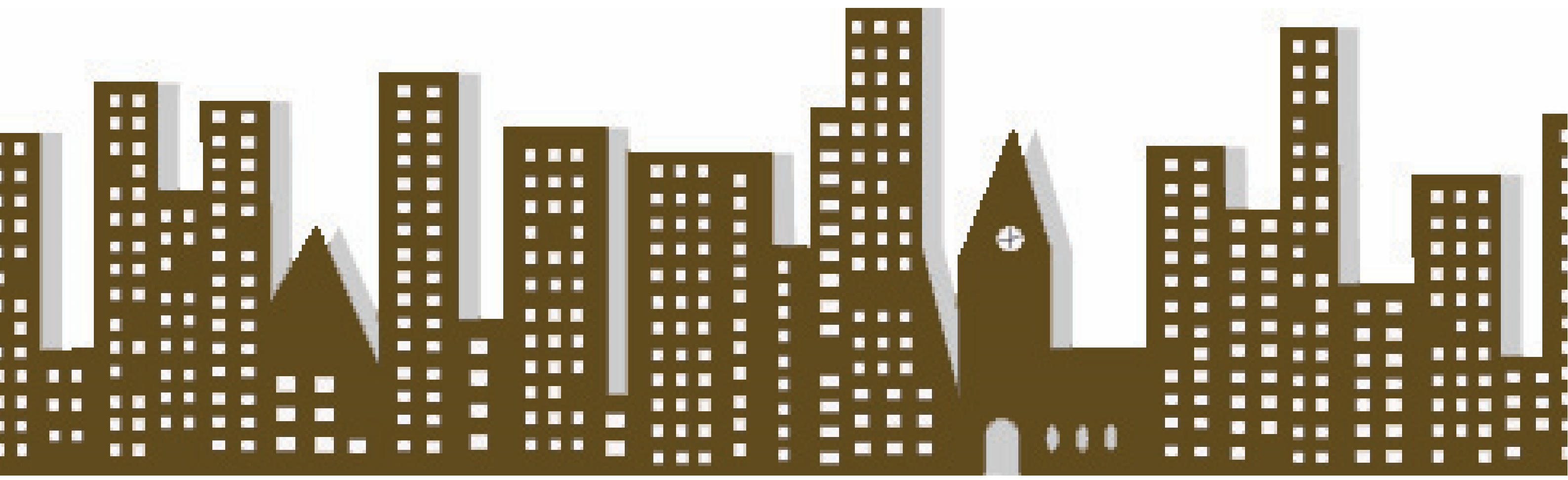
ZenN

Nearly Zero energy Neighborhoods

Improvement proposals for replication actions

D 3.4



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Executive summary

Making use of available data from monitoring carried out in D 3.3, and information regarding possible improvement actions and associated additional energy consumption reduction figures gathered during D 3.1, D 3.4 theoretically analyses the feasibility of improvement proposals. The results from D 3.4 is oriented towards safe inclusion of viable technologies developed during the course of the project.

The tables summaries improvement proposals for each building giving valuable information for replication actions. As the table shows the experiences is unique for each pilot but some common features can be seen:

- Energy reduction can be achieved by focusing on
  - Airtight building envelope
  - A high degree of insulation
  - Windows with a low U-value
  - Efficient ventilation system
  - Temperature control/thermostats
- The choice and design of the ventilation system is of great importance for the final energy consumption. A large degree of heat recovery is of importance.
- The use of PV for local energy generation on site has worked well for the pilot buildings.

Contents

List of abbreviations

BEMS	Building Energy Management System
DHW	Domestic Hot Water
EPBD	European Energy Performance of Buildings Directive
ESX	Exhaust and supply air ventilation with heat recovery
EU	European Union
FP7	EU's Seventh Framework Programme
LCC	Lice-Cycle Costs
nZEB	Nearly Zero Energy Building
PE	Primary Energy
PV	Photovoltaic
WP	Work Package

1 Introduction

In work package 3 the objective has been to study the technical solutions chosen in each case study for the four city neighbourhoods.

Deliverable D3.1 presents different retrofitting scenarios for each of the pilot buildings and chooses one scenario which presents how the final retrofitting will be done. Deliverable D3.3 presents results from the monitoring, to see how the calculated values corresponds to real life.

Making use of available data from monitoring carried out in D 3.3, and information regarding possible improvement actions and associated additional energy consumption reduction figures gathered during D 3.1, D 3.4 theoretically analyses the feasibility of improvement proposals. The results from D 3.4 is oriented towards safe inclusion of viable technologies developed during the course of the project.

2 Summary of improvement proposals from D3.1

Deliverable D3.1 gives the full overview of what technical measures the four city neighbourhoods have implemented and theoretical scenarios for what measures to implement if further energy- and emission reduction could have been achieved. This chapter gives a summary of the different scenarios for each city district.

The different scenarios are explained in short below.

Scenario 0: Current status

Scenario 1: Proposed actions

Scenario 2: Improved and implemented actions

Scenario 3: Best possible solutions

2.1 Lindängen, Malmö

Scenario 1 contains the measures described in the project proposal and allocates large resources on supplementary thermal insulation. ESX-ventilation is also a key measure in this scenario. 270 solar panels with a total capacity of 72.9 kW distributed in to the roof tops of three buildings into 15 arrays on each building with a total effective collector area of 441 m^2.

Scenario 2 is partly the result of the collaboration between Trianon and E.On, the district heating supplier. The package of measures includes low capacity exhaust air heat pumps to assist the space heating system. This approach aims at limited use of electricity and to apply heat pumps only for small temperature lifts resulting in efficient use of heat pumps and long service life of compressors. This scenario has a relatively low electricity use profile, compared to a high capacity heat pump, and a relatively high district heat use demand. The same setup for the PV installation as in scenario 1 is used in this scenario.

