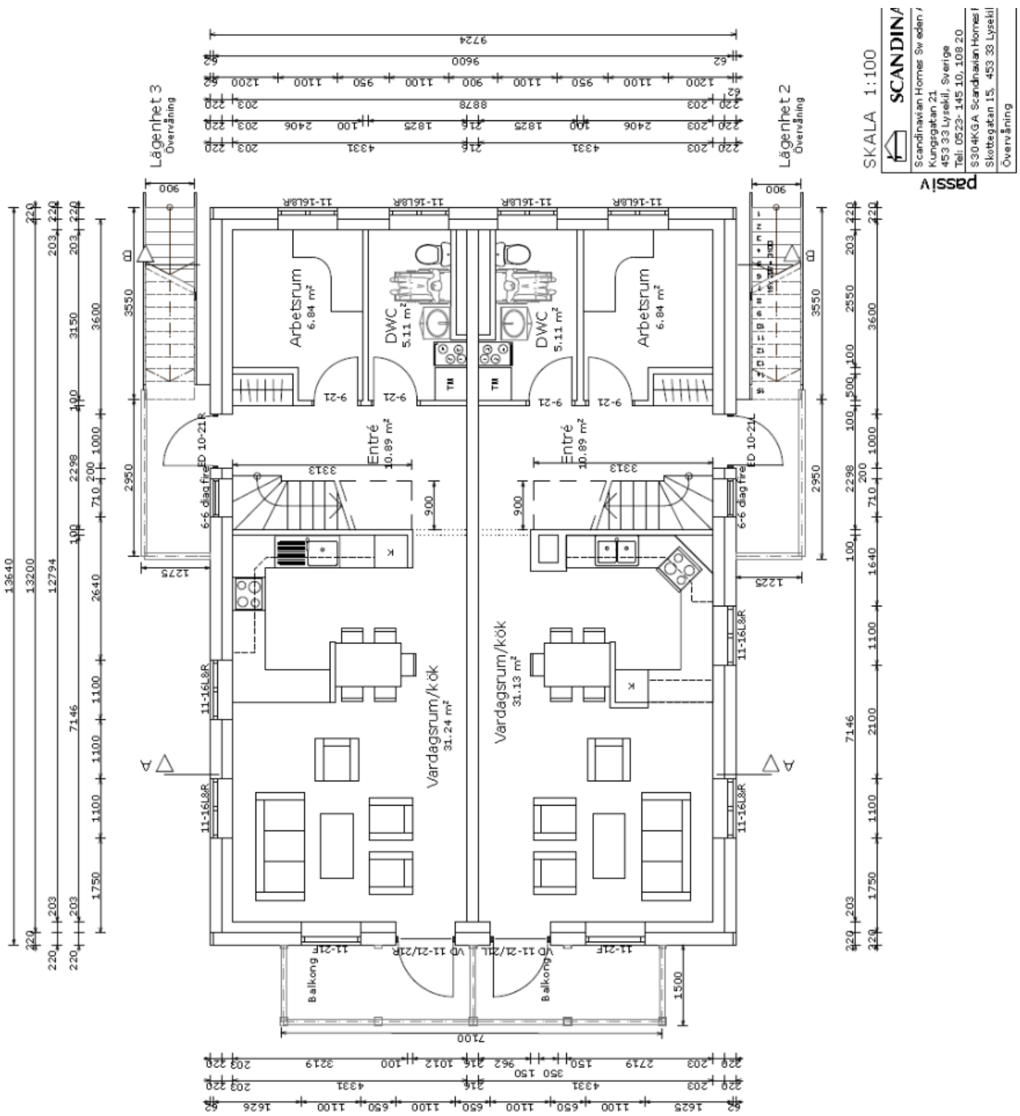
Kungsgatan, Building 1, First Floor Plan, showing position of Temperature sensors



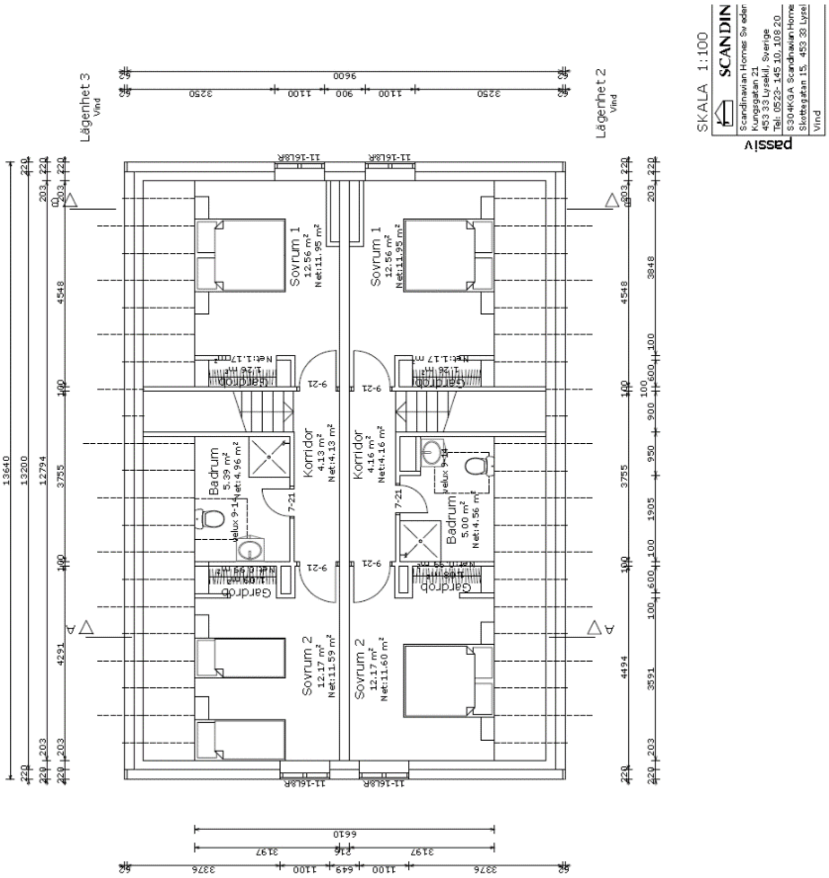
Kungsgatan, Building 2, Ground Floor Plan,



Kungsgatan, Building 2, First Floor Plan



Kungsgatan, Building 2, Second Floor Plan,


SKALA 1:100
SCANDIN
Lägenhet 3
Lägenhet 2
Sovrum 1
Sovrum 2
Korridor
Badrum
Gardrob