*2ndSKIN SCALER W*P2- Report 2019

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Introduction

After the Demonstrator project that resulted in the renovation of 12 apartment to zero energy level, the SCALER project follows, which aims at the renovation of 180 apartments. The apartment types of both projects are located in the same district and they have the same layout and construction details, following the SIMPLEX system (Priemus & Elk, 1971). However, in the Scaler project phase, the objective was not a zero-energy performance. Due to a lower budget per dwelling, the housing association did not attempt to achieve a zero-energy renovation but rather a zero-energy-ready (NOM-ready) renovation which improves the dwellings to energy label A+. Additional measures can be taken in the future to bring the building to zero-energy.

Evaluation of the previous solution

The 2ndSkin Demonstrator project phase concluded in an innovative solution for zero-energy apartments. The lessons learned during this project are three-fold: the technical solution, including building envelop and services upgrade; the occupants' acceptance process; and the performance guarantee. The renovation resulted in excellent insulation and airtightness, featuring external insulation on the walls, new window frames with triple gazing and new, prefabricated insulated roof panels, which are fully covered with Photovoltaic panels. As suggested by the national energy goals, the building is disconnected from the gas which complies with the current energy policy. The heating and DHW is provided by ground-source heat pump of COP6. The heat pump, water tank and heat-recovery ventilation unit are placed in insulated boxes that are located outside the houses on a new, enlarged balcony. The energy calculations show a net energy surplus on an annual basis for standardised occupancy. Those calculations allowed for a 25-year zero-energy performance contract to be agreed between the building services provider and the building owner. According to the contract, the building services provider guarantees the maintenance of the systems and the energy demand for a fixed amount per dwelling.

Despite the concept being innovative and achieving the zero-energy performance, the cost of this solution remains relevant high, compared to the budgets the housing associations are able to make available in large scale renovation project. The next challenge would be to find the balance between high energy performance and investment costs.

Aim of the SCALER project

The Scaler project aims at using the lessons learned in the Demonstrator project and scale the concept up for 180 apartments of the district (Figure 1) while adapting it to fit the much lower budget. As a result, the large scale renovation is not aiming at zero-energy, but zero-energy-ready. Moreover, the project provides the opportunity to test in few of the apartments the possibilities for additional, innovative interventions that constitute the next step towards Net Zero Energy V2.0.

Figure 1: Urban plan of the renovated district in Vlaardingen

Figure 2: The buildings during renovation

Technological development

The measures applied in the Scaler renovation aimed primarily at the high thermal performance of the envelope, and the energy generation with the use of Photovoltaic panels. The building services systems were upgraded to more efficient units, but not with the zero-energy objective. Those upgrades are according to the specification required by regulations and still improve the performance significantly, from an average label D to A+. Table 1 presents a comparative overview of the renovation measures.

Building envelope upgrade

The thermal resistance of the opaque parts of the façade was improved with the addition of an external insulation layer. The material used is rigid expanded polystyrene, supplied by STO. The needed insulation thickness, in order to reach the prescribed U-value, is 19 cm. This solution is the same as the Demonstrator. The only difference is that after with insulation is placed on the existing wall, with the use of an adhesive medium, brick stripes were added externally, to preserve the brick façade appearance. The insulation of the crawling space is also the same, as it was proven to be applicable and cost-effective.

More changes can be seen in the solution regarding the roof and the windows. The roof has been insulated with rigid EPS insulation boards and ceramic tiles on top, instead of the prefabricated sandwich panels of the demonstrator. The Scaler solution was easier to apply, as it made the connection between wall and roof easier. The windows are double glazed. Finally, the balconies are not replaced, which provides considerable savings in the investment of the new balcony construction

Figure 3: The installation of rood insulation and the renovated building envelope

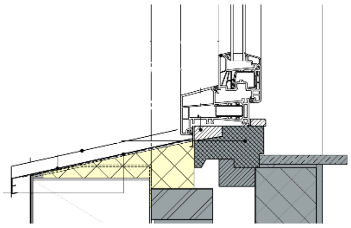
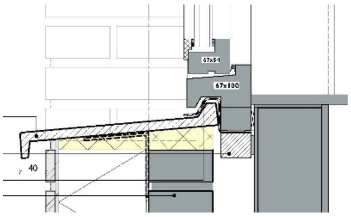
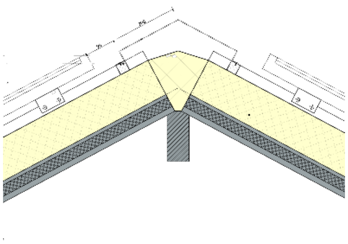
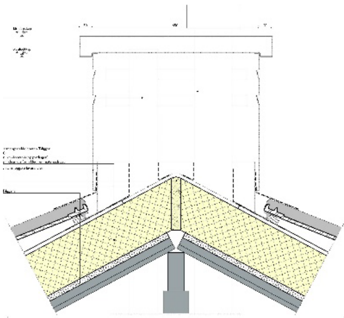
Building services upgrade

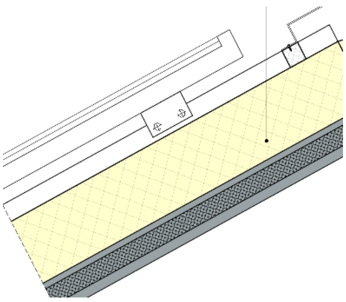
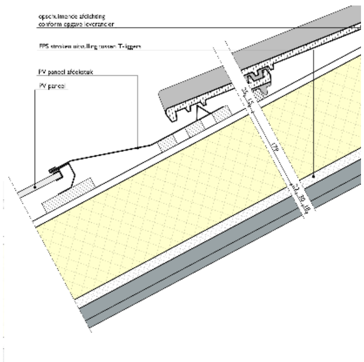
The ambition for the 180 apartments was zero-energy ready, with the investment cost kept at almost half of the Demonstrator cost. The building envelope thermal properties upgrade explained above are very similar to the previous concept and deliver a high performing shell, as it is considered the first important step in a step-wise approach. As a result, the building services were decided to have an efficiency upgrade, but not changing the energy source to a gas-free solution, as it would be a more costly intervention and would require additional site works. The heating and DHW are provided by a new, high-efficiency gas boiler. The ventilation of the dwelling is implemented by natural inlet through window trickle vents, with CO2 sensors, and mechanical outlet through a Climarad mini box, placed in the bathroom and kitchen.

Overview of the technical solution

As explained above, some of the technical options were modified from the Demonstrator project to the Scaler project. The reason for those decisions was mostly related to budget differences, as well as the different ambition level for the performance.

Table 1. Overview of technical options of the Demonstrator and Scaler projects. The explanation column includes the reasons for deciding for different measures in the scaler project.

		Demonstrator	Scaler	Explanation
Façade	Wall	rigid expanded polystyrene, by STO Plaster finishing U 0,16 W/Km2, Rc 6.0 	rigid expanded polystyrene, by STO Brick veneer (steenstrips) U 0,16 W/Km2, Rc 6.0 	The wall structure is in both phases identical, except for the outside cladding: plaster (demonstrator) and brick veneer (scaler)
	Windows	u-PVC frames Triple glazed panes Uw 1 g= o,8 	u-PVC frames Double glazed panes 	Because of budget reasons, the client chose to use double-glazed panes, instead of triple glazed.
	Roof	insulated panels, by Kingspan U 0,14 W/Km2 (Rc 7,0) 	insulated panels, Unidek Reno Dekfolie RC 6.0, by Kingspan U 0,14 W/Km2 (Rc 7,0) 	Because of budget reasons, the client chose to use these insulated panels.
	Basement	expanded polystyrene in granulated form blown crawling space U 0,28 W/Km2 (Rc 3.5)	expanded polystyrene in granulated form blown in crawling space U 0,28 W/Km2 (Rc 3.5)	This solution was proved to be the best solution during Demonstrator, so it

				didn't have to change in the Scaler phase.
	Balcony	remove and replace 	Existing Balconies, new balustrade 	Because of budget reasons, the client chose for this new option.
	Entrance	New closed entrance 	New closed entrance  (under construction)	Because of budget reasons, the client chose for this new option.
Services	Ventilation	mechanical ventilation with heat recovery, up to 95%,	Natural inlet through window trickle vents, CO2 sensor, outlet Climarad mini box, bath and kitchen	Because of budget reasons, the client chose for this new option.
	Heating	Ground-to-water heat-pump COP 6.00	Gas	Gas was financially a more appealing solution, so the client chose this option.
	DHW	Ground-to-water heat-pump COP 3.00	Gas	Gas was financially a more appealing solution, so the client chose this option.
	PV	PV capacity of 300 Wp /panel, 15 panels per home 	PV capacity of 300 Wp/panel, 5 panels per home 	Because of budget reasons, the client chose for this new option.

Evaluation and Further development

Evaluation round tables

The applied technical solution for the building envelope and the services was evaluated in round-tables with the participation of the general contractor BIKBouw, the building services engineers Giesbers B.V. and researcher from TUDelft.