Scenario 3 has the lowest total purchased energy use demand. This scenario primarily aims at ESX ventilation and a heat recovery application for DHW which is not tested in this kind of application to our knowledge. In this more ambitious scenario additional (compared to S1 and S2) 240 panels solar PV panels are installed on the roof tops north of high buildings. In total the capacity is 138 kW and a total effective collector area of 833 m^2. The total yearly electricity production is estimated to 126 MWh.

summarizes measures and calculated energy use results for the different scenarios. Some measures are common for all scenarios such as the window retrofit and retrofit of pumps, fans and motors. The difference in total energy performance is only 5.3 kWh/m^2 between Scenario 1 and 2, but the use of electricity is increased considerably in Scenario 2.

Table 2.1 Summary of measures related to consumption in each scenario and related energy reduction, Lindängen

<table>
<tr><th>Measures</th><th>Scenario 1</th><th>Scenario 2</th><th>Scenario 3</th></tr>
<tr><td>Building envelope improvements</td><td>• Supplementary roof and façade insulation
• Window retrofit
Supplementary insulation measures is relatively costly</td><td colspan="2">• Window retrofit

Supplementary insulation not considered as façade is in good condition and roof insulation is relatively good and expensive to address due to used attic floor area</td></tr>
<tr><td>Heat recovery</td><td>• Central ESX ventilation
Relatively high investment cost</td><td>• Exhaust air heat pump installation – low capacity design, only for space heating</td><td>• Central ESX ventilation
• Central grey water heat recovery for DHW production

DHW measure is chosen partly due to existing high DHW use</td></tr>
<tr><td rowspan="2">Individual metering of DHW use</td><td colspan="3">Applied in all scenarios</td></tr>
<tr><td colspan="2">Saving assumed to reach 20 %</td><td>DHW use assumed to reach level of national template data</td></tr>
<tr><td rowspan="4">Fixed electrical installations</td><td colspan="3">Installing low energy light fittings in common areas</td></tr>
<tr><td colspan="3">Installing of low energy pumps and fans for ventilation, DHW circulation and heating system</td></tr>
<tr><td colspan="3">New elevator motors</td></tr>
<tr><td></td><td colspan="2">New high performing laundry machines and driers for laundry room</td></tr>
</table>

Local RES use (EPBD energy included)	63 257 kWh PV electricity kWh/year (98 % of the PV el. production)	51 614 kWh PV electricity kWh/year (80 % of the PV el.production)	89 548 kWh electricity kWh/year (71% of the PV production)
Total energy reduction (%)	49%	53%	69%
Energy performance (kWh/m² year)	81.5	76.2	49.5

Table 2.2 Energy efficency economics, Lindängen

	Scenario 0	Scenario 1	Scenario 2	Scenario 3
Investment cost [k€]		7 162	4 972	6 614
Reinvestment cost [k€]		134	125	192
Reinvestment technical life [year]		10 and 15	8, 10 and 18	10 and 15
Maintenance [€/year]		6 330	3 900	8 553
Energy use [kWh/m2, year]	161.0	81.5	76.2	49.5
Energy price (heating) [€/kWh]	0.04 (summer) 0.07 (winter)	0.04 (summer) 0.07 (winter)	0.04 (summer) 0.07 (winter)	0.04 (summer) 0.07 (winter)
Energy price (electricity) [€/kWh]	0.12	0.12	0.12	0.12
Calculation period [year]	20	20	20	20
Discount rate 1 [%]	4.0	4.0	4.0	4.0
Inflation rate [%]				
Residual value [€]				
Decommissioning [€]				
Payback time [years]		65	52	45
Total cost in present value [k€]		9 178	6 974	8 062
Total energy cost in present value [k€]	3 620	1 846	1 874	1 209

Table 2.3 Primary energy and greenhouse gas emissions for each scenario, Lindängen

	Scenario 0	Scenario 1	Scenario 2	Scenario 3
Primary energy used from energy need in building	[kWh$_p$/m^2/y]	[kWh$_p$/m^2/y]	[kWh$_p$/m^2/y]	[kWh$_p$/m^2/y]
PE Sweden	97	51	72	42
PE EU	93	50	74	43
Greenhouse gas emissions from energy need in building	[kg/ m2/y] 25	[kg/ m^2/y] 13	[kg/ m^2/y] 13	[kg/ m^2/y] 9

2.2 Eibar, Mogel

In **Scenario 1** a primary energy reduction of 55 % is achieved. Main actions are related to reduce heat losses through the building envelope applying additional isolation in facades and roofs and also upgrading the windows with a double glaze solution. The change of windows and an adequate execution of the retrofitting works also reduce the air infiltrations in the building. Scenario 1 also includes a solar thermal field for supporting the DHW consumption.

The measures in **Scenario 2** are focused on further reducing the building heat losses through the envelope by adding more isolation to the opaque surfaces (roofs, facades and ground floors) and low-e double glazing solutions in windows, along with an increment in IAQ by means of local heat recovery devices. Also an upgrade of existing individual boilers to condensing boilers with better efficiency is adopted. With this scenario an energy reduction of 66% is expected.

Once the energy demand of the district is reduced in Scenario 2, measures in **Scenario 3** are focused on new energy generation and RES systems that reduce the primary energy needs for buildings up to an 89%. This set of measures include a new district heating network with a centralized generation (Biomass boiler + Geothermal Source Heat Pump + Condensive gas boiler) plus a new photovoltaic solar field. The LCC assessment of the different scenarios indicates that Scenario 3 reduces the total energy cost in present value in nearly 19% comparing to base scenario while increasing the total cost in 34%.

