AN INTEGRATED DESIGN PROCESS FOR A ZERO-ENERGY REFURBISHMENT PROTOTYPE FOR POST-WAR RESIDENTIAL BUILDINGS IN THE NETHERLANDS

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Abstract

Although refurbishment is a necessary step to reach the ambitious energy and decarbonisation targets for 2020 and 2050, which require an eventual reduction up to 90% in CO2 emissions, the rate of renovation is still relatively low. There is an increasing demand to upgrade both the physical condition and the performance of the building, with the minimum disturbance to the interior, so that the occupants do not have to be relocated during construction. Thus, the role of the occupant becomes essential not only in terms of performance during the post-refurbishment phase, but also in terms of the design and planning of the refurbishment. Furthermore, the traditional design and delivery processes are fragmented and are not efficient to take on the challenges ahead.

To address these issues, the 2ndSkin-BTA project brings different stakeholder together, aiming at reversing the traditional decision-making process, to integrate their expertise and objectives into an innovate building technology concept. The objective is to design, construct and monitor a renovation project that achieves zero energy use of a dwelling, while providing upscaling possibilities and broad adoptability of the process. This paper presents the first project phase, which is the integrated design process. To this end, the development of the preliminary design of the refurbishment strategy is based on a reference building. It proceeds in parallel with the prototypes' development and it benefits from the test results. Nevertheless, the proposed design is not a one-project solution but rather an approach that highlights the underlying argumentation line for different retrofitting measures, in different cases.

1. Introduction

Being one of the biggest energy users (Eurostat, 2013), the residential building stock needs to be upgraded in order to improve performance, reduce energy demand and eventually reach the ambitious energy and decarbonisation targets for 2020 and 2050 that require an eventual reduction up to 90% in building sector related CO2 emissions (European Commission, 2011). This reduction is larger than in other sectors such as transportation, agriculture and industry, indicating the importance of the building sector and the urgency of the measures to be taken. In order to achieve this significant reduction, the recast of the EPBD in 2010 suggests that new buildings should be low- or zero-energy buildings (DIRECTIVE, 2010/31/EU). As a greater challenge, however, the European Commission (2011) stated the refurbishment of the existing buildings, suggesting that over the coming decade investments in energy-saving building components and equipment will need to be increased by up to € 200 billion. While new buildings can be constructed with high energy performance levels, the existing stock is predominantly of poor energy performance and consequently in need of renovation work (Atanasiu and Kouloumpi, 2013).

In this context, the depth of refurbishment needs to grow. Superficial renovations, as opposed to deep renovation, significantly increase the risk to miss the climate targets and leave huge absolute savings untapped (Hermelink and Müller, 2011). The depth of the refurbishment is related to the level of energy or greenhouse gas emission savings that are achieved when refurbishing a building. A renovation is specified as "deep" when energy savings of 60-90% are achieved. An effective renovation plan has to be long-term, target the deep transformation of the existing building stock, and to significantly improve its actual energy performance towards nearly zero energy levels (Atanasiu and Kouloumpi, 2013). This level of energy saving typically requires a holistic approach, viewing the renovation as a package of measures working together (BPIE, 2011). Renovation with a zero energy objective can be achieved through high envelope insulation, air tightness, triple glazing, efficient heating and ventilation systems and renewable energy installations, such as photovoltaic. Several European exemplary renovation projects demonstrate that it is possible for renovation to achieve the zero energy objective (Attia, 2015, NeZeR, 2014).

Even though the need for refurbishment is urgent, the rate of renovation and the resulting energy savings are relatively low. Main barriers identified are related to the available investment funds, awareness, advice and skills and the separation of expenditure and benefit (BPIE, 2011). The role of the occupant becomes essential not only for the performance in the post-refurbishment phase, but also in the design and planning of the refurbishment, particularly since the demand increases to upgrade both physical condition and performance of the building, with the minimum disturbance to the interior, so that the occupants do not have to be relocated during construction. The satisfaction of the occupants is also important for the application and upscaling of the refurbishment (Cozijnsen *et al*., 2015). Furthermore, refurbishment of the building stock is a complex task with a lot of aspects to be considered, which determine the way each building is approached. In this sense, research (SHELTER, 2013, OneStopShop, 2012) has shown that current design and delivery processes are very often fragmented and not efficient and still contain a high level of uncertainty concerning long term performance.