Figure 4: Evaluation round table on the 8th Oct. 2018

The outcome of the discussion was the advantages and disadvantages (Table 2) of the zero energy concept currently applied, which also led to the identification of further developments and new concepts to be evaluated, within the framework of the 2ndSkin SCALER project.

Table 2. Demonstrator concept advantages and disadvantages

Advantages	*Disadvantages*
• Performance/ EPV/ zero energy guarantee • People satisfied/good reviews • Summer/winter situation • Good team process • Development of solutions while building • Innovation aspect • Good press • Nice design • Good approach with users • Short engineering time	• High investment cost • Fixing gardens • Too much weather dependent • Too much time inside the house • Clash of disciplines in construction, due to a tight timeline • Complicated user-technology interface • Chance of traditional system • Users do not understand the systems/ need to be explained • Interface acceptance • Component connections • Time intensive acceptance process • Long time monitoring • Oversized and heavy installation for such small apartments

The above evaluation of the 2ndSking concept concluded to some improvements that can be made to reduce the cost or improve the performance. On the one hand, a “no regret”, stepped approach can be a way to reduce the high initial investment costs while achieving the eventually required energy and carbon savings. Studies (BPIE, 2011) have shown that a stepwise approach to zero energy buildings has the potential to reach the climate goals for 2050.

In the case of the Scaler 2ndSkin, the concept applied for the “NOM-ready” apartments, which upgrades the envelop thermal properties and introduces energy generation on-site, can be considered as the first step. The next step will be to upgrade the building services. The energy concept used in the Demonstrator is an option, but other alternatives can be promising, to achieve the same high performance, with lower cost. The lower cost is related to the cost of the equipment themselves, but also to the space they occupy and their weight. If they are lighter and smaller, additional constructions to accommodate the building service can be reduced or avoided, thus saving in the construction costs.

New energy concepts, towards Net Zero Energy V2.0’

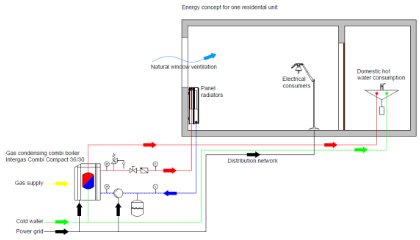
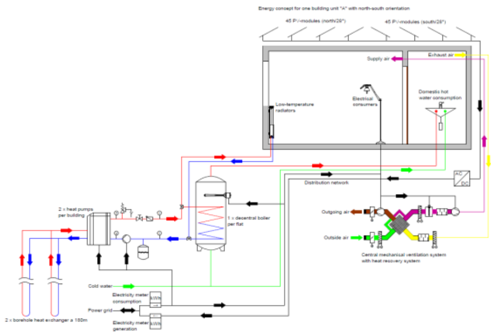
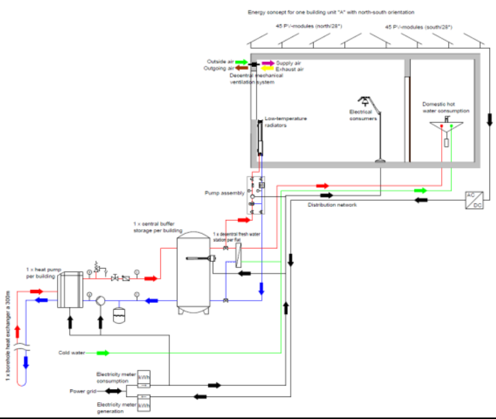
Energy-efficient building services and sustainable energy planning are the crucial aspects for an optimized building performance. Taking into account these essential design criteria a low primary energy demand and a cost reduction during the building operations can be reached. The desired objective of this WP2 is the development and investigation of different renovation concepts with the intention to prove and analyze the zero-energy standard for the restructuring of existing buildings. In this chapter the energy analysis of the 2ndSkin Scaler project is described. The investigation is focused on building technology and energy planning for heating purposes of space heating and domestic hot water, ventilation technology for fresh air supply and moisture proofing as well as solar technology for power generation.

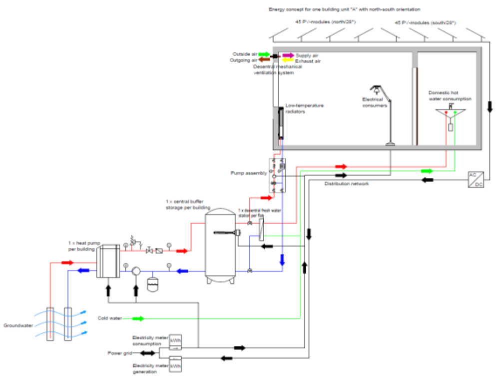
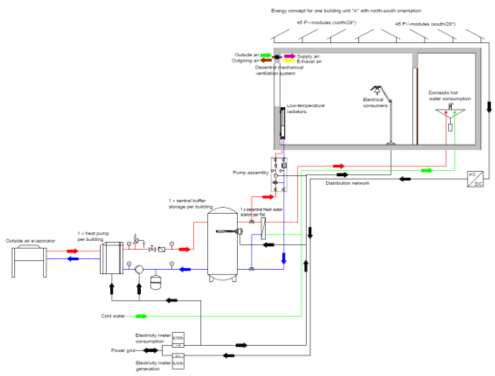
For the new energy concepts, the interaction between energy supply and energy demand should be optimized. This process has to take into account the sectors of energy-efficiency, sustainability and possible retrofitting capability. In order to meet these requirements seven various energy supply concepts are set up and the fields of heating technology for space heating and domestic hot water as well as ventilation technology are investigated. The selected variants have to be on the one hand innovative as well as future-oriented and on the other hand upgradeable. In addition the location-independent planning options was another task in this context. That means energy systems which are directly on the site e. g. heat pumps with all possible heat sources and otherwise the central energy supply with e. g. district heating network has to be considered. With regard to novel energy concepts electrical heating variants are introduced. The reason for this innovative approach is the decreasing primary energy factor of electricity due to renewable energies and some advantages in terms of retrofitting capability. In comparison to water based systems the pipes of feed and return water for heating purposes can be eliminated and leads to a reduced installation work. Furthermore with electrical heating it is possible to react on supply related location factors and increases design flexibility. Based on the referred boundary conditions and the broad range of requirements a broad matrix of energy supply concepts was developed.

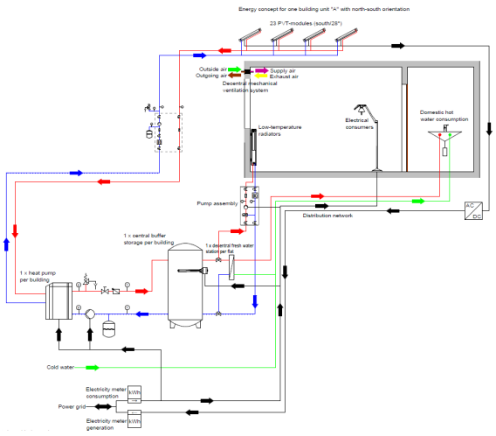
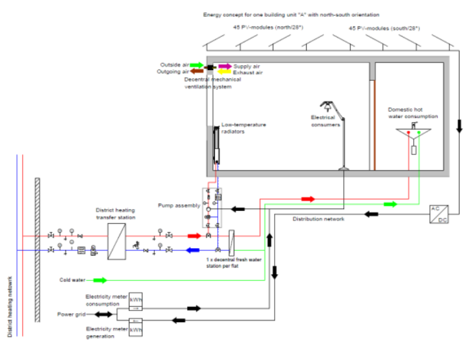
The options considered include improving the existing Demonstrator concept, for more space- and energy-efficient heat pumps and water tank. This improvement needs the collaboration of the units’ manufacturers. Moreover, an alternative to heat pump technologies for a gas-free solution, such as electric heating, should be deliberated and calculated for their efficiency. Finally, options to simplify the system, but still get the needed energy savings can be tested.

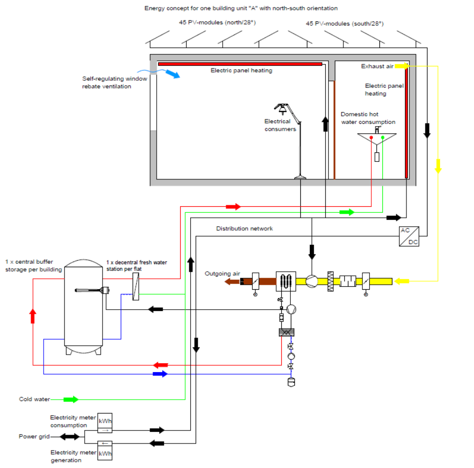
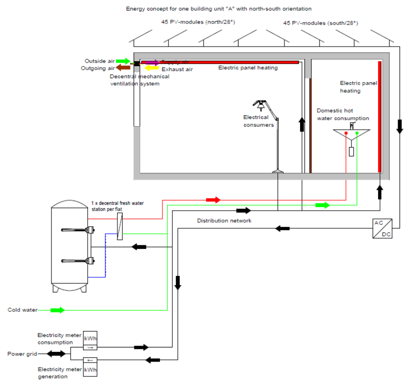
Table 3 shows schematic drawings of the investigated energy supply concepts including heating technology for space heating and domestic hot water as well as ventilation technology and where appropriate solar technology for power generation. Subsequently, those options will be simulated to give insights into their performance.