Table 2.4 Summary of measures related generation in each scenario and related energy reduction, Eibar

	Type	Scenario 0 (kWh/m^2 yr)	Scenario 1 (kWh/m^2 yr)	Scenario 2 (kWh/m^2 yr)	Scenario 3 (kWh/m^2 yr)
Existing energy infrastructure connected to the building	District heating	0,0	0,0	0,0	0,1
	National electricity mix	26,3	28,9	29,3	26,0
	Natural gas boiler	95,9	36,5	23,8	0,0
	Wood pellets burner	0,0	0,0	0,0	3,9
Building on-site generation systems connected to the energy infrastructure	PV	0,0	0,0	0,0	8,3
	Solar thermal	0,0	10,4	10,7	0,0
Energy storage on-site	Heating	0,0	0,0	0,0	31,4

Table 2.5 Energy efficency economics, Eibar

	Scenario 0	Scenario 1	Scenario 2	Scenario 3
Investment cost [€]	0	1.769.500 [46]	2.237.521	3.389.754
Maintenance [€/year]				14.000
Energy use [kWh/m2, year]	122,2	65,4	53,1	26,1
Energy price (heating, cooling, electricity) [€/kWh]		Natural gas[47]: 0,05039 Electricity[48]: 0,02413 Pellets: 4,5 c€/kWh		
Calculation period [year]		30	30	30
Discount rate 1 [%]			10	10
Total cost in present value [k€]	5.220	6.858	7.272	7.874
Total energy cost in present value [k€]	5.220	5.088	5.034	4.269

Table 2.6 Primary energy and greenhouse gas emissions for each scenario, Eibar

	Scenario 0	**Scenario 1**	**Scenario 2**	**Scenario 3**
Primary energy used from energy need in building	[$kWh_p/m^2/y$]	[$kWh_p/m^2/y$]	[$kWh_p/m^2/y$]	[$kWh_p/m^2/y$]
PE Spain	100,3	45,8	34,1	10,6
PE EU	101,9	46,3	34,4	10,5
Greenhouse gas emissions from energy need in building	[$kg/ m^2/y$] 24,6	[$kg/ m^2/y$] 13,1	[$kg/ m^2/y$] 10,7	[$kg/ m^2/y$] 5,2

2.3 Arlequin 40/50, Grenoble

For Arlequin 40/50 Scenario 1 correspond to the basic standard of building retrofitting in France with external thermal insulation and ventilation optimization.

The measures in Scenario 2 are focused on further reducing the building heat losses throught :

- Air tightness with a target of performance far better than usual one in France for retrofitting,
- Correction of all detected thermal bridges related to . singular cases like parapets, balconies, rooftop equipment, and so on
- The integration of thermal regulation controlling a 2 ways valve for inddor comfort condition control in the cas of 50 Arlequin,
- Optimization of pump electric consumption either for Domestic Hot water distribution and heating distribution,
- Adapatation of the ventilation systems to warranty indoor air quality,

Scenario 3 had the ambition to reduce dramatically DHW energy consumption with heat recovery on grey waters dor the Arlequin 40, and substitution of all the windows of the Arlequin 50.

Table 2.7 Summary of measures related to consumption in each scenario and related energy reduction, Arlequin 40/50

Measures	Scenario 1		Scenario 2		Scenario 3	
	40 Arlequin	50 Arlequin	40 Arlequin	50 Arlequin	40 Arlequin	50 Arlequin
[Measure 1]	Insulation of the building envelope by outside	Insulation of the building envelope by outside	Substitution the metallic skeleton light façade by a wooden frame	Insulation of balconies and reduction of thermal bridges	Implementing an energy recovery on grey waters	Substitution of all existing windows
[Measure 2]	Substitution of windows, French	Substitution of French windows and		Regulation of the heating temperature		Single-flow CMV humidity

	windows and shutters	shutters of living room		in every housing		controlled type B
[Measure 3]	New distribution networks heating and renovation of DHW distribution	Insulation of heat networks and loop of DHW		Single-flow CMV humidity controlled type A		
[Measure 4]	Single-flow CMV humidity controlled type A	Single-flow CMV humidity controlled type B				
[Measure 5]	PV power plant of 100 kWc		PV power plant of 170 kWc		Implementing of PV systems on flat roofs of 4,4 kWc	Implementing of PV systems on flat roofs of 9,6 kWc
Total energy reduction (%)	52	44	58	47	61	51
Total energy reduction (kWh/m² year)	91 (Except electricity)	76 (Except electricity)	102 (Except electricity)	84 (Except electricity)	110 (Except electricity)	90 (Except electricity)

Table 2.8 Summary of measures related generation in each scenario and related energy reduction, Arlequin

	Type	Scenario 0 (MWh)	Scenario 1 (MWh)	Scenario 2 (MWh)	Scenario 3 (MWh)
Existing energy infrastructure connected to the building	District heating	3 432	1 645	1 429	1 289
	District cooling				
	National electricity mix	?	149	152	149
	Natural gas boiler				
	Fuel oil boiler				
	Wood pellets burner				
	other				
	other				
building on-site generation systems connected to the energy infrastructure	PV		99	168	185
	Solar thermal				
	Small Wind turbine				
	Small CHP-plant				
	other				
	other				
building off-site generation systems connected to the energy infrastructure	PV				
	Solar thermal				
	Wind Power Plant				
	CHP-plant				
	other: Heat delivered to grid (abatement 0,4 biomass)	1 373	658	572	516
Energy storage on-site	Heating				
	Cooling				
	Electricity				

Table 2.9 Energy efficency economics, Arlequin 40

	Sceanrio 0 40 Arlequin	Scenario 1 40 Arlequin	Scenario 2 40 Arlequin	Scenario 3 40 Arlequin
Value estimated for the building [k€]	15 721			
Investment cost [k€]		6 590	6 590	6 870
Reinvestment cost (cost energy renovation) [k€]				
Reinvestment technical life [year]		40		40
Maintenance[69] [€/year]	10 000	11 000	11 000	11 000
Energy use [kWh/m2, year]	128	61	54	50
Energy price (heating, cooling, electricity) [€/kWh]	0,04[70] (heating) 0,1372[71] (electricity)	0,04 (heating) 0,1372 (electricity)	0,04 (heating) 0,1372 (electricity)	0,04 (heating) 0,1372 (electricity)
Calculation period [year]		40	40	40
Discount rate [%]		5	5	5
Inflation rate [%]				
Residual value [€]				
Decommissioning [€]				
Payback time [years]		>50[72]	>50	>50
Total cost in present value [k€]		7 850	7 713	7 909
Total Energy cost in present value [k€]		1 071	935	851

