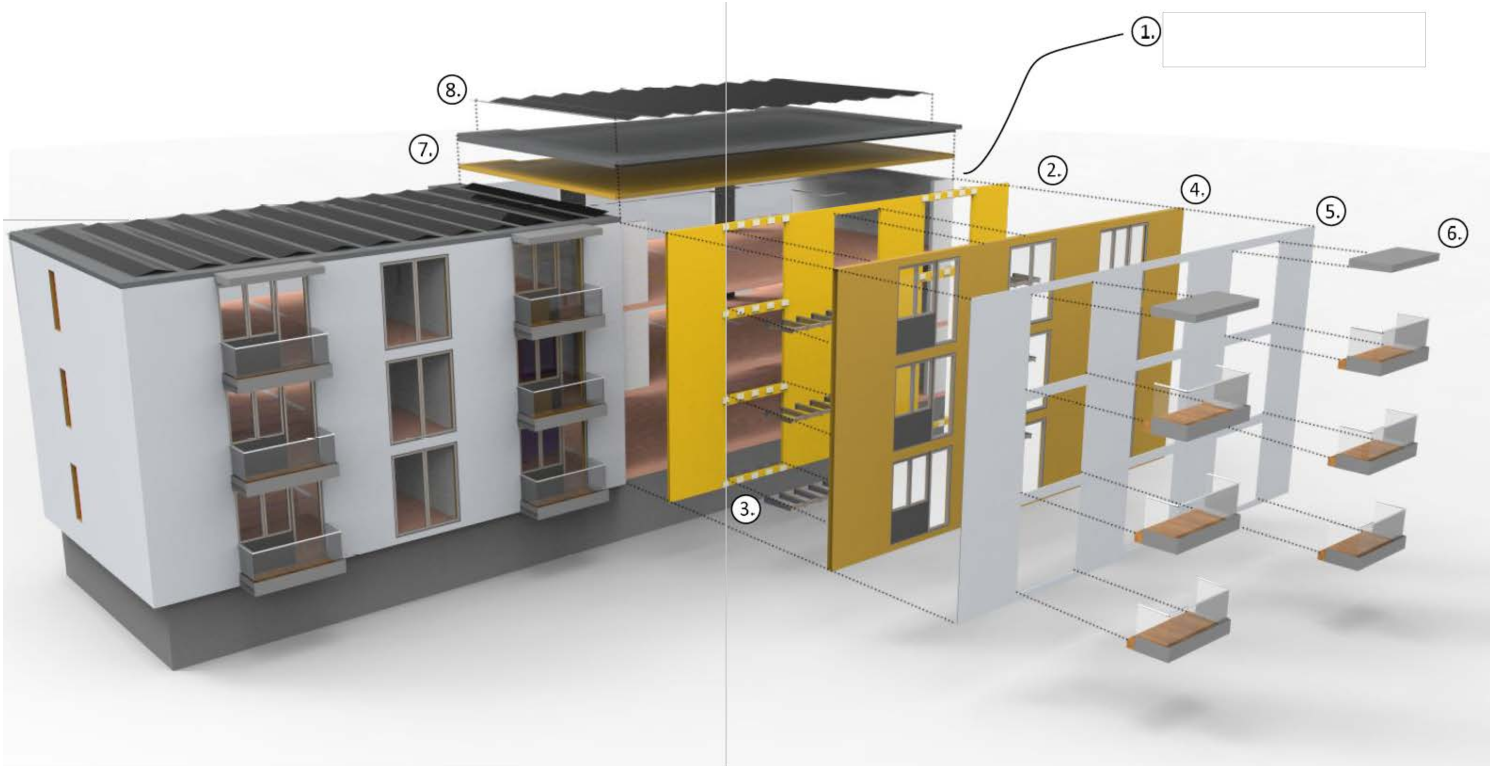
2ndSKIN

zero energy apartment renovation via an integrated façade approach



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Final Public Report
Project within the subsidy program Energy & Innovation, TKI/ENERGO
Reference Number TEGB 113029

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0 Preface

The 2ndSKIN project builds upon a long history of knowledge development, experiences with sustainable, energy efficient building and renovation by the partners of the 2ndSKIN consortium.

This TKI/ENERGO funded project started in the beginning of 2013 and ended in October 2016 with the formal withdrawal of the project lead BAM.

During this period a lot of changes took place in the context of the project. To mention some:

- The economic crises echoed in the building industry and as many others the BAM organisation went thru a severe reorganisation process
- The social housing sector – a potential 2ndSKIN customer - was critically evaluated by the Dutch parliament and had to face major financial offers and were forced to reduce their risks and had to focus solely on social housing again.
- Energy prices collapsed and stressed the payback time of numerous renewable energy and sustainability investments like 2ndSKIN.
- The political decision on the Energy Performance Compensation (EPV) took much more time than expected by the market and retarded a lot of zero-energy refurbishment initiatives, like the 'Stroomversnelling'.
- The financial uncertainty for long term investments in renewable energy introduced by the Dutch Government to restart the discussion about the so-called 'Salderingsregeling'.

A complicating factor for the 2ndSKIN project was the decision of the social housing organisation Woonbron -in the light of the aforementioned- to stop their participation by ending the offering of the prototype-location at Concept House Village, Heijplaat Rotterdam.

The 2ndSKIN project could not be finished the way it was planned. Although the consortium is able to provide a product for the zero-energy refurbishment of the targeted porch apartment buildings, the calculated costs of the solution is perceived as too high for a market implementation in due cause, by the consortium leader. More R&D thru (a series) of prototyping is needed to end up with affordable solutions for the specific market of social housing. Within the TKI-subsidy agreement it was not possible anymore to execute more prototyping.

The knowledge institutes expressed the ambition to take the initiative for making the next steps in the following-up of the TKI-2ndSKIN-project and in the meantime a successful application for funding a 2ndSKIN Demonstrator, subsidized by EIT Climate KIC.

Despite all these developments the need for zero-energy refurbishment is enormous. It is an inevitable step for society to fulfil the aim for a CO2-neutral urban environment in the year 2050. We are confident that the results of this project will contribute and form a perfect basis for the next steps needed to come to an affordable zero-energy refurbishment solution.

It was an honour to work together within a consortium of highly qualified and motivated people contributing to the development of zero-energy-refurbishment. I want to thank all researchers, designers, partners, students involved! Special thanks to Freek den Dulk who is advocating the 2ndSKIN approach already for a long time and was the founding father of this TKI-project.

Finally, we want to acknowledge the agencies of TKI & RVO for expressing the trust in the 2ndSKIN approach by providing not only the financial support but also the creative interaction needed for a fruitful innovation trajectory.

Sacha Silvester
TU Delft

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1 Summary

The ambition to renovate the post-war building stock to an energy-neutral quality is getting a lot of attention of social housing corporations and other institutional owners, financial institutions and users. Studies have reported huge potential for energy savings, improved health and comfort of the occupants', elimination of fuel poverty and job creation lay in the upgrade of existing buildings. The Energy Agreement for Sustainable Growth (SER 2013) (in accordance with the Energy Performance of Buildings Directive adopted by the European Union (DIRECTIVE 2010/31/EU) to improve the Dutch building stock to energy neutral) indicates that 300.000 dwellings have to be renovated in the Netherlands annually.

The post -war building stock, which represents 33% of residential buildings (CBS 2015), is particularly relevant for refurbishment. Despite its varied mix of construction types, from traditional to modern, from low rise to high-rise, it has as a common characteristic that the buildings were generally poorly insulated at the time of construction and that there is a need for renovation (Itard and Meijer 2008). Due to the circumstances of its development, the post-war housing stock has specific characteristics in terms of neighbourhood design, construction and problems. Moreover, being 50 years old, the building envelope has reached end of life while structure is in general sound (Andeweg, Brunoro et al. 2007). A number of facade solutions have been developed in recent years to solve the problem of large-scale renovation of housing (Sijpheer, Borsboom et al. 2016). In the Netherlands, front-running housing associations have the ambition to achieve an energy-neutral renovation approach, and so, some façade solutions aim at energy neutrality such as Stroomversnelling (Stroomversnelling 2013)

However, few address the complexity of multi-family rental dwellings and more importantly, the complexity of user behaviour in the actual performance of the buildings. To reach the ambition of the Dutch government for energy savings, it is necessary to develop products and processes for renovating the multi-family apartment blocks within the existing housing stock. Previous experiences showed that there is still an enormous challenge to fulfil the ambition to make the porch apartment energy neutral for an affordable price and in an acceptable way for the residents (Winter 1993, Silvester 1996).

In this context, the 2ndSkin project brings together different stakeholders of the building industry, aiming at integrating their expertise and objectives into an innovative building retrofitting concept that achieves zero energy use of a dwelling, while offering up-scaling possibilities. The hypothesis of the project is that zero-energy refurbishment can be promoted and its rate can increase if the application of prefabricated façade modules, which increase the installation speed and minimise disturbance for the occupants. Moreover, the objective is not only to find a successful refurbishment strategy for a specific building type, but also to determine the framework within which the proposed solution can be adjusted. The focus of the 2ndSkin project is the low-rise, multi-family residential buildings, accessed by separate stairwells per 6-8 apartments. This type of building represents about 300.000 houses. Nevertheless, the concept of the renovation can be applicable in apartment blocks of other than the post-war period, increasing significantly the impact of the solution with a potential target of 875.000 apartment blocks in the Netherlands (Voorbeeldwoningen 2011).