Table 3. Overview of new concepts for building services systems

Nr.	System Components	System representation	Pro	Cons
1	<u>Existing buildings</u> • Gas condesing combi boiler • Radiators • Natural window ventilation		<u>Heating:</u> • low investment costs • good degree of utilization due to condensing effect • maintainability • long service life <u>Ventilation:</u> • no investment costs	<u>Heating:</u> • non-renewable energy source • causing emissions • planned ban on natural gas by 2050 in the Netherlands • poor efficiency of old gas-boiler <u>Ventilation:</u> • risk of mould formation if building insulated
2	<u>Demonstrator</u> • Heat pump • Borehole heat exchanger • Low-temperature radiators • DHW-boiler • Central mechanical ventilation system • Photovoltaic system		<u>Heating:</u> • Optimised CO_2 balance (depending on system temperatures and primary energy factor) • Low operating costs and very efficient with low temperature radiators • Can be retrofitted in appropriate old buildings through little effort • Constant heat source temperatures trough borehole • Heating and cooling possible with reversible heat pump <u>Ventilation:</u> • Good air quality • Hear recovery	<u>Heating:</u> • High investment costs through geothermal probe • Some space for boreholes required • Efficiency depend on soil (quality) • Approval required <u>Ventilation:</u> • Expensive and high construction work impact
3	<u>Heat pump - soil</u> • Heat pump • Borehole heat exchanger • Low-temperature radiators • DHW-Tank • Ventilation system with heat recovery • Photovoltaic system		<u>Heating:</u> • Higher source temperature through deep bore holes • Low operating costs and very efficient with low temperature radiators • Optimised CO_2 balance (depending on system temperatures and	<u>Heating:</u> • High investment costs through deep geothermal probe • Some space for boreholes required • Efficiency depend on soil (quality) • Approval required <u>Ventilation:</u> • The outside unit causes noises, bad for installation near to sleeping room

			primary energy factor) • Heating and cooling possible with reversible heat pump <u>Ventilation:</u> • Good air quality • Little installation effort	
4	<u>Heat pump - water</u> • Heat pump • Absorption and extraction well • Radiator • DHW-Tank • Decentralised ventilation system with heat recovery • Photovoltaic system		<u>Heating:</u> • Optimised CO_2 balance (depending on system temperatures and primary energy factor) • Low operating costs and very efficient with low temperature radiators • Can be retrofitted in appropriate old buildings through little effort • Constant heat <u>Ventilation:</u> • Good air quality • Little installation effort	<u>Heating:</u> • Approval required, as contact with groundwater; strict requirements possible • Efficiency depend on ground water level • Some space for wells necessary <u>Ventilation:</u> • The outside unit causes noises, bad for installation near to sleeping room
5	<u>Heat pump - air</u> • Heat pump • Radiator • DHW-Tank • Decentralised ventilation system with heat recovery • Photovoltaic system		<u>Heating:</u> • Optimised CO_2 balance – (depending on system temperatures and primary energy factor) • Low operating costs and efficient with low temperature radiators • Cheapest heat pump system in terms of investment costs • Can be retrofitted in appropriate old buildings through little effort • Heating and cooling possible with reversible heat pump <u>Ventilation:</u>	<u>Heating:</u> • Fluctuating efficiency, less economy on cold days • Installation location at the ambient air must be available <u>Ventilation:</u> • The outside unit causes noises, bad for installation near to sleeping room

			• Good air quality • Little installation effort	
6	<u>Heat pump - PVT</u> • Heat pump • Radiator • DHW-Tank • Photovoltaic-thermal Collector • Decentralised ventilation system with heat recovery		<u>Heating:</u> • Low operating costs and efficient with low temperature radiators • Optimised CO_2 balance – (depending on system temperatures and primary energy factor) • Producing electricity and heat by one system • Heating and cooling possible with reversible heat pump <u>Ventilation:</u> • Good air quality • Little installation effort	<u>Heating:</u> • Excessive heat in summer • New technique with little experience • Monitoring is necessary <u>Ventilation:</u> • The outside unit causes noises, bad for installation near to sleeping room
7	<u>District Heating</u> • Transfer Station • Radiator • Decentralised ventilation system • Photovoltaic system		<u>Heating:</u> • Environmentally friendly, good CO_2 balance (dependent on energy suppliers) • Low investment costs • Space saving, little space needed for technology <u>Ventilation:</u> • Good air quality • Little installation effort	<u>Heating:</u> • In the annual balance the prices for district heating are often higher than those for oil or gas (dependening on energy suppliers) • Highly price dependending on energy suppliers <u>Ventilation:</u> • The outside unit causes noises, bad for installation near to sleeping room
8	<u>Electrical system + heat pump - air</u> • Electrical heating panels • Exhaust air system, combined with exhaust heat pump		<u>Heating/Ventilation:</u> • Only small space requirement • Maintenance rarely or not at all necessary	<u>Heating/Ventilation:</u> • High operating costs due to electricity price • Often no correlate between PV production / heating demand

	• DHW-Tank • Photovoltaic system		• Low investment costs for the heating panels • Efficient heat recovery • Constant heat source temperatures trough constant extract air temperature	• Bad primary factor electricity • Air pollution by coal generated electricity • Maintenance due to regular filter change • Additional investment costs
9	<u>Full electrical system</u> • Electrical heating panels • Decentralised ventilation system with heat recovery • DHW-Tank • Heating rod • Photovoltaic system		<u>Heating:</u> • Annual energy: possible to reach zero energy (with high number of PV modules) • Only small space requirement • Maintenance rarely or not at all necessary • Low investment costs for the whole system <u>Ventilation:</u> • Good air quality • Little installation effort	<u>Heating:</u> • High operating costs due to electricity price • Often no correlate between PV production / heating demand • Bad primary factor electricity <u>Ventilation:</u> • Air pollution by coal generated electricity

Evaluation of preliminary solutions

The following section concerns the system development of the building technology and investigates nine energy concepts for the fields of energy conversion, energy distribution, energy supply and energy output. Therefore a static energy demand calculation based on NEN7120 is made and this scenario is shown on one building unit “A” with different orientations in combination with the energy variants. Before the calculation the dwelling houses are divided into four buildings types due to orientation and number of external walls. As shown in figure XY there are three terrace houses with north-south orientation and split up into eight “A” units and two “A´” units. Four terrace houses according to 21.5 “A” units are east-west oriented. Furthermore there is for every orientation one more distinction due to the building characteristics with middle buildings (two external walls) and corner buildings (three external walls). Consequently there are four general building types in total which distinguish in terms of transmission losses and solar heat gains. Table 4 describes the four different building types which are shown in Figure 1.

Table 4: Classification and number of building types

Building type	Orientation	External walls	Number
Typ 1	north / south	north / south / east / west	5 * A

Typ 2	north / south	north / south	4 *A
Typ 3	east / west	east / west / north / south	7,5 * A
Typ 4	east / west	east / west	14 * A

In the developed calculation matrix the existing buildings and the Demonstrator standard were also considered and leads to 36 calculations in total, which was made with the software "Uniec2". In a following step the results are scaled up for all investigated buildings. Afterwards the building technology systems are compared due to the primary energy impact of the static energy demand calculation and the environmental impact is shown with the indicator of CO2 emissions. The result of the variant study is summarized in figure XY:

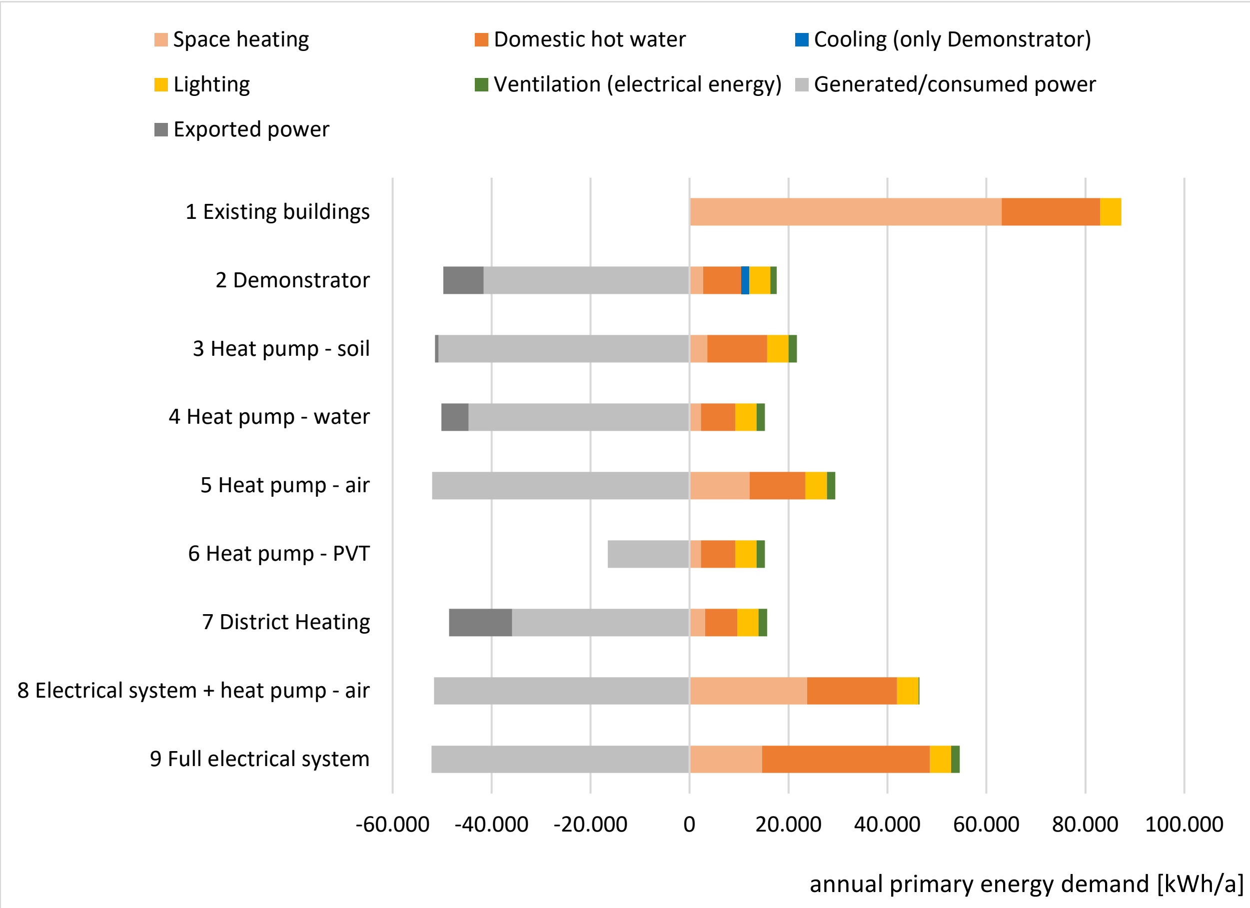


Figure 5: Annual primary energy demand for a building unit "A" and the quarter according to NEN 7120

At first glance the existing buildings have due to the high transmission losses of the building envelope and the gas based heating supply system the highest primary energy demand. All the others concepts show reduced primary energy demand because of the building insulation and renewable as well as alternative energy supply instead of gas. The slight differences concerning the heat pump systems are justifiable of the different COP´s for each heat source. With regard to the concept heat pump with PVT-collectors is was not possible to use the PVT alone as a heat source for the heat pump because the software "Uniec2" always couples it with soil in addition. The good outcome of the primary energy demand for the concept with district heating is justified by the centralized energy production in a district heating plant with high efficiency ratio. A weakness of the "Uniec2" software is the fact that isn´t possible to vary the electrical power for lighting. This value is fixed by 12.9

kWh/m²a and that´s the reason why for all energy variants the amount of lighting energy is the same. For a better overview the detailed specific results for every energy concept per building unit "A" are shown and analyzed in the following part. Therefore the specific primary energy demand was calculated based on the mean value of the four different building types for the whole district with the 30.5 buildings units. The table below shows the annual absolute and specific primary energy demand, the CO_2-emissions, the EPC and the identification for zero-energy buildings of all energy supply concepts for one building unit as well as the whole district. The energy concepts that have achieved the zero-energy goal are marked in green. The variants that did not reach the goal are highlighted in orange. If the zero-energy goal is achieved by a renovation, the abbreviation "NEH" is used to mark a zero-energy building. The primary energy demand, which remains after deduction of the generated and self-consumed electricity of the photovoltaics, is written in kWh/m²a after the abbreviation "NEH".

Table 5: Annual primary energy demand for a building unit "A" and the quarter according to NEN 7120

		1 Existing buildings	2 Demonstrator	3 Heat pump - soil	4 Heat pump - water	5 Heat pump - air
space heating	[kWh/a]	63'090	2'761	3'580	2'281	12'129
hot water heating	[kWh/a]	19'901	7'719	12'130	6'979	11'322
cooling (only Demonstrator)	[kWh/a]	-	1'555	-	-	-
lighting	[kWh/a]	4'301	4'301	4'301	4'301	4'301
ventilation (electrical energy)	[kWh/a]	-	1'306	1'698	1'698	1'698
primary energy demand - building	[kWh/a]	87'292	17'642	21'709	15'259	29'450
generated/consumed power	[kWh/a]	-	-41'640	-50'748	-44'659	-52'019
exported power	[kWh/a]	-	-8'108	-712	-5'469	-
primary energy demand - building (PV)	[kWh/a]	87'292	-23'998	-29'039	-29'400	-22'569
primary energy demand - quarter (PV)	[MWh/a]	2'712	-731	-893	-903	-689
primary energy demand (PV) (spec.)	[kWh/m2a]	260	-71	-86	-88	-67
CO2-Emissions - building	[kg/a]	17'370	-7'610	-5'441	-6'864	-3'813
CO2-Emissions - quarter	[t/a]	530	-233	-164	-207	-115
EPC		1.40	-0.50	-0.38	-0.45	-0.27
zero-energy building		-	NEH -71	NEH -86	NEH -88	NEH -67

		6 Heat pump - PVT	7 District Heating	8 Electrical system + heat pump - air	9 Full electrical system
Space heating	[kWh/a]	2'281	3'104	23'764	14'617
Domestic hot water	[kWh/a]	6'979	6'552	18'196	33'965
Cooling (only Demonstrator)	[kWh/a]	-	-	-	-
Lighting	[kWh/a]	4'301	4'301	4'301	4'301
Ventilation (electrical energy)	[kWh/a]	1'698	1'698	216	1'698
Primary energy demand - building	[kWh/a]	15'259	15'654	46'477	54'581
Generated/consumed power	[kWh/a]	-16'516	-35'842	-51'659	-52'167
Exported power	[kWh/a]	-	-12'753	-	-
Primary energy demand - building (PV)	[kWh/a]	-1'257	-20'188	-5'183	2'414
Primary energy demand - quarter (PV)	[MWh/a]	-36	-613	-158	87
Primary energy demand (PV) (spec.)	[kWh/m2a]	-4	-60	-15	7
CO2-Emissions - building	[kg/a]	1'346	-5'960	-326	1'733
CO2-Emissions - quarter	[t/a]	43	-180	-10	56
EPC		0.08	-0.42	-0.02	0.13
Zero-energy building		NEH -4	NEH -60	NEH -15	-

The best result for a zero-energy house refurbishment was achieved by the variant "4 heatpump - water" with an NEH-marking of -88 kWh/m²a, because it has a low primary energy demand and a high self-consumption of solar power. For example, in the static calculation the building with this energy supply concept has a primary energy demand of 15259 kWh/a. From this primary energy demand, the generated and self-consumed electricity of 44659 kWh/a is subtracted and a primary energy demand of 29400 kWh/a is remaining. Since additional electricity of 5469 kWh/a is generated and exported, the building achieves the net-zero standard. However, for the evaluation of a net-zero building only the remaining primary energy demand of 29400 kWh/a (equal spec. primary energy demand: 88 kWh/m²a) is recorded and written as "NEH 88". In other words, the smaller the number behind the abbreviation, the better the performance.

The values of Table 5 are evaluated in detail and describes the various primary energy requirements for the section of the space heating. Due to the high transmission heat losses through the building envelope, the pre-renovation building has the highest primary energy demand for heating supply of 187,8 kWh/m^{2}a. The primary energy demand for the heating of the demonstrator building (8,1 kWh/m^{2}a) is reduced by 96% compared to the pre-renovation building. Reasons therefore are the reduced heat loss through the insulation of the building, as well as the gained energy by the heat pump with geothermal sources. Even energy concept "3_heat pump with ground probe (300 m)" has a reduction in primary energy demand for heating (10,65 kWh/m^{2}a), due to the reasons just mentioned in variant "2". Likewise, in energy concept "4" a reduced primary energy demand for domestic heating (6,78 kWh/m^{2}a) can be determined, due to low heat losses through the building shell, as well as the gained energy from the heat source groundwater through the heat pump. The energy concept "5_air heatpump" has a primary energy demand for room heating of 36,1 kWh/m^{2}a and is higher than the primary energy demand of variants "2" to "4". This is because the air heat pump has the lowest COP of 3,5 for heating among the heat pumps. The result of the primary energy demand for room heating of the energy concept "6" (6,78 kWh/m^{2}a) should be considered critically, as PVT collectors as a heat source for a heat pump cannot be mapped realistically alone without another heat source in the calculation program "Uniec2", as this technology is very new. In variant "7_district heating", the Uniec2-software takes into account the district heating with a primary energy factor of 2,25 and results in a lower demand (9,2 kWh/m^{2}a) than that of variants "8" (70,7 kWh/m^{2}a) and "9" (43,5 kWh/m^{2}a). The reason for the high primary energy demand for the room heat supply of "8" and "9" is that the primary energy factor for electricity is in the Netherlands 2,56 and appropriate the same value for every case in the calculation. Between the energy concepts "8" and "9" it can be seen that variant "8" has a higher primary energy requirement for room heating due to the lack of heat recovery via the ventilation.