The envelope of a building can be the medium both for fabric and building serviced upgrade, combined with generation of energy with renewable sources, combining both passive and active measures (Konstantinou, 2014). In this way, it is possible to achieve improved performance and quality of the dwelling without interfering severely with the interior. Prefabrication of the retrofitting components can pose the potential to achieve high performance solutions, while minimising on-site construction time (IEAAnnex50, 2012).There are several examples of projects limiting construction time along with the energy demand, using methods such as prefabrication of the components (TES Energy Façade, 2014, EnergieSprong, 2014, Stroomversnelling, 2014). However, research is still underway for apartment buildings, which constitute an important part of the stock while they are particularly challenging in becoming energy neutral. This is due to their ratio of number of apartments versus available skin surface for energy generation. Additionally, a large amount of such buildings are social housing estates, with their particular groups of tenants and the specific ways of financing.

To address these issues, the “2ndSkin” project brings different stakeholder together, aiming at reversing the traditional decision-making process, in order to integrate their expertise and objectives into an innovate building retrofitting concept that achieves zero energy use of a dwelling, while offering upscaling possibilities and broad adoptability of the process. The objective is not only to find a successful refurbishment strategy for a specific building type, but also determine the framework within which the proposed solution can be adjusted. If the result of the 2ndSkin strategy is extracted on a nation-wide Dutch level, this would suggest 300.000 energy-neutral dwelling that are within the direct target group.

This paper presents the first project phase, which is the integrated design process, aiming not only at finding a successful refurbishment strategy for a specific building type, but also determining the framework and criteria within which the proposed solution can be adjusted and up-scaled. To this end, the development of the strategy is based on a reference building. It proceeds in parallel with the prototypes’ development and it benefits from the test results. Furthermore, an important part in the process was the development of performance criteria, regarding energy consumption, inhabitants’ disturbance and comfort, robustness, simplicity, etc. Finally, the preliminary design for a reference building was developed based on those criteria.

2. The Methodology and the Scope of the project

One of the main developments of the project was to determine a methodology that addresses the objective, but also the challenges of the project. It aimed not only at providing a solution to refurbish the case study buildings, but most importantly delivering knowledge and results that can be used in the refurbishment task on a national and European level. The development of the strategy integrates different aspects that determine the performance of the refurbished building. These are the building envelope, the building services and the occupant. The strategy development is based on a reference building, as it has been determined to serve the scope of the research. Furthermore, the design and implementation is tested in prototypes and the results are used to improve the reference building design. Finally, the project aims at extrapolating the reference design for more building types than the initial scope.

2.1 Methodology for prototyping and up-scaling

The relationship between the 2ndSkin final strategy and prototyping is one of the main project innovations. The 2ndSkin team has realised that a direct replication of the prototyping to the up-scaling strategy may be a factor that hinders the project and decision-making. This is because some of the technologies to be implemented need to be further proven before applied and used on a large scale. More flexibility should be brought into the prototyping strategy, meaning that the prototypes will be used to test the construction, performance and the user interaction with technologies to be implemented in the upscaling of the 2ndSkin strategy. For this reason the development of the 2ndSkin strategy is based on a reference building. It proceeds in parallel with the prototypes’ development and it benefits from the test results. The process of the project consists of the following steps:

A. Setting the scope of the refurbishment strategy
B. Design the solution based on reference building
C. Test specific aspects on Prototype 1
D. Consider test results and revise refurbishment strategy
E. Apply refurbishment in Prototype 2 - Up-scaling
F. Evaluate Prototype 2 and suggest up-scaling methods

In principle, there are two axis of the strategies development, shown in Figure 1. Steps B, D, F focus on the 2ndSkin strategy on the reference building, while steps C and E include the construction and testing of prototypes.

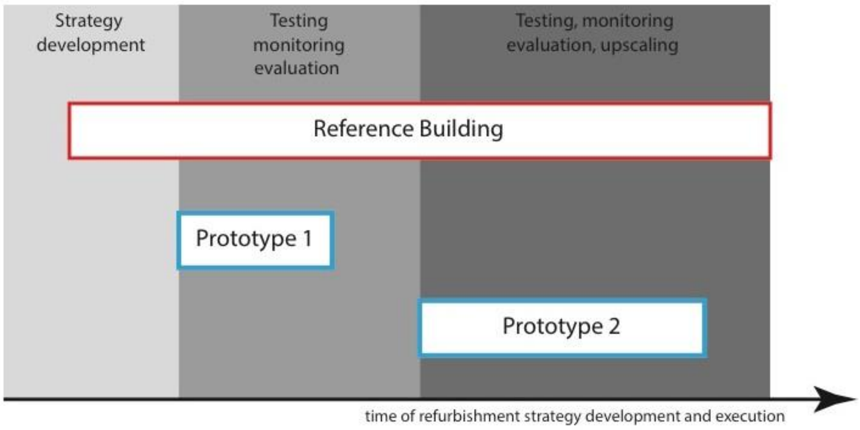


Figure 1 Timeline of the strategies' development, showing that the reference 2ndSkin strategy is developed in parallel to the