To address these issues, 2ndSKIN offers a prefabricated and integrated façade module that gives the possibility to improve the current energy performance up to zero energy, while ensuring minimum disturbance for the occupants, during and after the renovation. Given that the design and installation take this constrain into consideration, it is possible to reach zero energy by adding more efficient installations and energy generation, as well as taking possible behavioural changes into account. The technical upgrade of the proposed refurbishment solution is explained. Moreover, energy calculations to determine the energy generated needed to reach zero-energy are presented. Furthermore, the financial feasibility of the 2ndSKIN zero-energy refurbishment is dicussed.

1.1.1 The 2ndSkin refurbishment concept

The design of the renovation solution focuses on a reference building that has been identified as a type which, given the poor thermal quality of the construction and the number of units in the Netherlands, offers the best market and carbon emission reduction opportunities. To define the reference building, literature research and an on-site investigation was carried out in the area of Rotterdam-Zuid. Systematic documentation of the building characteristics was conducted during on-site visits. 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, as shown in figure 1, is a mid-rise apartment block with central staircase, accessible in the front façade, leading to two apartments per floor. Its construction characteristics are massive concrete wall and brick cladding with an intervening, non-insulated cavity, reinforced concrete slabs, continuous to the balconies, and large windows, incorporating lightweight parapet.

figure 1 The reference building

The 2ndSkin design principle to reach zero-energy dwellings is based on preventing the use of energy, then use sustainable energy sources as widely as possible (renewable) and, finally, if the use of finite (fossil) energy sources is inevitable, they must be used efficiently and compensated with 100% renewable energy (AgentschapNL 2013). The concept needs to combine the building envelope upgrade, the use of efficient building systems and the generation of energy. Moreover, both physical condition and performance of the building need to be upgraded with the minimum disturbance to the interior, so that the occupants do not have to be relocated during the construction. As part of the approach, requirement for the performance, such as building envelope thermal conductivity, ventilation rates etc., as well as standards for the occupant role, position and disturbance during and after renovation were developed (Konstantinou, Klein et al. 2015).

To meet the requirement of zero-energy consumption, the solution consists of three basic elements: Increase the thermal resistance of the building envelope, including walls, windows and roof, installing heat recovery ventilation, to reduce energy demand for heating while providing adequate indoor air quality (IAQ), and use photovoltaic (PV) panels to generate energy. The proposed renovation solution results in the required thermal characteristics of the envelope, in terms of thermal resistance and infiltration, as well as providing an updated the building services' performance, as summarised in Table 1. These benchmark values were also used in the energy simulation, explained in evaluation section of the paper.

Table 1 Input parameters for the building simulation software after renovation of the building

	Specifications
Roof	Rc 4.5
Facade elements	Rc 6.5
Ground floor	Rc 3.5
Window frames	Rc 0.8
Double glazing	U 0.8 (1.135) g_g o,8
Infiltration	0.4 $dm^3/s.m^2$
Ventilation system	Balanced ventilation efficiency 0.75

Next to minimising the energy use, the renovation needs to address the issues of occupants' position during and after renovation. The 2ndSkin refurbishment approach aims at eliminating the energy demand, while minimising construction time and occupants' disturbance and the owner needs to acquire the acceptance of at least 70% tenants, which is needed legally in the Netherlands for the renovation to proceed. To this end, the suggested construction process differs from conventional renovation process in the fact that the technology is seen as independent from the underlying structure of the building, and integrated into the facade. The system integrates heating and ventilation into the skin so it can be easily accessible from the outside of the building, therefore facilitating the maintenance. Heat recovery ventilation units are placed on the rooftop, while the ventilation pipes are integrated in an insulation board, attached to the sandwich panel that covers the opaque part of the existing façade. Regarding heating, the concept includes an all-electric decentral heat pump system for heating and domestic hot water, with a 200 litre buffer tank, per apartment. One of the possible locations in the façade of the staircase. The flexibility of the system and the accessibility from the outside the dwellings allows maintenance and upgrading the installations in further phases of the development during the lifetime of the building, thus increasing the time-span of the initial investment.

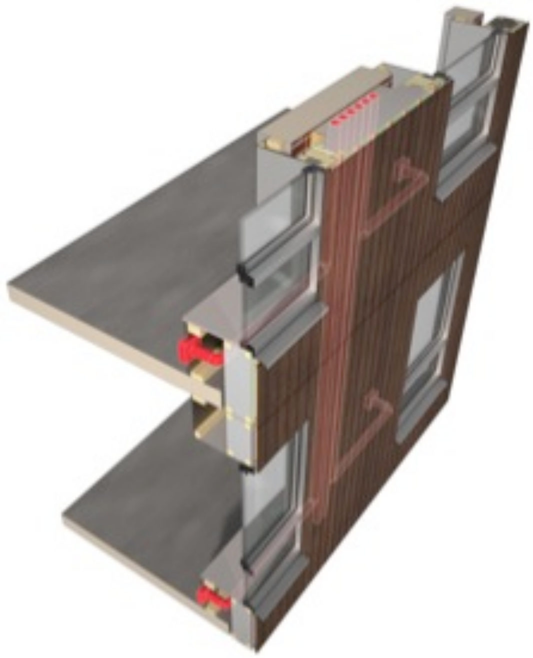


figure 2 Detailed 3D section, showing the ventilation pipes integration in facade panels

To achieve minimum disturbance, a starting point of the design was for the facade module to be prefabricated. During the renovation process, firstly the building envelope is insulated with prefabricated sandwich panels. Moreover, existing windows are replaced. The prefabricated, floor-height, sandwich panels, featuring new windows and integrated services pipes, are attached to the substructure that consists of wooden posts connected to external facet of the existing structures through steel U profiles. PV panels are installed on the roof, while installations to improve ventilation are also integrated in the rooftop. The ventilation pipes are integrated in an insulation board, attached to the sandwich panel that covers the opaque part of the existing façade. This panel is installed first and it comes to the building site as one piece, in order to minimise the connections between the pipes. The panels containing the windows are connected to the wooden posts subsequently.

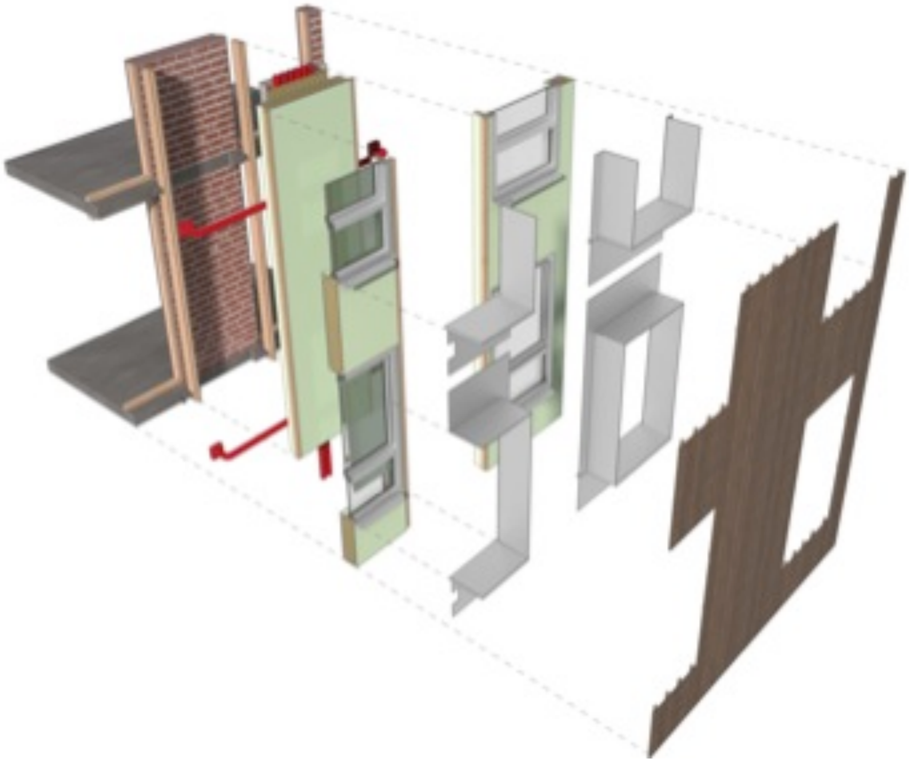
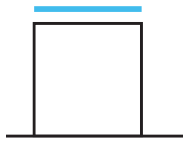
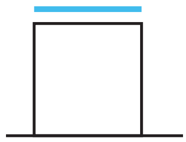
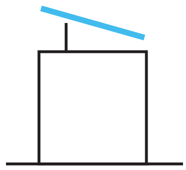
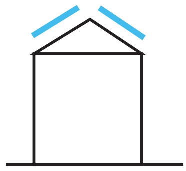
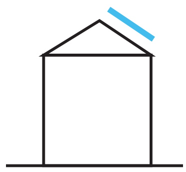


figure 3 The sequence of the prefabricated elements installation (from the left to the right)

Finally, photovoltaic panels are also integrated in the skin in order to reach the zero energy targets. Energy generation was calculated for five scenarios, taking into account the orientation of the building, the type of roof, and the possibility to provide an attic for installations. The five scenarios are: North-South orientation with flat roof, North-South orientation with pitched roof, North-West orientation with flat roof with an attic for installations, East-West orientation with flat roof, and East-West orientation with pitched roof.