Table 2.10 Energy efficency economics, Arlequin 50

	Scenario 0 50 Arlequin	Scenario 1 50 Arlequin	Scenario 2 50 Arlequin	Scenario 3 50 Arlequin
Value estimated for the building [k€]	12 000			
Investment cost [k€]		2 616	2 861	3 181
Reinvestment cost (cost energy renovation) [k€]				
Reinvestment technical life [year]		40	40	40
Maintenance[73] [€/year]	5 000	5 000	5 000	6 000
Energy use [kWh/m2, year]	130	73	69	64
Energy price (heating, cooling, electricity) [€/kWh]	0,04 (heating) 0,1372 (electricity)	0,04 (heating) 0,1372 (electricity)	0,04 (heating) 0,1372 (electricity)	0,04 (heating) 0,1372 (electricity)
Calculation period [year]		40	40	40
Discount rate [%]		5	5	5
Inflation rate [%]				
Residual value [€]				
Decommissioning [€]				
Payback time [years]		>50[74]	>50	>50
Total cost in present value [k€]		3 572	3 761	4 042
Total Energy cost in present value [k€]		870	815	758

Table 2.11 Primary energy and greenhouse gas emissions for each scenario, Arlequin 40/50

	Scenario 0	Scenario 1	Scenario 2	Scenario 3	
Primary energy used from energy need in building	[kWh$_p$/m^2/y]	[kWh$_p$/m^2/y]	[kWh$_p$/m^2/y]	[kWh$_p$/m^2/y]	
	128	61	54	50	40 Arlequin
	130	73	69	64	50 Arlequin
	EU 94	46	42	39	40 Arlequin
	EU 96	54	52	48	50 Arlequin
Greenhouse gas emissions from energy need in building	[kg/ m^2/y]	[kg/ m^2/y]	[kg/ m^2/y]	[kg/ m^2/y]	
	10,2	4,6	4	3,6	40 Arlequin
	10,4	5,7	5,3	4,9	50 Arlequin

2.4 Økern, Oslo

Scenario 0: 65% of total delivered energy is electricity from the grid and remaining 35% come from district heating. The building was old, had problem of leakage, had an inefficient ventilation system and there for a high energy demand.

Scenario 1: The demand for district heating is now reduced with 57% and the demand for electricity is reduced with 70%. The total energy demand has a reduction of 64%. 53% of total delivered energy is electricity from the grid, 40% come from district heating the remaining 7% is harvested from solar power.
This is accomplished through several retrofitting actions. The most important are:

- Increasing the thickness of insulation up to the Norwegian passive house level and increasing the airtightness making the U-value low
- Installation of balanced ventilation system with heat recovery
- Shift from direct use of electricity for space heating to waterborne system preheated by district heating
- PV installation on the roof to be partly self-served with electricity

Scenario 2: The demand for district heating is now reduced with 71% and the demand for electricity is reduced with 75%. The total energy demand has a reduction of 73%. 54% of total delivered energy is electricity from the grid, 33% come from district heating the remaining 13% is harvested from solar power. This was done through improvements from Scenario 1:

- Reducing thermal bridges and increasing air tightness further
- heat exchanger efficiency
- performance of the demand controlled ventilation
- Increasing the covered PV area also including parts of the facade

Scenario 3: The demand for district heating is now reduced with 74% and the demand for electricity is reduced with 84%. The total energy demand has a reduction of 80%. 44% of total delivered energy is electricity from the grid, 38% come from district heating the remaining 18% is harvested from solar power.
Scenario 3 accomplishes a reduction of 80% (compared to Scenario 0) through the same improvements from Scenario 2, but with lower level of the artificial lighting, average daytime airflow, increasing the amount of PV and better the U-value in the walls.

Table 2.12 Summary of measures related to consumption in each scenario and related energy reduction, Økern

Measures	Scenario 1	Scenario 2	Scenario 3
U-value wall [W/m²K]	0,15	0,15	0,10
U-value roof [W/m²K]	0,12	0,12	0,12
U-value floor [W/m²K]	0,12	0,12	0,12
U-value window [W/m²K]	0,86	0,86	0,65
Normalized thermal bridge value [W/m²K]	0,09	0,06	0,06
Leakage number– n_{50}	1,5	0,6	0,6
Temperature heat exchanger efficiency [%]	80%	85%	85%
SFP [kW/m³/s]	1,5	1,25	1
Demand controlled ventilation – average airflow daytime (normal use) [m³/hm²]	9	8	7
Artificial lighting – average daytime (normal use) [W/m²]	5,1	5,1	4
PV [kWh/m²]	10,4	15,8	17,0
Delivered energy [kWh/m²]	136,7	104,4	86,6
Total energy reduction (%)	64,1%	72,5%	77,3%
Total energy reduction (kWh/m² year)	243,6	275,9	293,7

Table 2.13 Summary of measures related generation in each scenario and related energy reduction, Økern

	Type	Scenario 0 (MWh)	Scenario 1 (MWh)	Scenario 2 (MWh)	Scenario 3 (MWh)
Existing energy infrastructure connected to the building	District heating	1290	556,7	374,3	338,7
	District cooling				
	National electricity mix	2402,4	722,3	602,6	387,4
	Other				
building on-site generation systems connected to the energy infrastructure	PV [MWh]	0	97,3	147,8	159,1
	Other				
building off-site generation systems connected to the energy infrastructure	PV				
	Solar thermal				
	Wind Power Plant				
	CHP-plant				
	Other				
Energy storage on-site	Heating				
	Cooling				
	Electricity				