2.2 Reference building

The target group for the present investigation are the post-war apartment buildings in the Netherlands. After World War II, most European countries experienced a large housing shortage due to war devastation, population increase and economic growth. This shortage was answered with a high level of building activities, focusing on quantity rather than quality (Andeweg *et al*., 2007), with a large degree of prefabrication and industrialised methods (Priemus, 1986). As a result, the European housing stock originating from this period accounts for a considerable share of the total stock, while it lacks technical and functional performance. Moreover, being 50 years old, the building envelope has reached its end of life while generally the structure is sound (Andeweg *et al*., 2007). Due to the circumstances of its development, the post-war housing stock has specific characteristics in terms of neighbourhood design, construction and problems.

To understand why this building type is particularly interesting in the Dutch context, the primary focus of this project, some data on the building stock is presented. The building stock in the Netherlands accounts for 7.5 million dwellings (CBS). During the period 1946-1974 more than 2 million dwellings were constructed in the Netherlands. As a result, dwellings of the post-war period account for approximately 1/3 of the residential stock. However, these buildings were generally poorly insulated at the time of construction and there is a need for renovation (Itard and Meijer, 2008). Of these 1.3 million are social housing (Platform31, 2013). Housing associations are an important stakeholder in this context. There are approximately 400 housing associations in the Netherlands that manage 2,4 million residential properties, constituting 34% of the total housing stock (AEDES, 2013). A large amount of those properties are in need of renovation, as the housing associations have the ambition to achieve energy label C for 80% of their properties and an average label B by 2020 (AEDES, 2012), while currently the average label for post-war buildings according to AgentschapNL (2011) is D-E.

Table 1 The Dutch building stock in numbers (source:Platform31, 2013).

	Total residential stock	**Post-war residential stock (1946-1974)**	**Total apartment flats**	**Post-war apartment flats**	**Industrialised systems (all dwelling types**
no. dwellings	7300000	2600000	878000	381000	450000
% of the total stock in the NL		**36%**	**12%**	**5%**	**6%**

Analysis and evaluation of the existing building is an essential first step in every refurbishment project. In the context of 2ndSkin, the building stock analysis is necessary in order to identify the building type into which the pilot refurbishment prototype will be implemented. Moreover, the specific characteristics of the construction can be important in shaping the retrofitting solution. About 15% of the post-war construction was carried out in a precisely defined, modular system that was replicated for thousands of dwellings. They were characterised as non-traditional and industrialised systems, because prefabrication, new materials and ways of constructions were predominant and they are well documented in the literature (Priemus and Elk, 1971). However, dwellings that were not constructed with industrialised systems still show a high degree of similarity, in terms of material, techniques and layout (Platform31, 2013). The analysis on the post-war residential stock is based on the non-traditional systems, as they are representative of the period and better documented. They serve the purpose of the research better, which is to identify the important building characteristics that determine the refurbishment strategy. These characteristics include floor plan layout, location of utilities spaces, balcony type, wall construction, connection with the slabs, and window-to-wall ratio.

Next to literature research, on-site investigation was carried out in the area of Rotterdam-Zuid. Observation and documentation concluded different building types in terms of wall, window, roof type, balcony location, the existence and construction of the parapet, staircase etc. Based on the building stock literature research and on-site analysis, a reference building type was determined, which is considered the most common type in the area of investigation while having typical characteristics found in the building stock analysis. The reference building is shown in Figure 2. The basic characteristics are as follows:

- Mid-rise apartment block
- Central staircase, accessible from the front façade, leading to two apartments per storey
- Massive wall with reinforced concrete slabs
- Brick cladding with cavity and no/little/out-dated insulation
- Large windows, incorporating lightweight parapet
- Continuous floor slabs in the balconies

Figure 2 Reference building

3. Design criteria

Next to the primary goal, which is the design, construction, monitoring and up-scaling of innovate building technology concepts that can achieve zero energy use of a dwelling, the requirements for the design where developed, addressing the different aspects of the refurbishment. These requirements will be eventually used as criteria to evaluate the solution. The requirements of the prototype, meaning the goals the refurbishment aims at achieving, can be related to the design of the strategy and user.

An issue as complex as refurbishment needs to fulfil requirements on different levels. The 2ndSkin design addresses considerations such as upgrade of thermal performance of the components, together with airtightness, thermal bridges, comfort, efficiency, installation and control of building systems. The production and construction aspects, such as modularity, flexibility and prefabrication, are very important for the concept, as well as the added value of the concept for the dwelling, e.g. the addition of extra space or improved architectural appeal.