Three new concept to further develop

Based on the static energy demand calculation, as presented in Table 5 and Figure 5, a further investigation of three energy concepts is made. The following variants were chosen:

- 3_Heap pump with 300 m deep borehole heat exchanger,
- 6_Heat pump with PVT-collectors
- 9_100 % electrical heating concept.

This decision was justified by the fact that these three options have shown promising results in the static energy demand calculation and have future-market-oriented and innovative character, while still be feasible in the context of building renovation in the Netherlands.

A dynamic-thermal building simulation is set up to analyse the primary energy demand in detail. The model design was made with two base models which image on the one hand a corner building (Figure 6a) with three external walls and on the other hand a middle building (Figure 6b) with just two external walls.

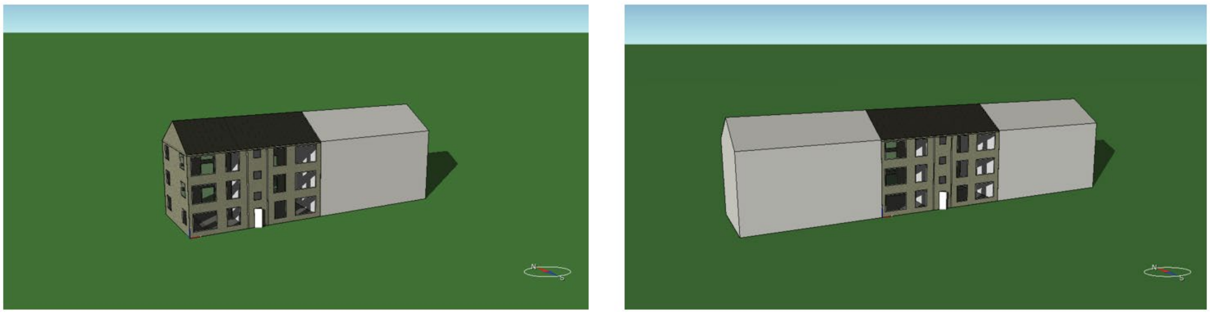


Figure 6: Model design of corner building and middle building in IDA-ICE

For the dynamic-thermal building simulation the software "IDA-ICE" (Indoor Climate and Energy) is used and the simulations showed following results for the primary energy demand in figure XY. This analysis included the energy balances for space heating and domestic hot water, ventilation technology, lighting, electrical household appliances and power generation. At this point it has to be mentioned that the demands of space heating and domestic hot water couldn´t be divided in IDA-ICE and is given as one value for heating.

The following diagram shows the results from the variant study for the three further investigated energy supply concepts.

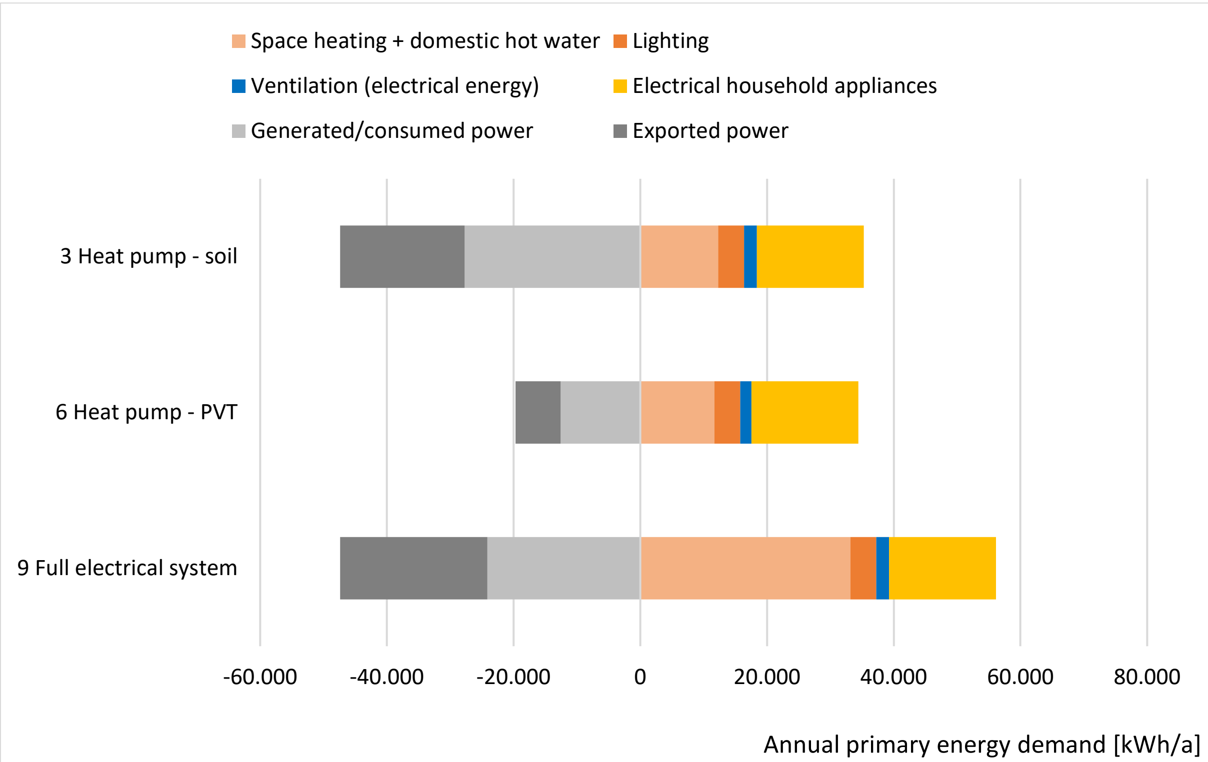


Figure 7: Annual primary energy demand for a building unit "A" and the quarter according to dynamic-thermal building simulation

The a zero-energy house refurbishment was achieved by the variant "3_Heat pump - soil", because it has a low primary energy demand and a high self-consumption of solar power. For example, in the dynamic-thermal building simulation the "3 Heat pump – soil" building has a primary energy demand of 35256 kWh/a. From this primary energy demand, the generated and self-consumed electricity of 27744 kWh/a is subtracted and a primary energy demand of 7512 kWh/a is remaining. Since additional electricity of 19620 kWh/a is generated and exported, the building achieves the net-zero standard.

The reason why the other two concepts do not reach zero-energy is the increased primary energy demand with 34434 kWh/a for the “6 Heat pump – PVT” variant and 56123 kWh/a for the “9 Full electrical system”. Due to the fact that in the dynamic-thermal building simulation all energy flows are represented the electrical demand for household appliances is also taken into account. In the end the “6 Heat pump – PVT” would need 14735 kWh/a to reach the net-zero energy goal. The difference for the concept “9 Full electrical system” is 8562 kWh/a. In this case already the whole roof surface is used for PV-panels. That means it would be necessary to reduce the primary energy on the consumption side e.g. reducing the transmission losses through improved insulation and due to more energy efficient light system or electrical household appliances.

Table 6: Annual primary energy demand for a building unit "A" and the quarter according to dynamic-thermal building simulation

		3 Heat pump - soil	6 Heat pump - PVT	9 Full electrical system
Space heating + domestic hot water	[kWh/a]	12'280	11'676	33'153
Lighting	[kWh/a]	4'088	4'088	4'088
Ventilation (electrical energy)	[kWh/a]	2'010	1'792	2'004
Electrical household appliances	[kWh/a]	16'878	16'878	16'878
Primary energy demand - building	[kWh/a]	35'256	34'434	56'123
Generated/consumed power	[kWh/a]	-27'744	-12'575	-24'137
Exported power	[kWh/a]	-19'620	-7'124	-23'242
Primary energy demand - building (PV)	[kWh/a]	7'512	21'859	31'986
Primary energy demand - quarter (PV)	[MWh/a]	229'116	666'700	975'573
Primary energy demand (PV) (spec.)	[kWh/m2a]	22.4	65.1	95.2
CO2-Emissions - building	[kg/a]	2'897	2'998	6'538
CO2-Emissions - quarter	[t/a]	88	91	199
Zero-energy building				

Conclusion for new energy concepts and the pilot concept

Within the further development of the 2ndSkin renovation, different options for building services were evaluated. The objective of such variations are that the 2ndSkin approach can offer different renovation packages, to match the context and objectives of different projects.

Next to the ground-source heat pump option, which was successfully applied in the Demonstrator, “NOM” renovation, the use of an air-water heat pump combined with PVT, which produce at the same time electricity and hot water, has proved to be very efficient. The electrical heating however has not proven to be very attractive due to the lower efficiency and the high electricity demand and the resulting CO2 emissions.