Table 2.14 Energy efficency economics, Økern

	Scenario 1	Scenario 2	Scenario 3
Investment cost [k€]	11.865	12.285	12.755
Reinvestment cost [k€]	931	974	1021
Reinvestment technical life [year]	10	10	10
Maintenance [€/year]	547.361	547.361	547.361
Energy use [kWh/year]	1.279.102	976.871	726.103
Energy price (heating, cooling, electricity) [€/kWh]	0,11 - 0,14	0,11 - 0,14	0,11 - 0,14
Calculation period [year]	20	20	20
Real discount rate [%]	4,15	4,15	4,15
Inflation rate [%]			
Residual value [k€]	5933	6142	6377
Decommissioning [k€]	564	564	564
Payback time [years]	39	36	34
Total cost in present value [k€]	19.460	19.204	19.125
Total energy cost in present value [k€]	2459	1854	1386

Table 2.15 Primary energy and greenhouse gas emissions for each scenario, Økern

	Scenario 0	Scenario 1	Scenario 2	Scenario 3
Primary energy used from energy need in building	[$kWh_p/m^2/y$]	[$kWh_p/m^2/y$]	[$kWh_p/m^2/y$]	[$kWh_p/m^2/y$]
PE Norway	457	151	119	85
PE EU	697	217	177	118
Greenhouse gas emissions from energy need in building	[$kg/ m^2/y$] 52,7	[$kg/ m^2/y$] 21,2	[$kg/ m^2/y$] 14,8	[$kg/ m^2/y$] 12,6

3 Improvement proposals for replication actions

3.1 Lindängen, Malmö

The four residential building blocks included in the Lindängen demo site were retrofitted through the measures listed in Scenario 2 of Deliverable 3.1 – see chapter **Error! Reference source not found.** above. As described in D3.1, the site struggled with unfortunate starting conditions; e.g. the heating and BEMS system was outdated and the façades had relatively poor insulation. According to the property owner the windows had "reached their technical life span" before the project (see deliverable 4.3). These prerequisites illustrate the big need of retrofitting that the buildings were in before the project.

The comprehensive monitoring program and the monitoring year carried out in Lindängen during September 2016 to August 2017 have given many clear insights to the level of success and improvement possibilities of the implemented retrofitting actions. The monitoring program has allowed extensive insight to the overall energy and environmental performance and the detailed performance of certain technical installations; due to an energy sub-metering system on the installations of one of the high-rise buildings. The monitoring program, metering systems as well as the detailed monitoring results and more information on the data processing are described in further detail in D3.3. General conclusions and improvement proposals are given in a shorter format below.

When assessing the monitored data for Lindängen, the retrofitted buildings seem to perform rather well compared to what was calculated (Scenario 2):

- The final energy demand of the retrofitted buildings is 96.5 kWh/(m^2*year), compared to the simulated 76.2 kWh/(m^2*year) and to the baseline with a demand of 161 kWh/(m^2*year). This means a final energy reduction of 40 % compared to the expected (simulated) 53 %. (A reason for the deviation is the individual billing of domestic hot water which was not possible to implement during the project period. The DHW consumption was 9 kWh/(m^2*year) higher than expected with the fully implemented billing system, which could imply that the final energy demand will be closer to the simulated after the DHW billing implementation.)
- The primary energy demand of the retrofitted buildings is 65.5 kWh/(m^2*year)[1], compared to the simulated 71.4 kWh/(m^2*year) and the baseline of 97.2 kWh/(m^2*year). The demand is lower than expected due to a higher district heating and lower electricity demand than in the calculation.
  The primary energy reduction is thus at a higher level than expected, at 33 % compared to the simulated 27 %.
- The climate impact of the building energy demand is 15.3 g CO_{2eq}/(m^2*year) [2], compared to the simulated 13.4 g CO_{2eq}/(m^2*year) and the baseline of 24.8 3 g CO_{2eq}/(m^2*year). The climate impact has thus decreased by 38 % compared to the expected 46 %.
- The exhaust air heat pumps have been monitored displaying a COP of 4.1, which is of high standard[3].
- The DHW demand is at 47.1 kWh/(m^2*year) compared to the baseline value of 60 kWh/(m^2*year) (see D3.1) even though the individual billing has not been implemented yet. This indicates a significant overall effect of the measures performed to increase efficiency in the district heating deliverance (new heat exchangers, new heat stations etc.).
- The total property electricity demand is lower than expected (12.2 kWh/(m^2*year) compared to 20.5 kWh/(m^2*year) in the simulation). One reason is that the exhaust air heat pumps have consumed less energy than expected. (Despite the good COP, they have therefore also recovered less heat than expected.) Since the sub-metering of electricity is only made in one of the buildings and extrapolated for the full site, any conclusions are uncertain. The sub-metering though indicates that especially the lighting electricity use is very low, implying that

[1] Calculated through the primary energy factors applied for the site in D3.1 and D3.3.
[2] Calculated through the greenhouse gas emission factors applied for the site in D3.1 and D3.3.
[3] Electricity use and transferred heat have been monitored for the exhaust air heat pumps in one of the high-rise buildings. The figures show a very similar performance for all of these three heat pumps, and they are assumed representative for the normal operation performance for all heat pumps in the other buildings.

the LED illumination retrofitting measure is very recommendable (see Deliverable 3.3 for further details).