Calculations were made assuming the use of a CSun255-60P solar panel (CSUN 2014). Results of the calculations are shown in Table 2. The energy generated in the roof of the building is divided by the number of apartments in the buildings. Such building types are usually either three or four-floor high. Given that the 2ndSkin strategy could be applied to both possibilities, we studied the results of the calculations considering both scenarios. The energy generated per apartment can be seen in the right-side columns of Table 2. The total energy production takes into account the potential of energy generation using the opaque parts of the façade.

Table 2 Total energy production per apartment in kWh/year per building/roof scenario

Scenario	Orientation	Type of roof	Production in roof (kWh/year/apartment)		Total energy production including facades / apartment	
			Porch 6 units	Porch 8 units	Porch 6 units	Porch 8 units
EW_flat	East-West		1738.4	1303.8	2553.37	1915.03
NS_flat	North-South		1299.2	974.4	1739.87	1110.41
NS_flat_b	North-South		**3257.4**	2443.1	**3698.07**	2579.11
EW_pitch	East-West		1738.4	1303.8	2553.37	1915.03
NS_pitch	North-South		869.2	651.9	1309.87	787.91

1.1.2 Evaluation of energy performance and financial feasibility

After the refurbishment concept was developed, it needed to be evaluated. The evaluation is based, firstly, on simulating the reduced energy performance, after the renovation and defines the scenario in which this demand can be compensated with the energy generation. Furthermore, the 2ndSKIN investment is calculated.

1.1.3 Energy performance

In this section, the energy calculations are presented. The simulation takes into account both building-related (heating, ventilation, lighting) and user-related (domestic hot water, appliances) energy consumption, as it was defined in the requirements (Konstantinou, Klein et al. 2015). The dynamic building simulations were carried out with Bink software (BINKSoftware 2015). Each room is modelled as one thermal zone, as we wish to investigate the effect of the room temperatures and spaces heated have on energy demand. Natural ventilation is only considered for the summer period, when external temperature reaches 18 degrees Celsius or internal temperature exceeds 25 degrees Celsius. Thus, natural ventilation does not have an effect on heating demand in the simulations.

For inputs regarding heating demand, two behavioural scenarios were used. In the first scenario, the occupants continue their pre-renovation state-of-the-art behaviour, based on the statistical analysis of the WoON dataset (WoON2012 2013), reflecting the lifestyle and preferences of Dutch households. In the second post-renovation scenario, we assumed an adapted behaviour, based on a better control on the heating system, by heating only occupied spaces and using a setback in the thermostat during unoccupied hours and night-time.

The internal heat gains are integrated into the simulation model in two ways. Artificial lighting is defined as specific artificial use patterns. Internal heat gains for appliances and electric equipment are calculated based on statistical data on electricity consumption per household type in reference dwellings (WoON dataset).

A second set of simulations were carried out assuming a change on behaviour after the renovation. In this scenario, we consider behavioural changes to the current situation, namely increasing the indoor temperature, and assuming a better control on the heating system, by heating only occupied spaces and using a setback in the thermostat during the night and during absent hours.

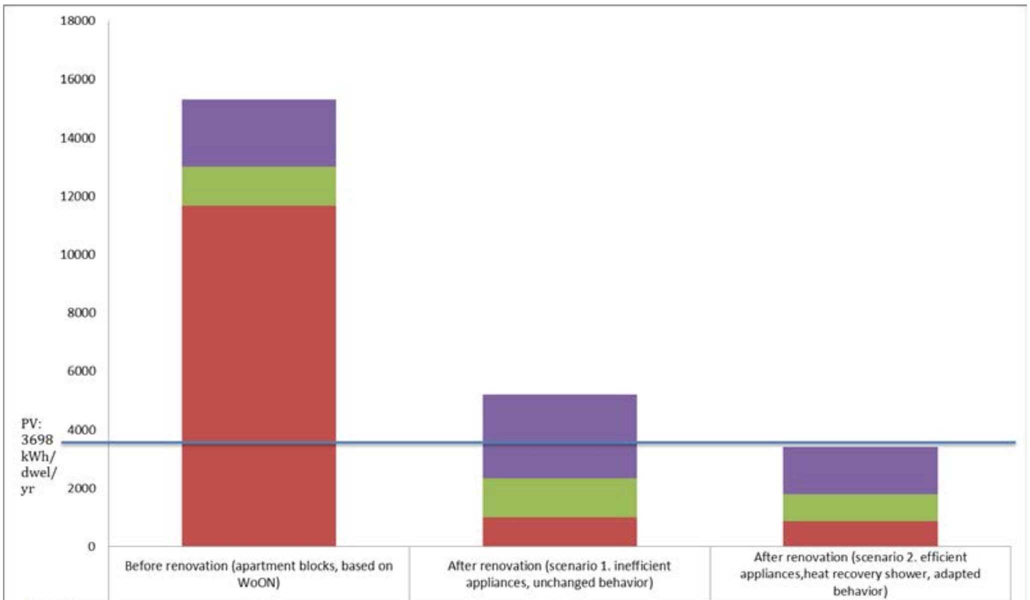
The energy demand for domestic hot water was calculated, assuming five minutes' showers per person per day, one and a half minutes using the sink per person per day, and using the kitchen sink for one minute per household per day. In addition, a scenario considering the use of a heat recovery shower was also calculated. According to specifications, these systems can save up to 100 m3 gas /year per household (ISO7730 2005) or 30% of the energy use. In order to take into account, the household size, we use the value of 30% reduction.

figure 4 shows a comparison between the energy (gas and electricity) consumed in the reference dwellings (based on WoON statistical (WoON2012 2013)), and calculated energy demand (for heating, domestic hot water and electricity) based on the two scenarios for behaviour and electric appliances explained above:

Scenario 1: inefficient appliances and unchanged behaviour, and

Scenario 2: efficient appliances and adapted behaviour.

Inefficient appliances and behaviours is based on the electricity demand calculated using the energy consumption of inefficient appliances, and the pre-renovation behaviour and they are average for different household types (Guerra-Santin, Bosch et al. 2016). Efficient appliances and behaviours is based on the electricity demand calculated using the energy consumption of efficient appliances, and the post-renovation behaviour. The figure shows that the energy demand of the 2ndSkin technical solution (i.e. only renovation without behavioural change or change for more efficient appliances) is reduced by 66%. If we also consider a scenario with improved appliances and behaviours, we reach a reduction on energy demand of 78%. If considering the heating demand alone, which accounts for the largest percentage of energy consumption in the building stock (BPIE 2011), it is minimised, with a reduction of 93% after the refurbishment solution.



	Before renovation (apartment blocks, based on WoON)	After renovation (scenario 1. inefficient appliances, unchanged behavior)	After renovation (scenario 2. efficient appliances,heat recovery shower, adapted behavior)
Appliances	2306,6	2861,2	1625
DHW	1333,11	1333,11	933,18
Heating	11671,0026	997,9	862,5

figure 4 Energy demand in kWh/dwelling/ year, calculated based on inefficient and efficient appliances and behaviours in comparison to the statistical energy consumption in reference dwellings. This explains the difference in the energy use for appliances between statistical and assumed appliances use. The blue line indicates the maximum electricity production in kWh/dwelling/year.

1.1.4 Zero-energy potential

The comparison of shows that only in the best case scenario for energy generation using PV panels on the roof (Table 2), which is a porch building with 6 apartments, and with the possibility to build an attic structure to support the PV panels, the energy generated barely covers the energy demand when domestic hot water and electricity are considered, considering the energy efficient scenario. Considering the inefficient scenario, the best-case energy generated covers half of the demand. For an east-west orientation, the total energy demand can be almost met with the energy production on-site for buildings with three levels (six housing units). To cover the energy demand of north-south orientations without attic provision, and apartment buildings with four levels, an extra surface of 12-20m2 of panels is needed.

Moreover, in all other roof scenarios, the energy generated only covers the heating demand in all cases, except in four-storey buildings with North-South orientation and pitched roof.

1.1.5 Financial assessment

For the financial assessment of the solution, first the initial investment was calculated. The costs included the façade module production and construction, roof insulation, building services units and PV panels, as well as preoperational works on the building site, such as removal of the components to be replaced and new foundations for the façade module.

In order to determine the financial payback time of a full 2ndSkin renovation, a comparison has been made between the benchmark energetic consumption of a typical case-study dwelling, and the simulated consumption of the unit after renovation. According to previous studies (Guerra Santin, Silvester et al. 2015), the current energy use of a model dwelling under average occupancy is approximately 1.200m^3 of gas (or nearly 12.000 kWh of thermal energy) and 2.300kWh of electric energy. Using energy price values for the Netherlands in 2015, according to data from the European Committee (Eurostat 2016), this adds up to estimated yearly costs of 1.340 euros. Considering energy prices in the last two decades have been subject to an upward trend which averages 4.5% per year (CBS 2012) the total cost of energy per dwelling in the coming 25 years could add up to nearly €60.000.