To organise this complexity, the following aspects have been specified during the design investigation of the 2ndSkin team. They were concluded as part of the project objectives or issues that emerge during the design elaboration. Some of the aspects can be translated into quantified design criteria. For aspects that are more qualitative, such as the robustness of the solution, Table 2 defines levels that allow to translate quantification into design criteria. The target of zero-energy refurbished building, while ensuring occupants' comfort, is the primary consideration. Keeping the investment at standard refurbishment costs, the possibility for new business in the supply chain and the flexibility of the solution are also very important for the concept application in the future and they constitute a big part of the investigation. Furthermore, defining and facilitating the role of the occupants is part of the design consideration. Table 3 provides an overview of the criteria quantification.

3.1 Zero-energy consumption

The main objective of the retrofitting is to achieve zero-energy consumption. To define a zero-energy building, the metric of the balance, balancing period and the type of energy use included in the balance are important issues (Marszal *et al*., 2011). The proposed metrics of the balance is Primary Energy (PE) demand. Primary energy demand is in accordance to the EPBD and takes into account differences between energy sources, which can help to make decisions during the design phase, for example selecting between the use of a small quantity of gas or renewable electricity for heating. An annual balance is preferred; otherwise the zero-energy targets would be difficult to reach given the differences of energy demand between summer and winter. This is the most favoured period of balance in current methodologies.

Two types of energy end uses have been defined: building related and user related. There is a direct correlation with occupants' comfort and the building-related energy consumption, as it is the energy used by HVAC systems, as well as lighting and other auxiliary energy, which are needed to ensure comfort. This consumption is influenced by the occupants' needs (indoor temperature setting) and lifestyle (retired, working at home, full-time working) and the type of household (single adult, couple, family, etc.). On the other hand, user-related energy consumption is made up by the end uses of domestic hot water (DHW), appliances and cooking. The zero-energy solution should cover at least all of the building-related energy consumption for all types of households. The building-related energy consumption per household type will be calculated through building simulations based on statistically defined occupancy patterns. Given that user-related energy consumption is less related to satisfying a need originated by occupying a space, and it may vary not only across different household types but also within the household type, the zero-energy solution could cover only the average energy consumption per household type.

The system boundary considered for the zero-energy calculation, systems' dimensioning and calculation on expected energy consumption can be based on one group of three to six flat units, accessed by a central staircase. Following phases of the research will focus on the feasibility of assessing the performance of the building on either a building level (a determine number of units), or neighbourhood level (all refurbished buildings belonging to the housing association). At this point it is important to make a clear distinction between the design and calculation phase and the evaluation phase. The design and calculation phase could be based on a building level since it implies the dimensioning of the systems, and it is determined by the occupancy in individual units (flats); while the evaluation phase could be made on the basis of building blocks or neighbourhoods since the focus of the zero-energy performance could be based on the property of the housing association (the investor, developer and manager of the buildings).

3.2 Costs

The targeted cost per dwelling is 50 000 euro, excluding VAT. This estimation is based on the current situation of the Dutch market, such as requested by housing association MITROS (2014). This is considered an average investment for standard refurbishment, even though the 2ndSkin concept aims at a more advanced solution, resulting in zero-energy consumption.

3.3 Possibility for new business model

For the concept design and most importantly the realisation, the supply chain plays a critical role. Proposing a new business model for the construction and delivery of the retrofitting components is part of the objectives. In the Netherlands, general contractors (GC's) are involved in almost all projects. They have a major role in facilitating a project and carry responsibilities towards the client. The architect makes general design specifications, but the real execution design is left to GC. A huge number of competing products is available on the market. Suppliers try to compete on quality and price levels. In many cases the façade builder gets bypassed and the GC has direct relations to the suppliers.

This model works well when known building methods are applied. General contractor and façade builder focus on improving building methods and on reducing costs. There is no incentive for completely new approaches in this competitive market, simply because the costs pressure is high, stakeholders work from project to project and financial risks must be minimized. Innovation only slowly finds its way into the process by incrementally improved products. Products that demonstrate a real innovative leap and do not comply with the traditional fragmented structure are difficult to introduce. The 2ndSkin projects aims at combining traditionally separated disciplines (Facades and Building Services), which are designed and built by different entities.