- The metered generation of PV electricity was higher than expected, 3.5 kWh/(m^2*year) compared to 3.1 kWh/(m^2*year) in the simulation. The share of internal use and export to the grid respectively was according to the expectations (0.7 kWh/(m^2*year) were exported compared to the simulated 0.6 kWh/(m^2*year)). Taking into account that the global radiation on a horizontal surface was 29 % higher in Malmö during the monitoring year than in a normal year (based on average for 1980 to 2010), a rough estimate (normal-year correction) made in D3.3 suggest that the electricity generation could be approximately 2.7 kWh/(m^2*year) during a year of "normal" amount of solar radiation. Overall, the PV solution though seems to be reliable and deliver what has been expected. Due to a lower total electricity use for the buildings than according to the simulation, the share of electricity use supplied by the PV cells is higher than expected.
- The monitoring program has also given a clarified view on the apartment indoor temperatures; this study was made for the 3 high-rise buildings. The average apartment temperature varied between approximately 21.3 and 21.6 °C during the heating season of October to April. They therefore seem slightly over-tempered since the property management aims for 21 °C as a continuous average during the heating season. The higher placed apartments (floor 6-8) also, without exceptions, had a lower average temperature than their lower placed equals (floor 2-5) for all the apartment categories studied (gable apartments, single-sided and double-sided). These data illustrates the general difficulties to adjust the heating system but gives also a better material for making further improvements than what was available before the project.

In an economical perspective, it could be concluded that many energy retrofitting measures that were excluded from the project have not proved to be economically justifiable. Facade renovation and ESX ventilation was considered to have high investment amounts and was not justifiable due to this and due to a too high disturbance for residents. Also, solutions for heat recovery in separated grey water was not been found to be economically viable.

The exhaust air heat pump solution was considered a cost-effective measure and was included in the renovation measures. The solution displays a somewhat dissonant relation between economy and *primary* energy efficiency. Despite the high monitored COP of the heat pump solution in Lindängen, the solution in itself contributes to a (marginally) *increased* primary energy use when applying the primary energy factors determined for the site within D3.1, despite the decrease of final energy demand. The primary energy factors are 0.45 for district heating and 2.26 for electricity. Based on these, the heat pumps must save approximately a 5 times higher amount of district heating than the electricity amount they consume for contributing to primary energy savings. The COP of 4 means that the heat pumps are rather close to achieving this, but still contributes to a (marginally) increased primary energy consumption. I.e., if the same amount of heat that is recovered by the heat pumps would instead have been delivered from the district heating grid, this would have resulted in a slightly lower primary energy consumption.

Improvement proposals for replication actions for Lindängen is presented by Table 3.1 Improvement proposals for replication actions, Lindängen.

Table 3.1 Improvement proposals for replication actions, Lindängen

Proposals for replication actions	Improvement proposals based on experiences from D3.1/D3.3	Reason
If applying an exhaust air heat pump heat recovery solution, the scale and efficiency of the Lindängen installation have enabled a rather balanced solution in terms of a significant final energy decrease at the cost of a marginal primary energy increase. Since both significant final and primary energy savings have been achieved overall (see the total reduction figures in summary above), a balanced total solution in both perspectives could be reached even when applying the heat pumps.	In the sole primary energy perspective, the exhaust air heat pump solution is not recommendable in today's conditions. If being able to reach a COP of approximately 5 and, for example, also ensuring a complete local renewable energy supply for the pumps, there would be a definite increase in the environmental reliability of the solution.	A COP of 5 means an approximately neutral effect of the heat pumps in a primary energy perspective (based on the determined primary energy factors, see the further explanations above the table), which would make it justifiable in this perspective. With also a purely renewable energy supply, a reliability improvement should also be reached in the climate perspective.
The performed property electricity retrofitting measures have improved the building energy performance more than according to the simulation. The sub-metering system indicates that especially the lighting electricity use is very low.	The higher level of success compared to calculation implies that the property electricity measures are recommendable and that it is difficult to evaluate if further improvements are likely for this type of buildings.	-
PV plants as installed in Lindängen seem to be reliable in terms of conformity between the expected and achieved energy generation.	The metered PV electricity generation was even higher than in the calculations. The normal-year correction indicates that the generation could be somewhat lower a normal year but still in line with what has been expected. Approximately 20 % of the PV electricity generated during the year was exported to the grid. For a better pure self-supplying system, there is therefore room for improvements, such as local energy storages, utilization also	Local energy storage or better local utilization of the excessive electricity should be assessed and tried furtherly for similar cases, e.g. for avoiding disturbances on the electricity grid that can be caused by small-scale PV electricity export.

	for household electricity or further types of local utilization of the excessive electricity.	
The achieved DHW demand of 47.1 kWh per m^2 and year compared to the baseline value of 60 kWh per m^2 and year (see D3.3) indicates an effect of the overall district heating deliverance measures (new heat exchangers, new heat stations etc.). Since the individual billing of DHW has not been implemented yet, reductions compared to the baseline value should be mostly due to these system improvements.	It is difficult to evaluate the success and improvement possibilities of the overall DHW measures furtherly since the individual billing system was not implemented during the project time.	-
The indoor temperature metering data gives a clear view of the heating system adjustment needs. It has given a good underlay for detecting inequality of temperatures between the different categories of apartments.	It is difficult to tell whether the meters are completely representative for the whole apartments (although the rather trends detected between the different categories improve the general reliability). For a more ensured view, several meters should be installed per apartment.	The temperatures could be significantly variable in the apartments, and any errors of nearby heat sources to the meters could not be detected with this one-meter-per-apartment system.
The sub-metering system of property electricity has given a good overview of the performance of the technical installations. Malfunctions in the system are very simple to detect if making a continuous follow-up of the data. Also, the general performance could easily be compared with expected values on e.g. a yearly basis.	The sub-metering system has only been implemented in one of the high-rise buildings. For a more assured overview and monitoring of performance of all of the buildings, the same detailed metering system should have to be installed in all.	Operation malfunctioning is not as easy to detect and assess in detail in the buildings without the sub-metering system. The possibility to assess the performance quality of each installation is also simplified with sub-metering and comparisons between all buildings.

3.2 Eibar, Mogel

The district of Mogel, retrofitted under the scenario , is composed of residential 21 buildings built in 1949 and located in the municipality of Eibar(Spain). These type of budilings fall under the category of "housing for industrial workers", and were usually constructions promoted by an industrial company.