Cost assessment of the 2ndSKIN concept performed during the project showed that costs are still a 160% of the targeted k€ 60 per dwelling.

1.1.6 Conclusion

Within the framework of the research program 2ndSkin, which aims at the development of a refurbishment approach for zero energy renovation of apartments, the TKI-subsidized project elaborated the technical solution, the construction process and evaluated the energy performance after renovation and the financial aspects. The project's main requirements are zero-energy demand and minimum disturbance for the occupants during the renovation. The proposed solution consists of prefabricated modules, in order to reduce the construction time, that integrate high insulation for wall and windows, together with ventilation pipes. In this way, both the envelope and the building services are upgraded. Furthermore, energy generation is necessary to reach the zero-energy target, energy is generated with PV cells on the roof and potentially the façade.

Taking into account the resulting energy demand after renovation (figure 4) and the possibilities for energy generation, using PV panels on the roof (Table 2), we conclude that the zero-energy target can indeed be met, under specific conditions.

The overall solution can, hence, be an answer to the need for upgrade the building stock to provide comfort and low energy demand, with minimum occupants' disturbance. The construction system is based on prefabrication, maintaining still some degree of flexibility, such as different type and size of windows or different cladding material. In this way, the concept aims at higher acceptability and, thus, applicability.

Most importantly, the market intake of such renovation is currently very slow, as housing associations are reluctant to invest the increased cost of a zero-energy refurbishment, despite the energy savings and the benefits for the occupants. This was one of the important reason for BAM – as project lead- to stop the project. A more complete financial breakdown of this case-study concept, as well as options to lower the initial investment, such as subsidies or alternative business models, need to be further elaborated, in order to provide insights for a more attractive business case. The TKI/ENERGO subsidised project was not offering this possibility anymore.

The TU Delft is investigating the possibilities of follow-up R&D to fill the gaps mentioned.

2 Introduction. Preface and problem description

2.1 Historical perspective

The ambition to renovate the post-war building stock to an energy-neutral quality is getting a lot of attention of social housing corporations and other institutional owners, financial institutions and users. This attention for improving the energetic quality of the existing housing stock is not new. On distinctive moments in recent history energy efficient building was high ranking on the political agenda.

In response to the Energy Crisis of 1973-1974 national energy policies were formulated to become less dependent on oil deliveries from the OPEC-countries (Wikipedia 2014). Energy conservation and diversification of energy sources became the two key concepts in energy policy in most Western European countries. In the building industry energy efficiency became an issue in the building regulations. Isolation of cavity walls, double-glazing and air tightness were increasingly applied in new buildings.

The 1979 oil crisis was an immediate effect of the Iranian Revolution and was characterised by widespread panic that topped the energy prices to a record. As a consequence, the economic activities in the industrial countries were slowed down. Energy efficiency again appeared high on the political agenda. It was still aimed at conservation and diversification but the cost-efficiency was added to it because of the economic recession of the early eighties. Experiments with new energy efficient building concepts emerged in the early eighties often funded by national and International research and innovation programs. For example in the Netherlands the national REGO – program was initiated in 1982 to stimulate the efficient energy use in the built environment (Silvester 1996). In the international arena the International Energy Agency fostered among others energy efficiency research and innovation programs in the built environment since its establishment in 1974 (IEA 2014).

2.2 E'novation

In the eighties living cost became a serious issue due to the high energy prices in the poorly isolated social housing estates built in the fifties & sixties of the 19th century.

In the Netherlands this notion initiated the start of the E'novation program in 1988 (Winter 1993). This program was aimed to demonstrate the synergy between house improvement and energy conservation.

The E'novation program intended to show that it was possible to change the existing housing stock – especially the huge amount of houses built in the period 1945 – 1975 - into comfortable, attractive and high valued dwellings. Twenty-one projects were selected as agents for the different building systems used in the mentioned building era. Social housing corporations owned all the projects; it showed very hard to involve large institutional landlords in the program. The improvement of the building and the indoor climate were the most important aspects to decide for renovation and were very positively evaluated after the transformation. Although overall evaluation of the energetic renovation was very high, the applied installations and the actual energy savings scored relatively low. The actual energy savings were about 25% and lower than expected. The average savings of 39% on space heating were partly undone by the increase of energy used to heat tapping water due to the new installations. No renewable energy technologies like PV or solar boilers were applied in the projects that time. The average costs of the projects were far above the amount of money spent by social housing corporations on standard renovation at that time (142%). The institutional private landlords are used to spend even less than the public organisations. The E'novation approach was assessed as too expensive by most of the social housing corporations in the Netherlands (Winter 1993). Important bottlenecks in the E'novation process were related to the users; the composition of the different options for renovation, the calculation of the increase of the rent related to the home improvements, the participation rate, the application of different solutions in one complex and the postponed application of renovation measures after mutation of renters who refused to participate in the first round.

2.2.1 Porch apartment buildings

Central case in the 2ndSKIN project is the so-called porch apartment. This type of building represents -with about 878.000 houses - 12% of the Dutch housing stock. It is a difficult type of building because of its variance in shape, design and quality. This is important reason why for this particular type of building zero energy renovation concepts are still missing.

In a demonstration project for the EU Directorate-general for Energy a complex of 418 porch apartments was energetically renovated and monitored in the period 1989 – 1991 (Silvester 1991, Jong 1992). The results were in line with the general findings of the E'novation program.

- The drop in energy consumption for space heating is largely nullified by the auxiliary energy-use of the combined air-heating/ventilation unit (pilot lights & fans).
- The living costs became higher than expected because of the unexpected higher total energy-use. One of the aims of this renovation concept, a lowering of the total living costs, wasn't achieved. The required level of airtightness for the applied balanced ventilation system, proved impossible to reach. The indoor climate has enormously improved (temperature stratification, NOx- & CO2-levels).
- The residents' surveys showed that on the whole the residents are very satisfied with the apartments as well as the installation. The residents stayed in the apartment during the renovation. 95% of the respondents were annoyed by the actual renovation activities and advise not to renovate again like this in an inhabited situation.
- The application of a second skin around the whole building including the balconies has proved to be a good solution. Thermal bridges disappeared, the kitchen has become lager and the open conservatory with sliding windows is much appreciated.

The costs of energetic renovation approach are much higher than the traditional approach, moreover in this historic case the cost didn't include the renewable energy technologies yet needed to make the apartments become energy neutral.

Because of the ambition of the Dutch government (SER 2013) -in accordance with the Energy Performance of Buildings Directive adopted by the European Union (EPBD 2002) to improve the Dutch building stock to energy neutral - it is necessary to develop products and processes for renovating the multi-family (porch apartment) complexes within the existing housing stock. The described experiences show that there is still an enormous challenge to fulfil the ambition to make the porch apartment energy neutral for an affordable price and in an acceptable way for the residents.

2.3 Problem statement

The current problems with the porch apartment buildings can be formulated as follows:

- Energy neutral renovation requires extensive insulation of the shell and an advanced installation for heating, hot water preparation, heat and ventilation. Within the floor plan there is usually not enough space.
- Insulation inside the shell construction often causes building physical problems and is unattractive.
- The traditional approach gives a lot of nuisance for residents. Therefore, residents have to be (temporarily) relocated, causing extra costs.
- Acceptance of the refurbishment by the households of the targeted complexes is crucial. At least 70% has to approve with the refurbishment to be able to initiate the process. Only 'energy saving' arguments are not enough to convince enough people to participate, more added values like comfort improvements or enhanced functionalities are needed.
- Large differences between the expected and actual energy consumption have been found in identical houses and between different types of households. The uncertainty in actual energy savings should be limited when refurbishment promises 'zero on the meter'.
- New installations (especially for ventilation) require a lot of maintenance. For professional maintenance one is dependent on the presence of the residents. This causes problems in the logistics of maintenance and costs, when residents are absent.
- There are no affordable and acceptable solutions for residents yet. Recently developed solutions, in which the outer leaf is entirely replaced by an insulated, prefabricated timber frame façade; require heavy equipment for transport and considerable assembly time.
- The current approach for this category of homes is priceless, and requires a major intervention outside and inside the homes.
- The available budget for energy neutral-floor porch renovation of homes is limited. The maximum investment for the refurbishment has to be depreciated at least within the lifetime of the renovation. Law in the Netherlands limits the maximum

increase of the rent, according to the home improvement levels. The same goes for the maximum rent for social housing.

2.4 Research question

The main research question is formulated as follows:

How can an effective affordable approach be developed for the refurbishment of existing porch apartment housing complexes towards an energy-neutral situation suited for a large scale uptake in the European housing stock?