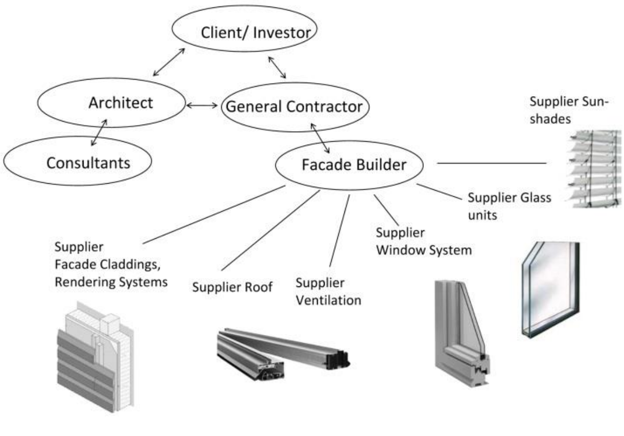


Figure 3 Scheme of the typical supply chain (source:Klein, 2013)

3.4 Up-scaling possibilities

The solution should be flexible to give the possibility for adaptation to different buildings. The main points of attention are the wall and window dimensions and their ratio, roof type, balcony location, the existence and construction of the parapet, staircase location and other.

3.5 Innovative character

As explained in the methodology, some of the technologies and their integration need to be further proven before applied and used on a large scale. Therefore, the project consists of three stages. The first prototype tests systems with available technologies. Secondly, we use the test results to develop future, more innovative solutions and, thirdly, we provide an outlook of an improved version that includes promising technologies available in the near future.

3.6 Inhabitants' disturbance

One of the starting points of the project development was that the occupant would not have to be relocated. To achieve that, the renovation has to be realised from the outside as much as possible, so that the occupants can continue living in the house, or need to vacate just for a few days. Renovation should not take more than 10 days for each apartment and noise and dust should be kept to a minimum. Prefabrication of the components can support these objectives.

3.7 Robustness, simplicity

Given the potential for mass-implementation, the concept needs to provide a simple and robust solution, to address users with different backgrounds and lifestyles. The control possibilities, ease of operation and maintenance will require limited user involvement, in order to minimise the chance of errors and unsuccessful performance.

Table 2 Levels used to quantify the qualitative aspects. Levels in general scale up from minimal actions to bigger engagement of the user

Aspect	Level A	Level B	Level C	Level D
User position	user stays in house, limited dust and noise disturbance	user will leave house for less than a week	user will have to leave house for more than a week	user relocated
User control	no possibility	basic and limited control	full control	
Maintenance or exchange components	independent from interior use	done by layman/user	by all technical personnel	by specialist
Operation	no active operation needed by user	simple operation with clear choice of limited options	need to read simple manuals and understand choices	need to read manuals, comprehensive understanding and regular adjustment

The following table (Table 3) shows how the determined aspects are translated into design parameters and criteria. Moreover, those parameters are relevant to different levels of the solution, from material to components or building level. The prototype will help to determine the values for some of the criteria, to be applied in the upscaling.

Table 3 List of parameters, requirements and quantified criteria of the 2ndSkin refurbishment concept. The criteria can be influenced by different levels, from material to component, or whole-building solution.

Parameters	Criteria	Value	Unit	Material (e.g. cladding, insulation type)	Sub-component (e.g. window frame)	Component (service system, façade)	Building (2ndSkin solution)
			Energy				
Energy performance	Energy consumption	0	kWh/dwel/yr				X
	Energy generation:	Not fixed	kWh/dwel/yr			X	X
			Comfort				
Thermal comfort	Temperature living spaces	20-25/ 23-26	^{o}C				X
	Temperature aux. spaces	16-25	^{o}C				X
	Relative humidity:	25-60	%				X
Indoor air quality/ Airflows	Air flow	7	l/s/person		X	X	X
		0,7	l/s/ m2 (external envelope)		X	X	X
	Min air flow during occupied periods	0.05 - 0.1	l/s/ m2			X	X
	Air change per hour (estimated for space height 2.5m)	0,6	ach				
	Air speed (draft)	0,2	m/s			X	
Lighting	Illumination levels	100-200	lux				X
	Daylight Factor (DF)	2 to 5	%		X		X
Noise level (Not to be exceeded)	Living room	25-40	dB(A)		X	X	X
	Bedroom	20-35	dB(A)		X	X	X
			Renovation from the outside as much as possible				
Inhabitants' disturbance	User position	A	level				X
	Building duration max.	10	days		X	X	X
			Robustness, simplicity				
	User control level	B	level		X	X	
	Ease of operation	A-B	level		X	X	
	Ease of maintenance	A	level		X	X	
			Facade				
Façade construction	Roof	5	m2K/W	X		X	
	Facades	5	m2K/W	X		X	
	Glazing:	0,8	W/m2K	X	X	X	
	Window frame	0,8	W/m2K		X	X	
	Airtightness:	0,4	dm3/s.m2		X		
	Construction depth	30	cm	X	X		
			Costs				
Investment cost	Costs for the whole apartment renovation	50000	€/dwel	X	X	X	X