Based on those conclusions, three test concept were installed in pilot buildings. Those pilots have the purpose of testing the feasibility, space requirement and ease of installation for the energy concepts to future projects. The three pilot installations are the following:

1. **Hybrid system:** Vaillant VWS36 heat pump and 8 VolThera PVT panels, connected to the existing Combiketel and the existing radiators, providing a maximum needed output temperature of 55°C (for 10°C outside).

Figure 8: The hybrid heatpump and gas boiler, installed in the attic

2. **Decentral ventilation with heat recovery**. The existing ventilators on the window frame have been closed.

Figure 9: Decentral ventilation units on the external wall of the top-floor dwelling.

3. **All-Electric system** with Vaillant VWS36 heat pump and 16 stuks VolThera PVT panels,a 200 ltr water buffer, new, low-temp radiators with a temperature target of 40/35°C (A/R) (for -10°C outside). New heat recovery ventilation using the existing ventilation shafts is installed at the attic.

Figure 10: The new heat pump installed in the attic and the new LT radiators.

Figure 11: Installation of the PVT panels

LCA and circularity

LCA based on the demonstrator study

With the modular 2nd Skin system, the TU Delft developed a method to renovate post-war apartment buildings from the outside. Therefore, dwellings can be modified and energetically upgraded while the users are still able to occupy the building and the modification has little to no impact on neither the buildings physical, nor its social structures. Energy savings during the use stage of buildings are crucial to meet the goals set by the EU for a low carbon urban environment and a zero-energy (ZE) refurbishment rate of 3% of the existing building stock is needed to meet the goals by 2050.

While the 2nd Skin Demonstrator project offered a ZE solution for two units, the 2nd Skin Scaler project aims to increase the amount of units drastically to 30.5 building units. To achieve this increase in scale, the Demonstrator system was modified, lowering the energy standard to zero-energy ready. Since both 2nd Skin systems reduce the energy consumption during the use phase to a bare minimum, thus, reducing operational energy emissions, the systems embodied energy becomes more relevant. Embodied energy will further become the building sectors main energy consumption in the near future and has hence to be addressed.

The life-cycle assessment (LCA) focuses on each stage of a materials life-cycle and elaborates its energy consumption. As seen in Figure 1, the life-cycle is divided in four stages A-D. The production of materials is described by stages A1-A3, including supply (A1), transportation (A2), and manufacturing (A3), stage A4-A5 describe the construction process. Stage B looks into the operational phase, while the final stage C evaluates demolition (C1), transport (C2), recycle (C3), and final disposal (C4).

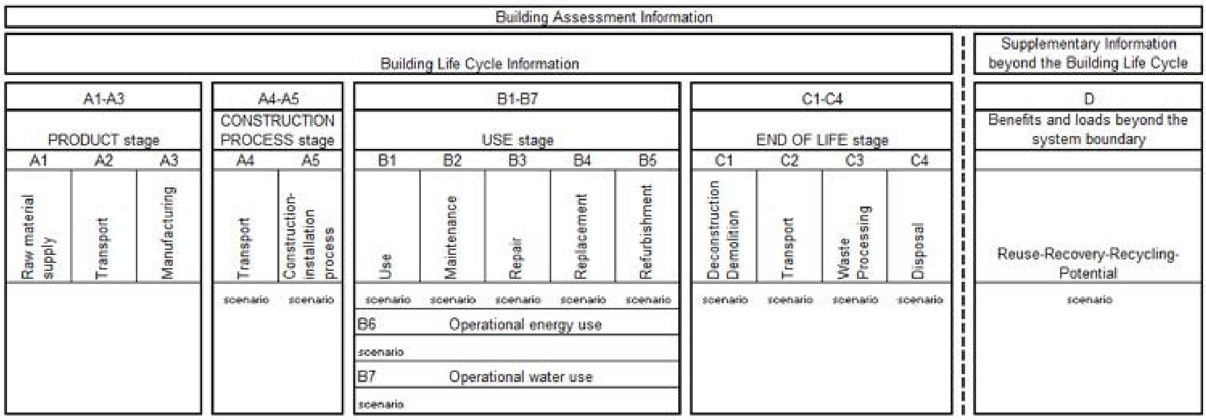


Figure 12: Process Stages of the Life-Cycle Assessment (EN 15804, 2012)

To compare the different 2nd Skin systems, the main indicators were chosen: primary energy (PE) non-renewable, PE renewable and the global warming potential (GWP). To get the necessary data for calculating the LCA, the “Ökobau.dat” was used, a German database supplied by the German Federal Ministry of the Interior, Building and Community.

In a first step, the production stage (A1-A3) of each component was examined, using the “Ökobau.dat” data and a custom Excel chart. On the foundation of the plans and Table 2 (differences Demonstrator / Scaler) this data was used to calculate the indicators for 1m² of each building element (façade, roof, floor plate, windows, pv). These results were then scaled up to the size of one dwelling (1 x A) and lastly to the size of the quarter (32.5 x A). It is thus possible, to compare the environmental impact of the different systems on multiple scales. Due to the innovative nature of the project, data does not exist for all components or materials. Missing values were estimated based on comparative materials.

To further analyze the performance of the system during the usually estimated lifespan of 50 years, the end of life stage (C3+4) and the recycling potential (D) were also scrutinized and calculated using the same methodology as for stage A. The period of use for each material was determined using the “*Building Component’s Period of Use for Life-Cycle Assessments According to the Rating System*

Sustainable Building" (BNB). Since none of the used materials last for less than 25 years, one refurbishment cycle can be estimated.

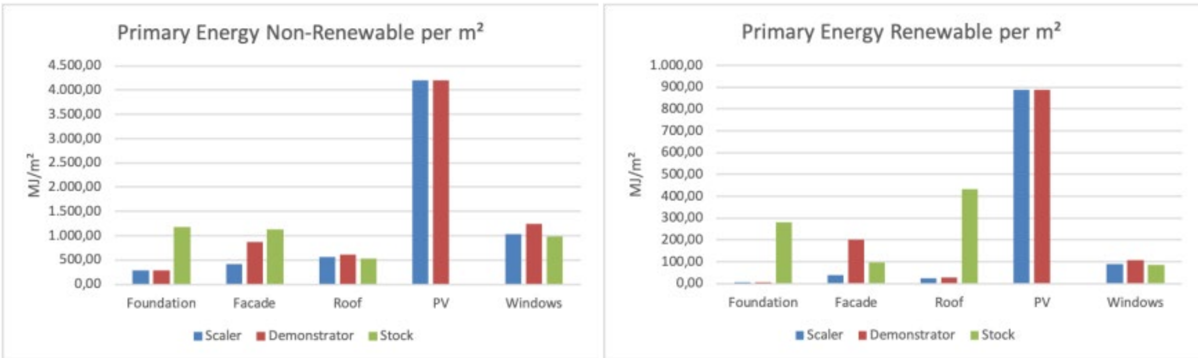


Figure 2: PE n-r and PE r per m² for LCA stages A1-A3

Looking at a square meter of each element, offers an overview of the different environmental behaviors. While the Stock values contain the structural mass of the building, the 2nd Skin values show the embodied primary energy of the added insulation layers. Thus, the differences between the Stock and 2nd Skin values for the Foundation and Façade values result and mainly derive from the used concrete components. When looking at the façade structures, the Scaler system with its brick veneer cladding performs better than the Demonstrator system, using synthetic resin rendering.

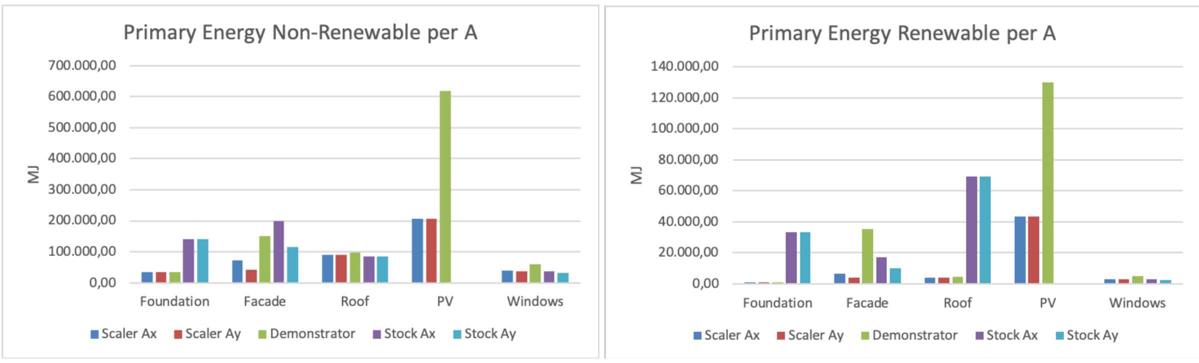


Figure 3: PE n-r and PE r per unit A for LCA stages A1-A3

The different sizes of the buildings lead to two different types of units, the ones at the start and end of each building with three exterior walls (in the diagrams referred to as Ax) and the ones in between with two exterior walls (referred to as Ay). Those types vary in façade surface and window area. The Demonstrator project was executed on two Ax units and compared to the Scaler project, received triple the amount of PV panels.