2.5 Objectives of the research

The development of an integrated method to refurbish existing porch apartments consist of:

- A modular facade system, which could be adjusted to the existing structure without any major construction adjustments of the existing building, as a 2ndSKIN to improve the insulation as well as reducing the infiltration needed to meet the demands to become an energy neutral dwelling.
- To avoid building activities in the dwellings as much as possible the obtain the approval of the tenants needed to start a refurbishment project, all the required pipelines are integrated in the 2ndSKIN facade.
- The system should be flexible on the integration of solar panels or solar collectors either at the moment of refurbishment or later during live span of the dwellings.
- All the installations needed are to be situated in an installation-box outside the existing building in order to separate the structure of the building and installation to make a division in property possible.
- By dividing the property in installation and structure the ownership of the installation could be a third participant. Initial investments by the owner could be convert into lease, or service packages, which will have a significant influence on the investment budget needed to improve the dwellings.
- Exploitation, service and ownership, and all day accessible by the owners should considerable reduce the costs of maintenance.
- The installation-box should be designed to adapt any major changes in the nearby future as well in technical development as in energy source. Which should be provide the short term strategy to start with low cost well known cv- boiler and to change in the long term to a more efficient system which will be too complex at this moment.
- The 2ndSKIN together with the installation-box will be designed as in integrated system to meet the demands set by the requirements of an E-neutral dwelling

2.6 Partners & project organisation

The 2ndSKIN consortium started working together in the following composition:

Lead partners:

BAM Woningbouw Rotterdam is an important general contractor involved in the refurbishment of porch apartment buildings in the Rotterdam Region. The 2ndSKIN approach offers a solution for the deep renovation of this type of buildings. BAM Woningbouw is the project lead, coordinates this TKI project and is responsible for the execution of the prototyping.

Eneco installatiebedrijven develop the installation box together with the sustainable energy components.

Hogeschool – Rotterdam (HR) and Technische Universiteit Delft (TUD) provide the fundamental, industrial and applied supporting research, measuring and monitoring the construction and operational phase and evaluate the results

Associated partners:

Zehnder- Stork Air develops and applies the ventilation system with the starting point of a façade-integrated installation box and ventilation ducts.

Spee-Architects takes care of the architectonical integration and the building permitting.

Woonbron provides information about requirements, social housing operations and maintenance management and participate in the evaluation of the project.

Defined workpackages and involved partners

WP	Short description of activities	Involved partner	Project results
1.1	Formulation of generic program of requirements	All	Generic design principles
1.2	Development of façade system	BAM	Modular façade system
1.3	Development of installation box	ENECO	Industrial Climate Box
1.4	Definition of 2ndSKIN concept	All	Program od requirements industrial design phase
1.5	Realisation of prototype	BAM ENECO	Prototype
1.6	Monitoring of the realisation phase	HR	Feedback realisation
1.7	Monitoring of the use phase	HR	User experiences & -evaluation
1.8	Evaluation and Conclusions	HR	Updated design principles
2.1	Formulation of a specific program of requirements	All	Design principles experimental phase
2.2	User acceptances, participation and behaviour	TUD	Rate of acceptance for the 2ndSKIN
2.3	2ndSKIN : physical boundaries	TUD	Living preferences, value increase 2ndSKIN
2.4	Acceptance by owners and service providers	TUD	Client oriented stock management of social housing organisations 2ndSKIN
2.5	Realisation of experimental project	BAM ENECO	Execution of experimental phase
2.6	Monitoring and evaluation	HR	Feedback realisation and user experiences
2.7	Evaluation & final conclusions	HR	Publish developed knowledge

During the project the project team is extended with **Ventilation Service** for the specific advices on ventilation, **Giesbers & van de Graaf** for advices on heating and domestic hot water installations, **HFB** for visuals and **SBRCURnet** for the knowledge management & dissemination.

The 2ndSKIN TKI-subsidised project started in January 2014 and was formally ended in September 2016.

In 2014, 2ndSKIN was also adopted as a project within the Flagship Program Building Technology Accelerator (BTA) of the Climate KIC of the European Institute of Innovation and Technology (EIT). Additional BTA-funding made it possible to extend the research and innovation activities on business development, user acceptance, statistical analysis on national & international energy data, European market scans to test the international feasibility of the 2ndSKIN approach, the prototyping of the Mock-up and building an international network.

3 Reference building

3.1 Selection of reference buildings

Next to literature research on national and international level for post-war apartment buildings, on-site investigation was carried out in the area of Rotterdam-Zuid. The on-site investigation

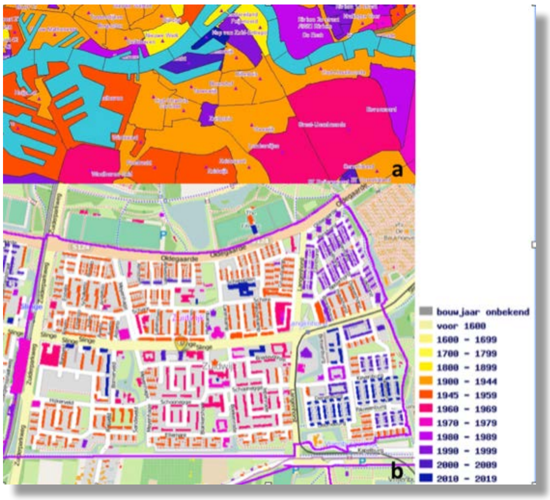


figure 5 Classification of Rotterdam-Zuid neighbourhoods according to the average construction period of their dwellings (above). Detailed overview of buildings construction period on a neighbourhood level (example of Zuidwijk) (below) (source (EduGIS 2014)

was organised according to maps such as the ones of figure 5, which highlighted the areas where the targeted buildings are located. They were also supported by statistical data on the areas, presented in Table 3.

Table 3 Number & Type of dwellings in Rotterdam-Zuid

No.	Neighbourhood	**Total number of dwellings**	**Totaal portiek**	**Portieken van totaal woningen**	**van de totale portiek won-ingen**	**Van de totale woningvoorraad. Hoeveel is huur en hoeveel koop**			**Most common construc-tion period**	**Energy label**
						rental	owner	unkown		
1	Tarwewijk	5954	2.522	42,36%	5,51%	67%	30%	3%	1900-1944	G
2	Carnisse	5927	4.241	71,55%	9,27%	51%	48%	1%	1900-1944	G
3	Zuidwijk	6469	3.935	60,83%	8,60%	80%	20%	0%	1945-1959	G
4	Oud-Charlois	6629	3.038	45,83%	6,64%	62%	36%	2%	1900-1944	G
5	Wielewaal	544	0	0,00%				0%		
6	Zuidplein	754	703	93,24%	1,54%	72%	27%	1%	1980-1989	D
7	Pendrecht	5800	3.813	65,74%	8,33%	72%	27%	1%	1945-1959	G
8	Zuiderpark	512	296	57,81%	0,65%	61%	38%	1%	1900-1944	G
9	Kop van Zuid-Entrepot	3579	2.852	79,69%	6,23%	70%	30%	0%	1980-1989	D
10	Vreewijk	6864	993	14,47%	2,17%	87%	12%	1%	1900-1944	G
11	Bloemhof	6310	1.602	25,39%	3,50%	76%	22%	2%	1900-1944	G
12	Hillesluis	4939	1.607	32,54%	3,51%	70%	26%	4%	1900-1944	G
13	Oud IJsselmonde	2689	1.087	40,42%	2,38%	33%	66%	1%	1900-1944	G
14	Lombardijen	6632	4.171	62,89%	9,12%	70%	30%	0%	1960-1969	G
15	Katendrecht	2010	1.051	52,29%	2,30%	75%	25%	0%	2000-2009	B
16	Afrikaanderwijk	3722	2.496	67,06%	5,46%	89%	10%	1%	1900-1944	G
17	Feijenoord	3085	2.377	77,05%	5,20%	93%	7%	0%	1800-1899	G
18	Noordereiland	1916	1.414	73,80%	3,09%	70%	29%	1%	1800-1899	G
19	Groot IJsselmonde	13513	6.775	50,14%	14,81%	70%	30%	0%	1960-1969	G
20	Beverwaard	4817	705	14,64%	1,54%	63%	37%	0%	1980-1989	D
21	Heijplaat	871	64	7,35%	0,14%	88%	11%	1%	1900-1944	G
22	Waalhaven	21	5	23,81%	0,01%	60%	30%	10%	1945-1959	G
Totaal Rotterdam-Zuid		93.557	45.747	49%	100%	70%	28%	1%		

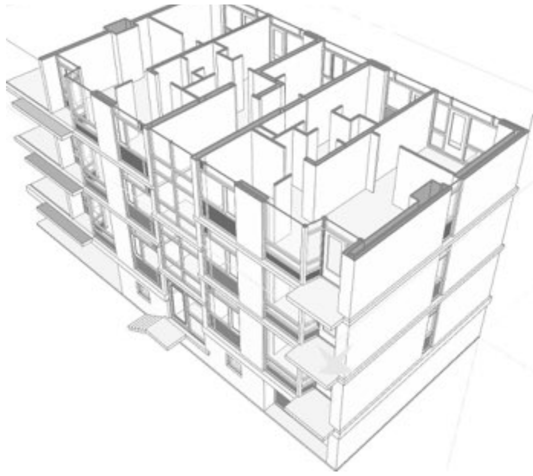
Subsequently, systematic documentation of the building characteristics was conducted during the on-site visits. The observation and documentation has concluded in different building types, according to wall, window, roof type, balcony location, the existence and construction of the parapet, staircase 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 6. The basic characteristics are the following:

- Mid-rise apartment block
- Central staircase, accessible in the front façade, leading to two apartments per floor
- 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

3.2 Reference households

Energy consumption in dwellings is affected by household demographics (age, gender, household composition), socio-economical level (education level, income), and lifestyle (retirement, full-time work, unemployment). These factors are known to influence energy consumption and are considered to be very important because of the great variation within and between types of households. For example, two-person households with similar income could have very different energy consumption because of the age, background, employment status and health condition. The 2ndSKIN approach aims at considering these factors.

figure 6 Reference building (Rotterdam-Zuid, left) and 3D-drawing (right)



The most common type of Dutch households, and their socio-economic characteristics have been defined through analysis of the building stock. The definition of the reference households is important for the project because the renovation is aimed at social housing in the Netherlands, and so it is likely that the occupants of these buildings hold special socio-economical characteristics in comparison to a national sample. These characteristics, such as income, lifestyle and background could have an effect on occupant behaviour and energy consumption. In addition, targeting specific solutions according to occupants' characteristics can increase the acceptability of the project and it would help designers to make choices regarding the final solution of the renovation.