4. Preliminary design

Based on the design criteria explained in the previous section, the preliminary concept design was developed. The design was conducted around three axes, corresponding to three design teams; one focussing on the skin (building envelope), another on building services (ventilation, space heating energy production and water) and a third on user interaction (monitoring, acceptance & interfaces). The design elaboration process has resulted in a number of options on a component and sub-system level. Based on the systematic organisation and evaluation of options, the design teams have come up with combinations for the 2ndSkin preliminary design.

The 2ndSkin design principle to reach zero-energy dwellings is based on the “Trias Energetica”; first prevent the use of energy (prevention), then use sustainable energy sources as widely as possible (renewable) and, finally, use fossil fuels as efficiently as possible. Particularly for zero-energy buildings, if the use of finite (fossil) energy sources is inevitable, the third step suggests using them very efficiently and compensate with 100% renewable energy (AgentschapNL, 2013). It becomes evident that the concept needs to be integrated, combining the building envelope upgrade, the use of efficient building systems and the generation of energy. As a first step, the building envelope retrofit needs to reduce the energy demand for heating and cooling, by increasing the thermal resistance and the air-tightness of the envelope components. This is achieved by replacement of existing windows and the addition of insulation on the opaque elements of the façade and roof. Moreover, energy generation is necessary to reach the zero-energy target; thus, PV panels are installed on the roof, while installations to improve ventilation are also integrated.

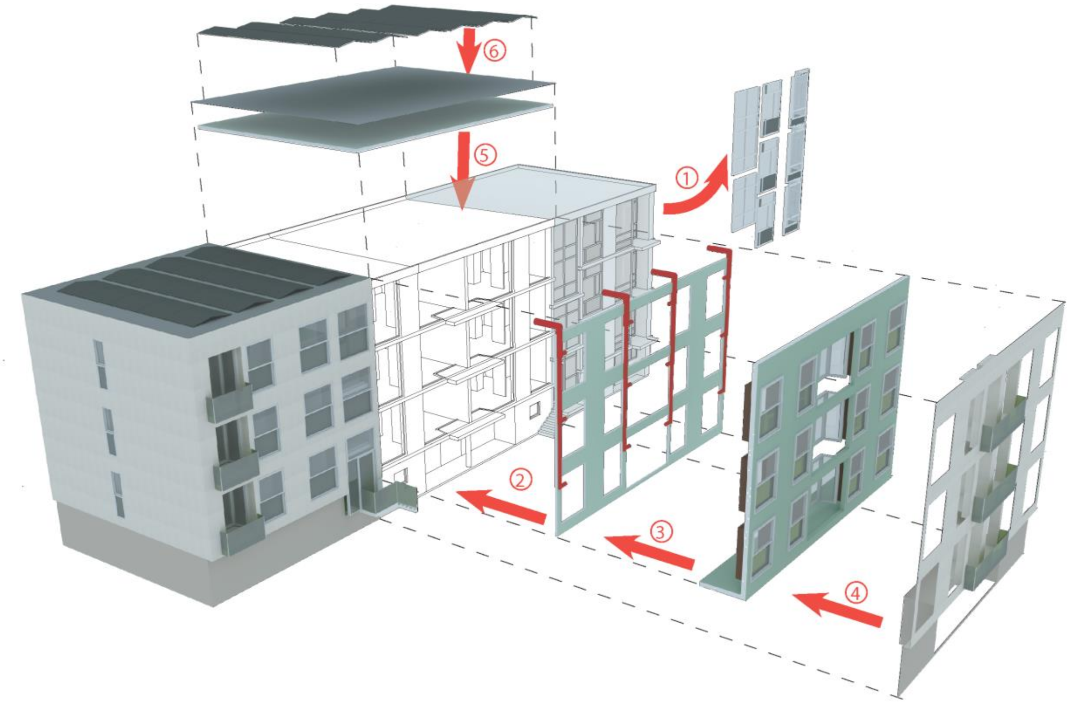


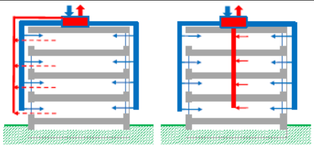
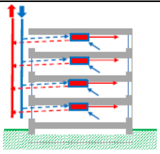
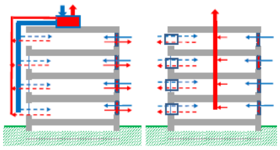
Figure 4 Exploded view demonstrating the production sequence of the 2ndSkin concept (illustration SPEE Architecten)

Finally, the architectural appearance of the retrofitted buildings needs to be refreshed and modernised. Figure 5 shows the new architectural language developed for the 2ndSkin concept, comprising upgraded façade components, as well as building services replacement. Based on this concept design, the production plans are realised, in collaboration with the architect, the contractor and the product suppliers.