Industrial development has been one of the key drivers in the creation of urban morphology in the Basque Country. This important development took place in a very short time to accommodate the immigrant population from the 40's and 50's until the 60's, originated a construction of low quality and with important problems of accessibility in the building. Current tenants of these areas are usually or either the relatives of the innitial owners or or more

vulnerable social groups (this one, depending on the location and the conservation status on the building)
Usually these buildings do not present any thermal insulation, are leaky constructions and lack mechanical ventilation and any centralized HVAC systems, as it is the case of Mogel.

With poor envelope and lack of mechanical ventilation, the major uses of energy in Mogel were related with space heating and domestic hot water production, which is mainly supplied by individual gas boilers . On the other hand, accesibillity to the dwellings represented a social issue, since there are 4 story buildings with no lift.

The retrofitting measures of scneario 1 that have been implemented in Mogel include the

- insulation of the building façade with an ETHI solution of 12cm EPS and roof with 20 cm of mineral wool;
- the replacement of old windows to double pane low-E windows,
- the installation of a hot water production system by means of solar panels with central storage system,
- the installation of elevators in the buildings and the replacement of common areas lighting to LED luminiares.

The expected energy saving with the application of scenario 1 were 47% when referred to final energy and 54% when referred to primary energy. Estimations were based on energy simulation of preintervention status and post-intervention taking inconsideration user behavior patterns.

Monitored data has shown that the average energy use is above from waht was exepected. Main desviation is due to space heating, which specific energy consumption is 66 KWh/m2.year, where expected was 47KWh/m2.year. It is worth noting that there is a huge dispersion in dwellings real values of energy use for space heating, and it is mainly related with the user behavior and operation of the individual boilers.

Two dwellings out of the 10 monitored do not or semdonly use space heating, being winter time average indoor temperatures of around 16.5ºC. On the other hand, from the ones that are space conditioned, there are three which average indoor temperatures are above 20ºC,.which specific space heating consumption is above 90 KWh/m2.year. Taking into consideration (1) the space heating energy use is much higher. Taking in consideration (1)the energy consuming paterns and indoor comfort conditions of the monitored dwellings sample, (2) building tenants vulnerability and (3) construction characteristics of similar buildings in that area, the recomendation for future retrofitting projects of buildings of these type will be to prioritize envelope integral solutions, paying special attention to the execution , then act on the systems performance and finally on the RES.

Improvement proposals for replication actions for Eibar is presented by Table 3.2.

Table 3.2 Improvement proposals for replication actions, Eibar

Proposals for replication actions	Improvement proposals based on experiences from D3.1/D3.3	Reason
Promote/encourage the substitution of poor windows although it is an individual actuation	Higher space energy use for dwellings with old windows.	Poor thermal transmittance and leaky windows lead to increase the space heating needs because of the low surface temperatures of the glazing's and higher infiltration rates.
Integral retrofitiing of building envelope	Waranty insulation continuity and air tightness in the whole building envelope, specially in window /façade joints.	The joint of the façade/window is one of the weak points of the façade and lead to unwanted external air infiltrations.
Airtight shutter/roller boxes	Ensure the well execution of roller boxes, plugs or any wire coming from the façade	These are generally weak points related with airtightness
Ensure insulation is warantied between conditioned and non-conditoned spaces		In order to reduce any thermal losses between roof/ceiling slabs and ground/floor slab.
Ensure insulation continuity in thermal bridges(balconies) and any recessing surfaces	IR thermography has shown that these are areas that need further analysed	
Promote the substitution of existing boilers for condensing boilers		In order to improve the performance ratio.
Recommend the installation of thermostats	In order to warranty a stable indoor comfort temperature and this not surpassed.	Any additional ºC of space heating increases sharply the space heating energy use.
Optimize solar thermal panels function mode and commisioing	Panels performance is far from what was expected.	A better performance cab be achieved with the primary circuits set points.

3.3 Arlequin 40/50, Grenoble

ARLEQUIN 40 and ARLEQUIN 50 are retrofitted with the measures listed in scenario 2 (D3.1). The buildings were old, had problem of thermal insulation and air leakage inducing a high level of discomfort for inhabitants.

The retrofitting actions as described in chapter 2.4 with distinction for ARLEQUIN 40 and ARLEQUIN 50. The most important are:

- Air tightness with a target of performance far better than usual one in France for retrofitting,
- External thermal insulation with correction of all detected thermal bridges related to . singular cases like parapets, balconies, rooftop equipment, and so on
- The integration of thermal regulation controlling a 2 ways valve for inddor comfort condition control in the cas of 50 Arlequin,

- Optimization of pump electric consumption either for Domestic Hot water distribution and heating distribution,
- Adapatation of the ventilation systems to warranty indoor air quality and energy efficiency,
- PV installation on the roof of the parking lot,

When looking at the monitored data and inhabitants feedback(D 3.3) the buildings are performant with some troublesalready solved to be solved :

- The PV installation on the parking lot delivers what expected but a manufacturing problem has forced GEG to substitutes the panels to ensure next year energy production,
- For the 50 ARLEQUIN, the energy savings related to more efficient building envelope has not been as large as expected. A technical problem on temperature sensor communication has been detected, wich leads us to keep indoor temperature setting value constant up tu 22°C during the first winter. Such a decision has been made to compensate noise and disturbance due to retrofitting works, for the on-site inhabitants. Nevertheless, the heating consumption has been lower than expected initially in the frame of teh project before ZenN optimization inputs.

The monitored data (D 3.3) show the **actual efficiency of enveloppe thermal insulation and air tightness optimisation**. For example, the 50 ARLEQUIN building retrofitting project had a target of 69 kWh/m².year before ZenN optimization inputs, and has been monitoring at 52.6 kWh/m².year taking into account wetaher correction.

Improvement proposals for replication actions for Arlequin 40/50 is presented by Table 3.3.