The determination of the reference household (based on the reference building) will inform on the type of households most likely to occur in the reference building, and in the demographics and socio-economic characteristics of the households. This information will allow us to calculate more accurately the expected building-related and user-related energy demand, and thus to calculate more accurately the sizing of energy generation technologies.

3.2.1 Energy consumption in reference households

Household types on a national level were defined according to household size and age of the household members, specially taking into account the presence of children and elderly people, groups that have shown to have an effect of energy consumption. For the investigation of Dutch households, the WoON 2012 dataset was used (CBS 2011). The dataset contains 69,000+ cases, from which 4800+ include a building audit. The dataset included information on building characteristics, energy consumption, occupants' behaviour and household demographics. The resulting household types were: single senior, single adult, seniors couple, adults couple, three adults, single-parent household and nuclear family.

Based on the Dutch household types defined, a Chi-square test was used to determine the prevalence of specific types of households in the reference building. The WoON dataset was split into a sub-dataset containing only the cases of building similar to the reference building: low rise (three to five levels) rental apartments built between 1946 and 1975. The sub-dataset contains 2194 cases. The Chi-square test showed that the households more likely to inhabit the reference buildings are: single senior, single adult and single-parent household; while the households less likely to inhabit the reference buildings are three adults and nuclear family (χ 2(6)=1231.97, p<0.001).

As stated previously, reference household types might have different preferences, behaviour and lifestyles, and thus, energy requirements might be different than those of average Dutch household types. To investigate such differences, an independent samples t-test was conducted between the energy use (gas and electricity) in the reference buildings, and the energy use in other types of buildings. The results of the t-test on gas consumption showed that less gas is used in reference dwellings (M=1175, SD=613.9 m3 gas) than other buildings (M=1699, SD=896.6 m2 gas), t= 38.9(2628.2), p<.001. The results of the t-test on electricity consumption also showed that less electricity is used in reference dwellings (M=2139, SD=1131.9 kWh) than other buildings (M=3424.6, SD=1774.8 kWh), t= 51.4(2629.5), p<.001.

To determine the differences on energy consumption between household types, Analysis of Variance tests were carried out on the complete dataset (all building types) and on the subset containing only the cases determined as reference buildings. The ANOVA results on the complete dataset showed that there are statistically significant differences on gas (F(6,16080)=659.1, p<.001 Welch statistic) and electricity (F(6,16059)=3054.8 p<.001 Welch statistic) consumption between all household types (see descriptive statistics in Table 4

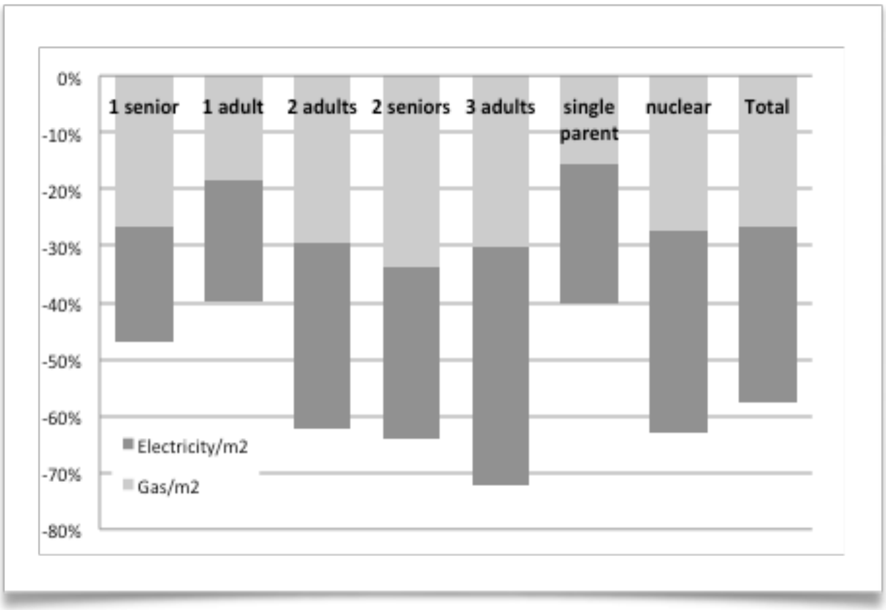
The ANOVA results on the reference building subset showed that gas consumption (F(6,538)=10.7, p<0.001 welch statistic) and electricity consumption (F(6,536)=39.5, p<0.001 welch statistic) are statistical significantly different for some types of households; energy use in smaller households is different to energy use in larger households (see descriptive statistics in Table 4.

Table 4 Descriptive statistics for gas, electricity and water consumption in all dwellings and reference dwellings

	ALL DWELLINGS			REFERENCE DWELLINGS		
		Gas (m3)	Electricity (kWh)		Gas m3	Electricity (kWh)
	N	Mean	Mean	N	Mean	Mean
Single senior	6648	1521.0 (908.2)	2162.2 (1143.7)	293	1113.1 (551.5)	1724.2 (857.4)
Single adult	11429	1310.3 (790.2)	2341.3 (1397.4)	888	1069.7 (583.5)	1837.3 (991.8)
Adults couple	13056	1682.6 (858.0)	3479.4 (1609.9)	329	1185.7 (604.1)	2338.4 (1183.7)
Seniors couple	8236	1876.8 (987.1)	3358.3 (1503.8)	192	1241.7 (558.4)	2342.3 (1048.9)
Three adults	3892	1914.6 (856.7)	4681.2 (1816.4)	80	1334.6 (680.7)	2725.8 (1190.3)
Single parent	2202	1572.5 (749.6)	3193.9 (1528.3)	185	1328.3 (765.1)	2405.3 (1127.5)
Nuclear family	13021	1859.5 (831.8)	4309.1 (1708.6)	227	1349.4 (605.1)	2772.9 (1243.9)
Total	58484	1668.6 (887.4)	3341.4 (1752.3)	2194	1231.8 (612.3)	2306.6 (116.9)

The differences on energy consumption between the household types in the reference buildings are not as large as in the complete sample. figure 7 shows in percentages, the difference on energy use per household in reference dwellings in comparison to all types of dwellings. As a consequence of the reference dwellings being smaller than the average Dutch dwelling, the households in reference buildings use from 40% (single adults) to 70% (three adults) less energy in comparison to households living in all types of buildings. These results suggest that in the reference building, occupants' behaviour might have a smaller effect than in other types of buildings. This could be caused by the fact that all social rental apartments have similar characteristics, and by the fact that the households in these apartments tend to have lower incomes.

figure 7 Differences in energy consumption between average building stock and the inhabitants of reference dwellings



3.2.2 Socio-economic characteristics of the reference households

Further, occupancy was investigated in terms of background and socio-economical characteristics. In order to identify further the characteristics of the reference households, beyond composition, age and presence of children and seniors, Chi-square tests were performed to identify other socio-economical characteristics (see Table 5). The sample was split again into reference building and non-reference building. We investigated that certain social and economic characteristics would be more likely to appear in the households living in the reference building. In addition, Chi-square tests were also used to determine lifestyle of the households living in the reference type building (see Table 4) to determine the presence at home and other habits that might be useful to define occupants' profiles.

The results showed that in the reference type building, the households are more likely to have lower education, have a foreign background, have less often contact with friends, participate less often in activities out home, sport less often, less likely to work at home, have a non-western religion, and have a lower health condition in comparison to other types of building. Therefore, we can conclude that we are more likely to find minorities and elder people in this type of buildings (see Table 5 & Table 6for the statistics).