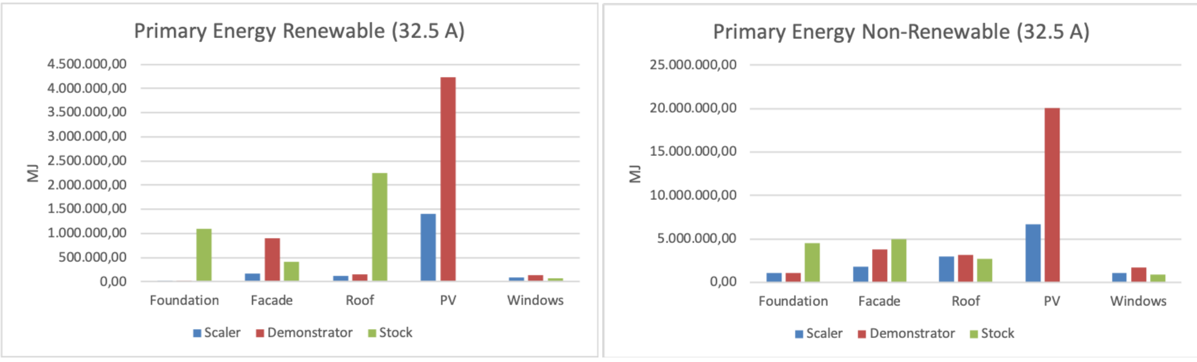


Figure 4: PE n-r and PE r of 32.5 A for LCA stages A1-A3

As seen in Figure 4, the PE consumption of the PV panels is by far the biggest. Nevertheless, they have the opposite effect when looking at stage C and D. Their vast recycling potential leads to a complete negation of the initial PE. Figure 5 shows this effect after 25 years, after 30 years when the façade and roof systems have to be refurbished, the embodied energy again slightly increases. Since both 2nd Skin projects used comparable materials, the lifespan does not vary.

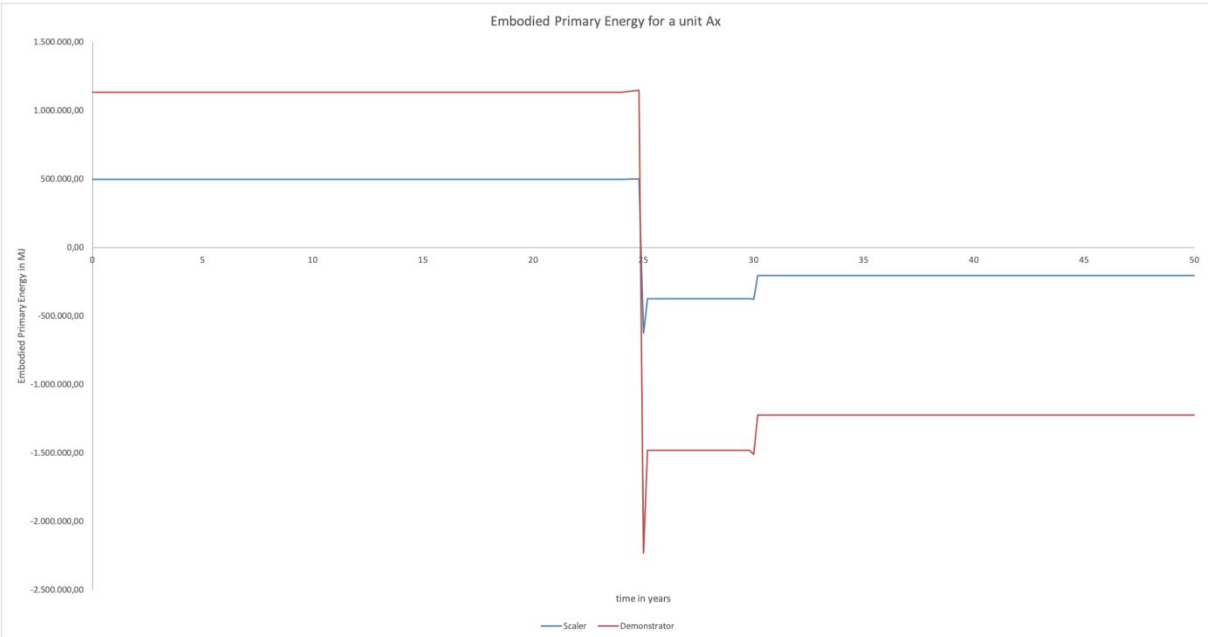


Figure 5: Embodied PE of one A over a lifespan of 50 years including LCA stages A1-A3, C3-C4, and D

Another important indicator for circularity is the global warming potential (GWP). The value shows the influence of the material on global warming through an equivalent amount of CO2. Natural materials therefore perform better than synthetic ones. Figure 6 shows this effect. The existing roof mainly contains wooden materials, the added insulation on the other hand is a synthetic composite, thus the big difference. Furthermore, the synthetic resin rendering raises the GWP of the Demonstrator façade and the Demonstrator's triple glazing has higher values than the double glazing used in the Scaler.

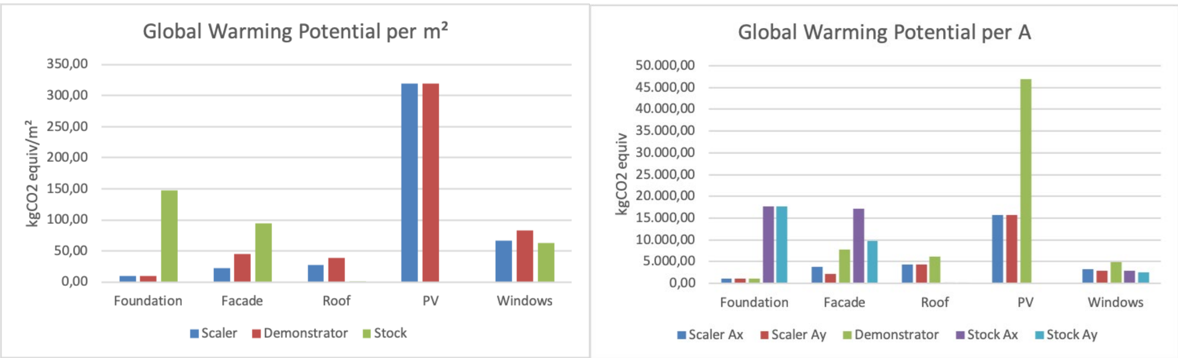


Figure 6: global warming potential (GWP) of 1m² compared to one A for LCA stages A1-A3