Table 3.3 Improvement proposals for replication actions, Arlequin 40/50

Proposals for replication actions	**Improvement proposals based on experiences from D3.1/D3.3**	**Reason**
Renovation of building envelope with a large emphasis on energy efficiency and detail correction (Thermal bridges) thank to a thermal bridge reference book to be considered for any new retrofitting operation.	The buildings were renovated according to the French Low Consumption retrofitting standard. The requirements to reach a higher level of performances lead to focus on reduction of thermal bridges resulting in better U-values in walls, and roofs.	The engineering firms do not consider thermal bridges impact when energy performances are estimated. It has been demonstrated that the thermal bridges could induce an increasing of the heating demand up to 50%. Moreover, for some cases, the thermal bridges can be responsible for moisture development in the apartment.
Air tightness improvement process	The usual value for air tightness according to the French Low Consumption retrofitting standard has not been considered as sufficiently	The French standard Q4 in m3/h/.m² is not the most adapted to control correctly the quality of air tightness. It is possible to get better

	ambitious. A target at level of Q4 < 1.1 m3/h/.m² (French standard) has been chosen but only an average maximal value wad specified for the tested apartment. A maximal value for each test with the European indicator N50 in ACH will be specified for any new retrofitting operation.	result by choosing a flat with a high rate of walls and ceiling in contact with the outdoor. The European standard will be specified to get a reliable air tightness indicator whatever is the location of the flat in the building.
Indoor thermal regulation	The control of indoor temperature has been improved for the building ARLEQUIN 50 with a 2 ways valve controlled by temperature sensors located in the living room. It has allowed to reduce overheating during winter time and to reduce heating energy consumption.	A monitoring campaign in Lyon of a 55 flats social housing retrofitted building has shown the efficiency of such a technical solution. A reduction of 20% of heating energy consumption has been measured with 2 ways valve controlled by temperature sensors located in the living room compare to usual thermostatic valves mounted on the heater.
Auxiliary pump optimisation	As heating demands has been dramatically reduced thanks to thermal insulation, specific electric consumption can reach an high part of global energy balance of buildings. Consequently, the circulation pump control strategies should be optimized, if possible with integration of storage capacity to allow pump stopping	Building monitoring campaigns have proven that auxiliary pumps could reach more than 20 kWhEp/m².year if they are not controlled in a correct way for heating and DHW. With adaptation of hydraulic architecture and control strategies, such energy consumption can be dramatically reduced.
Installation of ventilation system with minimal controlled air flow	The installed ventilation equipments ensure minimal air flow in dwellings to warranty indoor air quality (hygrometric A instead of usual Hygrometric B according to French standard).	The CO2 rate can reach up to 2000 ppm in a case of Hygrometric B ventilation system in dwelling, because of too low air flows. Only Hygrometric A ventilation system show a good compromise between air quality and energy efficiency.

3.4 Økern, Oslo

Økern nursing home is retrofitted with the measures listed in scenario 1 (D3.1). The building was old, had problem of leakage, had an inefficient ventilation system and therefore a high energy demand. 64% reduction of total energy demand is achieved from Scenario 0 to Scenario 1. This is accomplished through several retrofitting actions as described in chapter 2.4. The most important are:

- Increasing the thickness of insulation up to the Norwegian passive house level and increasing the airtightness making the U-value low
- Installation of balanced ventilation system with heat recovery
- Shift from direct use of electricity for space heating to waterborne system preheated by district heating
- PV installation on the roof to be partly self-served with electricity

When looking at the monitored data (D 3.3) the building seam to perform very well compared to what was calculated (Scenario 1):

- The PV installation delivers what expected and proves to be a good alternative to traditionally energy systems.
- The energy savings related to more efficient building envelope and balanced ventilation system are large
- The shift from direct use of electricity for space heating to waterborne system connected to the district heating works fine

Going beyond Scenario 1, a total energy demand reduction of 73% (compared to Scenario 0) was accomplished in Scenario 2. Scenario 3 accomplishes a reduction of 80% (compared to Scenario 0).

Looking at the economical evaluation the general impression is that reducing energy through the mentioned improvements gives fairly similar life cycle costs. The three scenarios have quite comparable life cycle costs, but scenario 2 and 3 seems to be a bit more profitable. However, the energy measures in scenario 2 and 3 have a higher risk for deviations between calculated and real energy performance, and unforeseen costs. Even so, this means that reducing energy is sustainable, not only in environmental terms, but also economically.

Improvement proposals for replication actions for Økern is presented by Table 3.4.

Table 3.4 Improvement proposals for replication actions, Økern

Proposals for replication actions	Improvement proposals based on experiences from D3.1/D3.3	Reason
A large share of electricity consumption can be covered by locally produced energy	The walls can be used (together with the roof as was done in Scenario 1) to get a larger area of PV panels installation (this was presented by numbers in Scenario 2 and 3).	The installation of PV panels for energy production has proved to be successful and also economical beneficial according to the LCC analysis of Scenario 2 and 3.
Renovation of building envelope with a large emphasis on energy efficiency	The building was renovated up to the Norwegian Passive House level. Although the requirements was high, there could have been	Renovating buildings up to the Norwegian passive house level results in an increased level of insulation

	larger focus on reduction of thermal bridges and increased air tightness (Sc 2 and 3), resulting in better U-values in walls.	and large emphasis on air tightness. This makes a large difference when the starting point is a building from the 1970's (Økern was built in 1975). The resulting building envelope ended up as a very efficient building, but some more energy reduction would have been possible if the requirements on energy efficiency were stricter.
Installation of balanced ventilation system with heat recovery	The installed ventilation equipment had 80% heat recovery. The heat exchanger efficiency can be increased further by technical equipment chosen as basis for calculations in Scenario 2.	Balanced ventilation with 80% heat recovery is a common and settled technology and more progressive heat exchanger technology can be found at the market to increase the energy efficiency further.