Figure 5 Impressions of 2ndSkin Reference Building (illustration SPEE Architecten)

Throughout the design investigation, as well as the options evaluation workshop, the choice of ventilation system is considered critical in order to determine the refurbishment strategy. To this end, it has been decided to test three ventilation concepts with Prototype 1. Retrofitting the other systems and components will adjust respectively. The choice of ventilation strategy has proven crucial for the development of refurbishment concepts. Therefore Prototype 1 will test different ventilation concepts and the respective incorporation in the building envelope. Table 4 shows the concepts to be tested.

Table 4 Preliminary concepts to be tested in Prototype 1

Ventilation system	Advantages	Considerations	SKIN
 Heat recovery, collective air in via facade	Collective installation Easy maintenance	Limited flexibility Likely unsatisfactory because users will circumvent the system.	Ducts running through facade External insulation Replace windows with HR++ Integrate air inlet/outlet into window frame
 Heat recovery from inside the building, decentral ventilation per apartment	Ventilation system 4 is safer and could be implemented next year Well-known, robust	Limited flexibility Not expressing 2nd Skin approach as parts are inside	Ducts running through facade External insulation Replace windows with HR++ Integrate air inlet/outlet at staircase
 Heat recovery decentralised per room	Flexible Innovative	Difficult to develop such a system anew and upscale it to 20 units within a year Rooms not adjacent to façade	External insulation Replace windows with HR++ Integrate ventilation unit into window frame or wall

5. Conclusion and Further Research

Given the need to upgrade the existing housing stock in the Netherlands and achieve low energy consumption, the research project 2ndSkin sets out to propose a concept to achieve zero-energy retrofitting in post-war apartment buildings. Defining the objective, the scope and, most importantly, the requirements of the project was an essential step to lead to the 2ndSkin strategy. Moreover the methodology specifies the development of the strategy on two axes: the reference strategy that will result in the 2ndSkin refurbishment approach, and the prototyping that tests technologies and user interaction. The evaluation of the prototypes supports the development of the final strategy.

The investigation of building stock in the Netherlands was a necessary step to set the project scope, in order to identify the typical reference building, on which the 2ndSkin strategy development is based. Most importantly, it enables the identification of the characteristics that can differ and determine the 2ndSkin strategy modification in the up-scaling phase. Finally, the paper presents the preliminary design, which integrates the building envelope upgrade with efficient building services, to ensure comfort and low energy demand. The choice of ventilation strategy has proven crucial for the development of refurbishment concepts. Therefore Prototype 1 will test different ventilation concepts and the respective incorporation in building envelope.

The project development described in the paper corresponds to methodology steps A and B described in the methodology section, which refers to the scope of the refurbishment strategy and the preliminary design of the solution. The next step is to build the first prototype. Before it is applied in an actual building, a mock-up will be constructed. Even though the energy performance of the 2ndSkin renovation cannot be determined by the mock-up, its design, construction, assembly and testing can provide insights into technical aspects, logistics and user related aspects. The technical aspects that are tested in the mock-up include constructional principles and materials, alternative cladding materials, panel dimensions in relation to integrated installations, integration of pipes (central unit on roof), horizontal and vertical pipes etc. Moreover, it will be an important step towards defining the level of prefabrication that the solution can have, the time needed for construction and assembly on-site and the supply chain. Finally, tests can be conducted to determine some user related aspects, such as user preferences for windows dimensions and acceptance for altered apartment floor area and thicker building walls, after the existing envelope upgrade and services integration.

6. Acknowledgement

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7. References

AEDES. 2012. *Energieconvenant: in 2021 naar energielabel B* [Online]. Available: http://www.aedes.nl/content/artikelen/bouwen-en-energie/energie-en-duurzaamheid/energieconvenant--in-2021-naar-energielabel-b.xml [Accessed 17-03 2014].

AEDES. 2013. *AEDES- Vereniging van woningcorporaties* [Online]. Available: http://www.aedes.nl/content/feiten-en-cijfers/feiten-en-cijfers.xml - corporation-system [Accessed 20-05 2014].