Table 5 Reference households; socio-economic variables

Education level (highest in household, including current level)	Low education LBO MAVO-MULO-VMBO HAVO-VWO-MBO HBO-University Other	$\chi2$ (5)=493.6, p<.001
Etnicity	Categorical variable 1. Autochthone 2. At least 1 western 3 At least 1 non-western	$\chi2$ (2)=990.5, p<.001
Income	Continuous variable - Euro	t(3487.7)=68.48, p<.001 in all M=55842.3, SD=44825.26 in reference M=29256.3, SD=16466.3

Table 6 Reference households; lifestyle variables

Lifestyle – frequency contact with family	Interval variable - frequency	X2(4)=49.7, p<.001
Lifestyle – frequency contact with friend	Interval variable - frequency	X2(4)=47.9, p<.001
Lifestyle – frequency participation in clubs	Interval variable - frequency	X2(4)=267.3, p<.001
Lifestyle – hours TV per week	Continuous variable - hours	t(2341)=12.26, p<.001 in all M=15.44, SD=11.4 in reference M=19.17, SD=14.2
Lifestyle – hours sports per week	Continuous variable – hours	t(2375.6)=2.66, p<.01 in all M=4.60, SD=5.9 in reference M=4.23, SD=6.4
Working at home	Interval variable - frequency	X2(1)=153.1, p<.001
Religions and beliefs	Categorical variable	X2(9)=675.7, p<.001
Health condition	Dichotomous variable	X2(4)=427.8, p<.001
Health long-term illness, disease, disability	Dichotomous variable	X2(1)=107.8, p<.001

Only some of the above-mentioned socio-economic and behavioural variables have an effect on gas and electricity consumption. However, they are important to determine the characteristics of the households. The characteristics of the reference households can be thus identified in Table 7, Although three of them tend to be more likely to live in the reference building, for the current investigation we focus on all household types.

Table 7 Socio-economic characteristics of 2ndSKIN reference buildings

EDUCATION	More likely to have lower education Less likely to have higher education
LAND AND ETNICITY	More likely to have a non-western background Less likely to have a Dutch background
LIFESTYLE	Less likely to have frequent contact with family and friend Less likely to be part of a club More likely to watch more hours TV per week Less likely to work at home Less likely to spend time doing sports
HEALTH CONDITION	More likely to have poor health condition More likely to suffer a disability
RELIGION	Less likely to be Roman-catholic, protestant, Hervormd, Reformed church More likely to be Islam, Moslim, Mohammedaans, Hindu

4 Analysis (Industrial design phase)

4.1 Setting the scope of the refurbishment strategy

During the start of the 2ndSKIN program the following research questions were formulated to be answered in this TKI/ENERGO-project:

RQ1
What typologies within the existing housing stock might be suited for the 2ndSKIN approach and what typical details or characteristics should be taken into account?

RQ2
What costs and investments are acceptable for the different stakeholders?

RQ3
How can residents become a driving force behind this concept? Which aspects and interventions provide added value? Can residents be involved as co-creators?

RQ4
To what extent is the energy neutrality of the 2ndSKIN - concept vulnerable to occupant behaviour?

RQ5
What kind of requirements are to be met from the different ownership situations?

RQ6
How can the space occupied by installation and structural facilities be limited?

RQ7
Is phasing in the transition process towards energy neutrality possible (for example, first the facade / skeleton of the house and later the installations)?

RQ8
Is robustness of the energy concept and the business model strong enough for changes in the energy market and energy infrastructure?

In this report, the research questions are grouped in 5 topics: 1) research on building typologies, 2) type of building ownership, 3) design criteria, 4) energy performance, and 5) possibilities for new business models and up-scaling possibilities. Following sections introduce the topics.

4.2 Building typologies

The target group for the present investigation are the post-war, porch apartment blocks (portiek-etagewoning) in the Netherlands. To understand why this building type is particularly interesting, some data on the building stock are presented. The building stock in the Netherlands accounts for 7.5 million dwellings (CBS 2014). Dwellings of the post war period account for approximately 1/3 of the residential stock (Itard and Meijer 2008), out of which 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 for 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 the post-war building according to AgentschapNL (2011)is D-E (approx. 350-400 kWh/m2/year primary energy), resulting in an expected energy consumption approximately 20.000 kWh/dwelling/year.

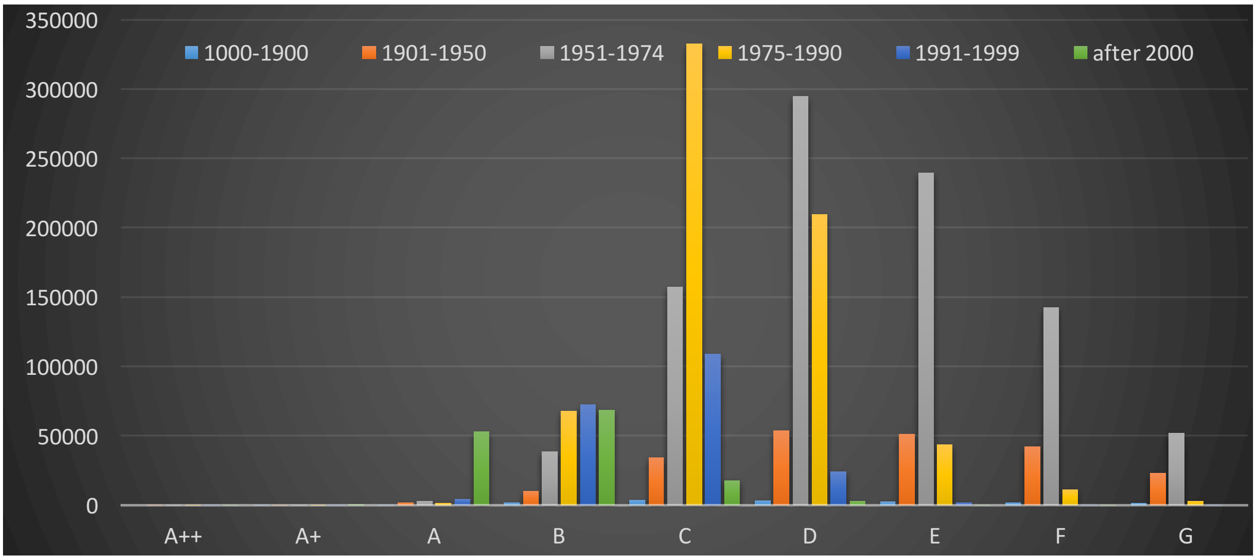
Table 8 Dutch building stock in types, numbers & % of total stock (source: (Platform31 2013))

	Total residential stock	Post war residential stock (1946-1974)	Total porch apartments	Post-war porch apartments	Industrialised systems (all dwelling types
no. dwellings	7.300.000	26.00.000	878.000	381.000	450.000
% of the total stock		36%	12%	5%	6%

Analysis and evaluation of the existing building is an essential first step in every refurbishment project. In the context of the 2ndSKIN, the building stock analysis is necessary in order to identify the building type where the pilot refurbishment prototype will be implemented.

Moreover, the specific characteristics of the construction can be important in shaping the retrofitting solution.

figure 8 Energy labels of residential building stock (AgentschapNL, 2011). The majority of dwellings of the post-war period score label D or lower.



4.2.1 The post war residential building stock and non-traditional building methods

The post-war period is particularly interesting for the present research and the refurbishment discussion in general, as it was a turning point in the development of the residential building stock. There has been a shift away from traditional construction methods to enable the production of large numbers of housing units, as quick and economical possible.

After the World War II, most European countries experienced a large housing shortage, due to war devastation, population increase and economic growth. These shortage was anticipated with a high level of building activities, focusing on quantity rather than quality (Andeweg, Brunoro et al. 2007). As a result, the European housing stock originated from this period accounts for a considerable share of the total stock, while it lacks technical and functional performance. A second benchmark for the housing stock is the oil crisis in 1970s. The increasingly awareness of fossil fuels deficiency brought concerns on the energy efficiency of the building stock, resulting in legislation related with building insulation and material.

This particular part of the stock, which represents almost one third of residential buildings, is not very homogenous. A varied mix of construction types exists, from traditional to modern, from low rise to high-rise. A common characteristic, however, is that the buildings were generally poorly insulated at the time of construction and that there is a need for renovation (Itard and Meijer 2008). Moreover, being 50 years old, the building envelope has reached end of life while structure is in general sound (Andeweg, Brunoro 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.

During the development of post-war housing stock, there has been a significant change in construction techniques, which were looking to achieve quicker and cheaper housing production. The new systems are in general characterised as “non-traditional” and they are dominated by industrialisation in the construction. The idea of industrialised building systems have been developed since the interwar years and the Modern movement (Moe and Smith 2012). The social and economic conditions after the World War II helped to realise these systems in a large scale, as the building capacity of the traditional construction was not enough to cover the demand. In many countries industrial building methods were sought, to solve the shortage of skilled building trade operatives. The answer was sought above all in labour-saving concrete constructions, mostly in element building methods or cast in-situ methods. Element building means that large concrete wall and floor elements are made in the factory, transported to the building site on large trucks and assembled on the spot with a large building crane. In cast-in-situ methods, a formwork (often of steel) is used in which the concrete is poured. Such systems cost less than traditional building methods if the series are large ones. The pressure to increase the size of orders and to apply high-rise (in which these methods specialized) was great, partly because of the strong market position of the building firms (Priemus 1986).