Circular building

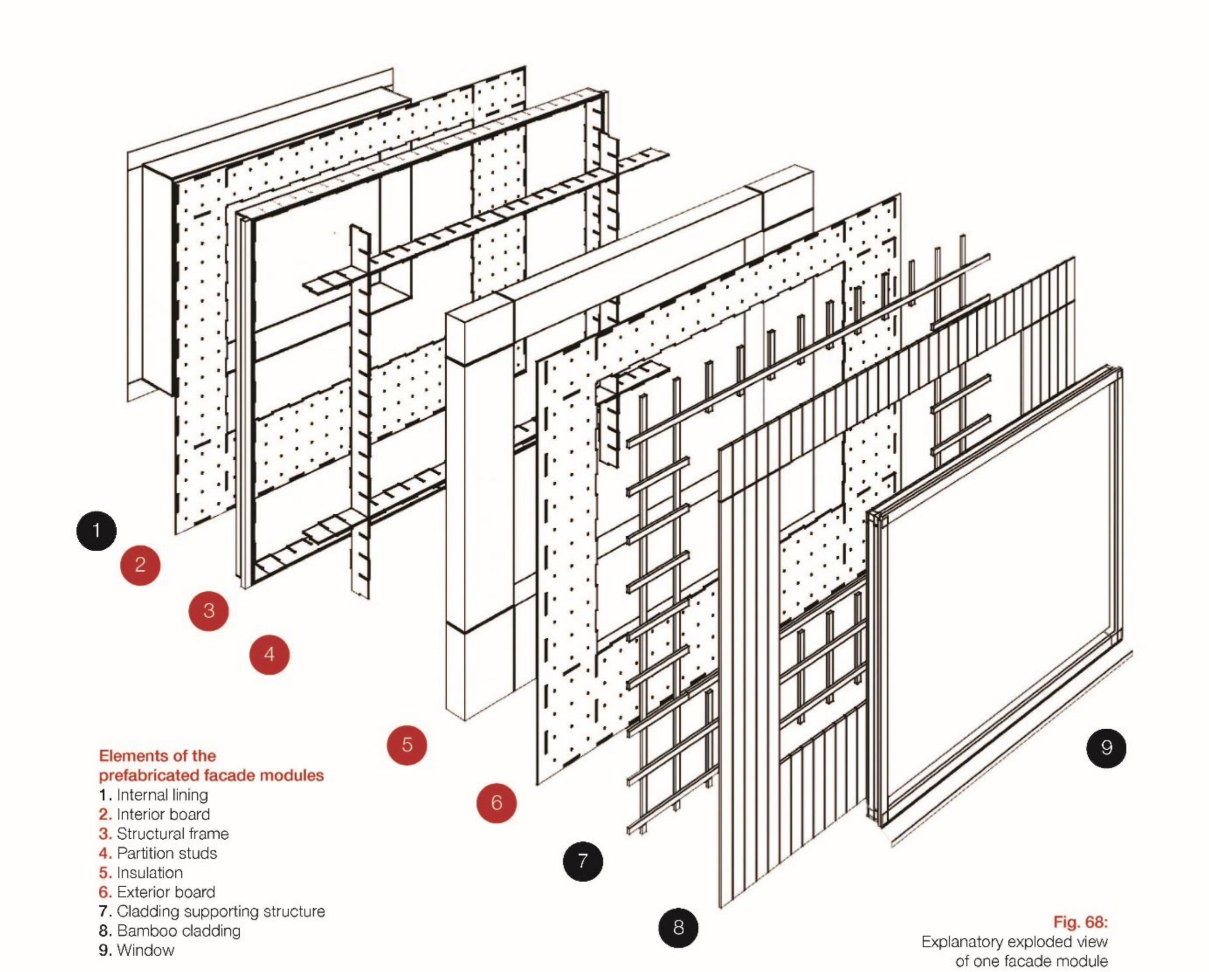
As part of the project, the circularity of the solution is discussed. Even though it is not the main driver in the decision making for the current solution, considering end-of-life scenarios for the components is an important issue for the future implementation of the renovation strategy. Many different interpretations of the concept of the Circular Economy have been developed in the past decade. Based on the analysed literature, the following definition is utilized for this research: The Circular Economy aims to close and extend the loops of material cycles, to preserve the value of materials, resulting in decreased raw material consumption and waste generation in our current society. To be able to shift from the linear model of take-make-dispose, that is dominant in our current society, to the Circular Economy, products should be designed in such a way that they can optimally be repaired (step 1), reused (step 2) and recycled (step 3), while taking into account minimal embodied energy of the materials. Important to mention is the complexity of the system, due to a large number of actors with different benefits and interests that are involved and interconnected in the system.

The circularity and LCA study of the previous Demonstrator phase presented that the benchmarking of circularity based on a unique indicator (the global warming potential) leads to profound and reasonable results. The analysis has shown that the global warming potential is the essential indicator to identify the potentials for the Circular Economy.

The study also concluded that there are two main drivers to minimise the global warming potential: the use of natural materials and the reduction of refurbishment cycles. Modular constructions, like the prefabricated structural insulation panel, help to remain materials as long as possible in the system. Modular constructions with releasable joints provide the replacement of inoperable layers by extending the usage of still executable structure materials.

Concept design for disassembly

A concept study to improve the level of circularity of the 2nd Skin Façade Refurbishment system was executed in collaboration with the Graduation project of Quirine Henry, student of Building Technology track of the MSc Architecture, Urbanism and Building Sciences programme at TU Delft. The following figure summarises the concept of the façade panel, which followed the principle mentioned before: one the one hand choose natural material, on the other hand, aim for modular, prefabricated construction with mechanical, instead of chemical, connection.



(source: Henry Q, 2018, "Circular Facade Refurbishment", thesis, TU Delft.)

As a first step in the redesign of the 2nd Skin Façade Refurbishment system, alternative materials are chosen that consist of secondary feedstock and have the potential to be restored at the end of life through preferable reuse and recycling. In the redesign the EPS insulation will be replaced by Metisse insulation, that consists of recycled cotton, coming as waste stream from the clothing industry. The structural frame of the prefabricated panels will be made of ECOBoard instead of chipboard because ECOBoard mainly consists of agricultural waste feedstock and is biodegradable and recyclable at the end of life. As cladding material is chosen for Accoya wood, instead of bamboo, due to its dry connection method and its biodegradability at the end of life. When the architectural appearance of the existing façade needs to be preserved, proposed is to choose for a different type of brick cladding system, in which the brick strips are chemically connected to a fibre cement board, which is in turn mechanically connected to the facade supporting structure. This way the cladding can be removed from the prefabricated panels without damaging the surrounding components, which was the case in the original situation.

In the redesign, the type of connections within the prefabricated panels has been changed from wet to dry connections. Instead of using a chemical connection between the insulation and the structure of the prefabricated panels, the connections have been made with premade geometry, that enables easy reconfiguration and replacement of elements within the module without the need to disassemble the complete module.

Next to that, the standardisation of the elements is increased to enable direct component exchange between two case study buildings that are in need of refurbishment. The horizontal and vertical studs of the prefabricated modules are dimensioned on a grid of 150 x 150 mm that fits to the façade arrangement of different buildings studied. This way direct reuse of the horizontal and vertical studs is possible for the same application, with as little adjustments as possible.

The main advantage of the proposed redesign in terms of circularity, is that the elements that the prefabricated modules of the redesign consist of have become reusable at the end of their functional service life. The high level of standardisation makes reuse of elements for the refurbishment of a second or even a third residential building with a different facade typology possible. At the end of their technical lifetime, the materials that the prefabricated modules consist of, can all be recycled for the production of new building products. Besides, reconfiguration of the facade is enabled without disassembling the complete system. Replacement of components that have reached the end of their technical lifetime during their functional service life have been enabled by making the components easily accessible. For these reasons, the Disassembly Potential of the system has increased by allowing to remove, modify and replace the building components without changing the frame.

Future development towards circular product

Improving the circularity of the 2ndSkin solutions is a main ambition for the consortium. Next to the above mentioned studies, the consortium has taken the following steps towards circular product development.

New façade concept Rockwool

The 2ndSkin consortium in collaboration with the insulation manufacturer ROCKWOOL, have developed a lightweight façade component that is possible to easily assemble and disassemble. It provides the required insulation thickness, also according to the 2ndSkin standards and different possibilities for cladding. This construction can replace the currently applied EPS external insulation.

Figure 13: Segment of the circular facade component.

Circular façade development: Test case Reigersbos buildings, Amsterdam

The 2ndSkin consortium is in collaboration with the City of Amsterdam and housing and owners' associations in the district Reigersbos in Amsterdam-Zuidoost, with the objective of applying the 2ndSkin renovation to those buildings. There is a particular request for circular solutions and, to this end, it is planned to design, construct, monitor and disassemble a façade panel on an apartment of the building shown in Figure 10.

Figure 14: The pilot site in Reigersbos, Amsterdam-Zuidoost

2ndSkin packages

The main conclusion of the investigation within the WP2 of the SCALER project is the definition of the 2ndSkin as a renovation product, that offers different packages, to match the future projects' objectives. The following packages are offered:

Table 7: Overview of the 2ndSkin option packages

Package	Description	Benefit
Premium	- Façade RC= 4,5 - Roof RC= 6,0 - Floor RC= 3,5 - Double-glass panes (HR++) with PvC frames - Gas boiler - Mechanical ventilation with CO^2 sensors - Trickle Ventilation on the windows - Radiator maintained OPTIONAL: PV panels	- Improved building envelope to high-efficient - Improved comfort - Low price
Hybrid	- Façade RC= 4,5 - Roof RC= 6,0 - Floor RC= 3,5 - Double-glass panes (HR++) with PvC frames - Gas boiler (if replaced ≤5 yrs) - Mechanical ventilation with CO^2 sensors - Trickle Ventilation on the windows - Heat pump **3kW** - 4 **PVT** panels - Radiator maintained - Upgrade of electrical system OPTIONAL: PV panels	- Improved building envelope to high-efficient - Improved comfort - Low price - No-regret/future proof renovation - Electricity and heat generation
All Electric* **Lucht/Water** ***Gasfree**	- Façade RC= 4,5 - Roof RC= 6,0 - Floor RC= 3,5 - Heat-pump 6kW - 4 **PVT** panels - 11 PV panels - Heat recovery ventilation, ventilation pipes on the facade - Triple-glass panes (HR+++) with PvC frames - Radiator maintained - Upgrade of electrical system - Energy performance subsiry (EPV) monitoring	- Improved building envelope to high-efficient - Improved comfort - Electricity and heat generation - Disconnect from natural gas - Low energy demand - Possibility for subsidy
Zero Energy (NOM)* **Ground source** ***Gasfree**	- Façade RC= 4,5 - Roof RC= 6,0 - Floor RC= 3,5 - Triple-glass panes (HR+++) with PvC frames - Heat recovery ventilation, ventilation pipes on the facade - Ground source heat pump (reversible heating/cooling) - 15 PV panels - New convectors - Upgrade of electrical system - Energy performance subsiry (EPV) monitoring	- Improved building envelope to high-efficient - Improved comfort - Electricity and heat generation - Disconnect from natural gas - Zero energy demand - Possibility for subsidy

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