AgentschapNL. 2011. *KOMPAS Energiecijfers* [Online]. Available: http://senternovem.databank.nl/ [Accessed 03-10 2011].

AgentschapNL 2013. Infoblad Trias Energetica en energieneutraal bouwen. *In:* Zaken, A. M. V. E. (ed.). Utrecht.

Andeweg, M. T., Brunoro, S. & Verhoef, L. G. W. 2007. *Cost C16- Improving the quality of existing urban building envelopes: State of the art*, IOS Press.

Atanasiu, B. & Kouloumpi, I. 2013. Boosting building renovation. An overview of good practices Brussels: Buildings Performance Institute Europe (BPIE).

Attia, S. 2015. Screening and analyzing retrofit systems for zero energy renovation and their potential application in Liège, Belgium. *In:* Intec, A. (ed.) *International conference on high-quality retrofit and redensification with timber construction systems.* Graz, Austria: AEE – Institute for Sustainable Technologies.

BPIE 2011. *Europe's buildings under the microscope,* Brussels, Building Performance institute Europe.

CBS. *Centraal Bureau voor de Statistiek* [Online]. Available: http://www.cbs.nl/nl-NL/menu/home/default.htm [Accessed 20/02 2011].

Cozijnsen, E., Leidelmeijer, K., Borsboom, W. & van Vliet, M. 2015. Resultaten uit monitoring over: Tevreden bewoners. Energiesprong | Platform31.

DIRECTIVE 2010/31/EU. on the energy performance of building. Brussels: THE EUROPEAN PARLIAMENT AND OF THE COUNCIL.

EnergieSprong. 2014. *Inspirerende projecten* [Online]. Den Haag: Platform31. Available: http://energiesprong.nl/blog/category/inspirerende-projecten/ [Accessed 14-11 2014].

European Commission 2011. A Roadmap for moving to a competitive low carbon economy in 2050. *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS.* Brussels.

Eurostat. 2013. *"Consumption of energy" - Statistics Explained* [Online]. Available: http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Consumption_of_energy [Accessed 04/08 2013].

Hermelink, A. & Müller, A. 2011. Econimics of deep renovation. Berlin: Ecofys by order of Eurima - European Insulation Manufacturers Association.

IEA Annex 50 2012. Project Summary Report. *In:* Zimmermann, M. (ed.). United Kingdom: AECOM Ltd.

Itard, L. & Meijer, F. 2008. *Towards a sustainable Northern European housing stock,* Amsterdam, IOS.

Klein, T. 2013. *Integral facade construction: towards a new product architecture for curtain walls.* S.n.

Konstantinou, T. 2014. *Facade Refurbishment Toolbox: Supporting the Design of Residential Energy Upgrades.* PhD, Delft University of Technology.

Marszal, A. J., Heiselberg, P., Bourrelle, J. S., Musall, E., Voss, K., Sartori, I. & Napolitano, A. 2011. Zero Energy Building – A review of definitions and calculation methodologies. *Energy and Buildings,* 43**,** 971-979.

MITROS. 2014. *Flat met toekomst: Initiele vraag* [Online]. Available: http://www.mitros.nl/flatmettoekomst/de-uitvraag/initiele-vraag/ [Accessed 10-03 2015].

NeZeR. 2014. *Promotion of smart and integrated NZEB renovation measures in the European renovation market* [Online]. IVL Swedish Environmental Research Insitute Ltd. Available: http://www.nezer-project.eu/2.1f96676d145d7c93741c57.html - .Val-z8aqqko [Accessed 18-06 2015].

OneStopShop. 2012. *One Stop Shop: From demonstration projects towards volume market: Innovations for sustainable renovation* [Online]. Passiefhuis-Platform vzw. Available: http://www.one-stop-shop.org/ [Accessed 25-07 2014].

Platform31 2013. DOCUMENTATIE SYSTEEMWONINGEN '50 -'75. Bouwhulp Groep.

Priemus, H. 1986. Post-war public high-rise housing estates: what went wrong with housing policy, with the design and with management. *Netherlands Journal of Housing and Environmental Research,* 1.

Priemus, H. & Elk, R. 1971. *Niet-traditionele woningbouwmethoden in Nederland,* Alphen a/d Rijn, Samsom.

SHELTER 2013. The Guide for Integrated Design. *SHELTER: Promoting Energy Renovation.*

Stroomversnelling. 2014. *Maak de Stroomversnelling mee!* [Online]. 2014].

TES Energy Façade. 2014. *SmartTES* [Online]. Munich: Technische Universität München. Available: http://www.tesenergyfacade.com/index.php [Accessed 10-07 2013].