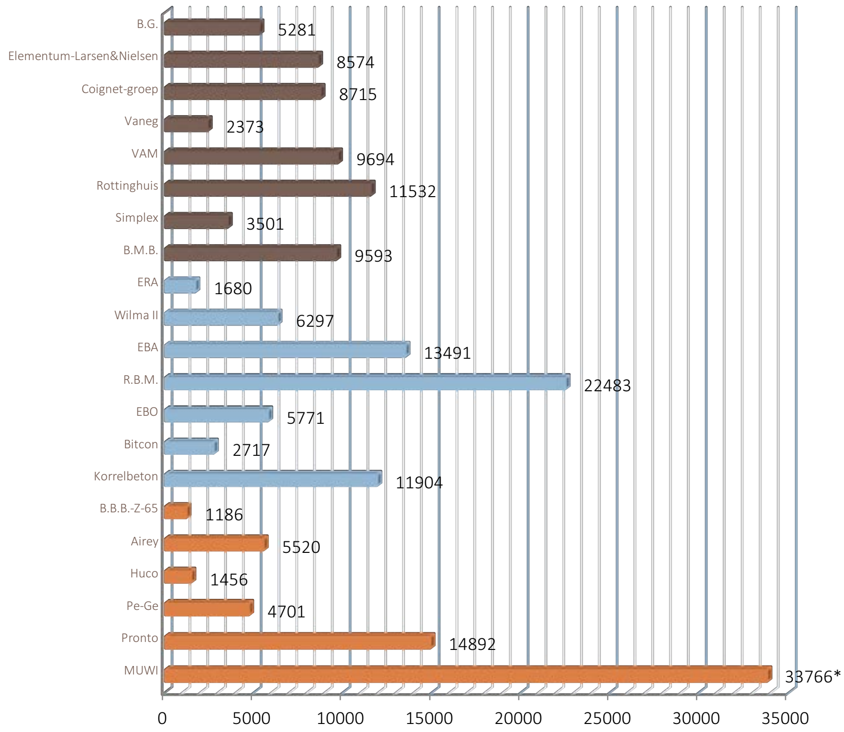
4.2.2 Common types of buildings in the Netherlands

Table 9 Overview building systems in the Netherlands (<1971)

	Nr of houses per system, until 1971[1]	Nr of houses per system [2]		Slab extension	Parapet	Balcony/ loggia
MUWI	33766	37831	11%	no, only at the windows	no, mostly façade panel	Apprx 1.25m cantiliever
R.B.M.	22483	32292	7%	yes	no	yes
Coignet-groep	8715	31378	9%	no	yes	half loggia, half cantiliever. Accessed from living+bebdoom
B.M.B.	9593	29369	9%	no	yes	half loggia, half cantiliever. Accessed from living
EBA-giet-bouw	13491	19291	6%	no		yes
Pronto	14892	17836	5%	no, only at the windows	yes, cavity wall	small part loggia. Apprx 1m cantiliever. Accessed from bedroom
Rottinghuis	11532	17000	5%	no	no, lightweight	loggia
Korrelbeton	11904	15394	5%	no	no, façade panel	half loggia, half cantiliever. Accessed from bedroom
VAM	9694	14000	4%	yes	no, lightweight	half loggia, half cantiliever. Accessed from living+bebdoom
B.B.B.-Z-65	1186	13118	4%	no	yes, cavity wall	no
Wilma II	6297	12579	4%			
Pe-Ge	4701	12000	4%	no	yes, cavity wall	no
Smit II		10000	3%			
Airey	5520	9975	3%	no	yes,	
ERA	1680	9810	3%			
Elementum-Larsen & Nielsen	8574	8574	3%			
Vaneg	2373	7000	2%			
Bakker V.B.		5643	2%	no	yes, cavity wall	loggia infront of bedrooms, accessed also from baclonies
Welschen		5602	2%			
B.G.	5281	5581	2%			
tramonta		4845	1%			
EBO II	5771	4586	1%	no	no, wood	yes
Schokbeton H-I		4000	1%			
Simplex	3501	3800	1%			
Bitcon	2717	2245	1%	yes	no, wood	yes
Sanders		1883	1%			
Bouwvliet		1616	0%			
Huco	1456	1042	0%	no	yes, lightweight	no
GBS		643	0%			
Heykamp L		589	0%	no	yes	no
Lisman		521	0%	no	no, lightweight	yes
PBG		481	0%	no	no, lightweight	no
Breda		446	0%			
Total		340970				
						[1] (Priemus and Elk 1971) [2] (Platform31 2013)

Given the importance of the post-war building stock in the refurbishment discussion, we focus on the situation in the Netherlands. During the period 1946-1974 more than 2 million dwellings were constructed in the Netherlands. About 15 percent of new construction is carried out in a precisely defined, modular system that has been replicated for thousands of dwellings. They were characterised as non-traditional and industrialised systems, because prefabrication, new materials and ways of constructions were predominant. Those systems usually developed and named after construction companies that invented and apply them and they are well documented in the literature (see (Priemus 1986) and Table 9). However, dwelling that were not constructed with industrialised systems still demonstrate 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 these non-traditional systems, as they are representative of the period and better documented. They serve better the purpose of the research, which is identifying the important building characteristics that determine the refurbishment strategy. These characteristics include floor plan layout, location of utilities spaces, balcony type, construction of the walls, connection with the slabs, and window-to-wall ratio.

figure 9 Number of dwellings built with different industrial systems in the Netherlands until 1971

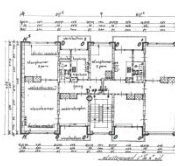
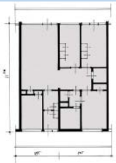
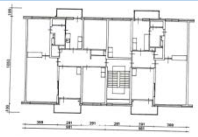
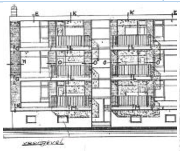
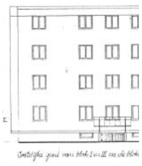
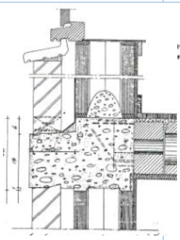
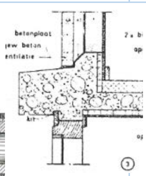
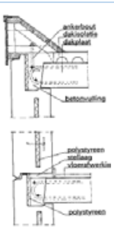
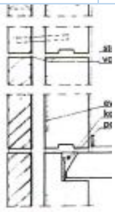
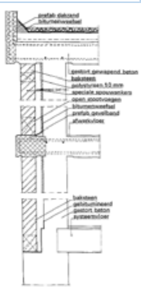
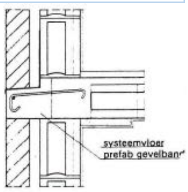
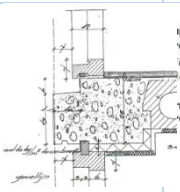
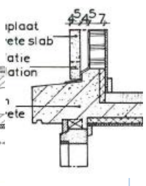
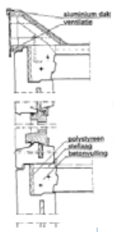
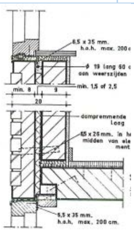
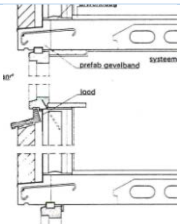


4.2.3 Comparative analysis of construction and floor plan characteristics.

Given that the proposed refurbishment solution needs to be applicable in a large number of buildings, part of setting the research scope is analysing characteristics of the construction and floor plan layout that can influence the 2ndSKIN design. Even though this analysis cannot cover exhaustively the post-war building stock, it is still indicative of the types of construction, layout and differences encountered between buildings.

The Table 10 provides a comparative analysis of the 6 most popular building systems, which represent approximately half of the stock built with non-traditional methods. Table 8 includes an overview of most building systems used in the Netherlands, with the respective number of dwelling and characteristics.

Table 10 Overview of layout and construction characteristics of the six most popular non-traditional systems

	MUWI	R.B.M.	Coignet-groep	B.M.B.	EBA-gietbouw	Pronto
						
Nr of dwellings	37831	32292	31378	29369	19291	17836
Percentage of post-war systems	11%	9%	9%	9%	6%	5%
Typical floorplan						
Typical façade						
Utility rooms position/ distance from facade	Kitchen on façade. Bathroom adjacent (appx.1-2m from façade)	In the middle of apartment (appx. 2m from the façade)	In the middle of apartment (appx. 3-4m from the façade)	Kitchen on façade. Bathroom adjacent (appx.1-2m from façade)	In the middle of apartment (appx. 3-4m from the façade)	Kitchen on façade. Bathroom adjacent (appx. 1m from façade)
Balcony type	Half-loggia	Cantilever	Loggia	Loggias and cantilever	Cantilever	Mostly cantilever
Façade detail Wall						
Façade detail Window						
Percentage of openings (Approximation)	60% (Parapet in the façade panel)	30-60 % (Varies significantly between portiek and gallery flats	30%	30%		60%
Wall construction	Cavity wall: MUWI wall (Stacked concrete blocks with poured in-situ concrete) Brick wall exterior	Cavity wall: Lightweight concrete and Brick wall exterior	Sandwich concrete panels with 2-2,5 cm polystyrene	Cavity wall: prefab beton, prefab baksteen	"Cavity: Siporex, 1cm polystyreen, baksteen"	Cality wall: Prefab concrete elements Brick wall exterior
Slab extension	No	Yes	No	No	No	No

4.3 Design criteria / Program of requirements (WP 1.1)

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 12 defines levels that allows 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 13 provides an overview of the criteria quantification.

4.3.1 Cost and investing level

The targeted cost per dwelling is € 60,000, including VAT (BTW). 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 plus the additional investments for the 2ndSKIN concept aiming at a more advanced solution, resulting in zero-energy consumption.

These investments are huge. In recent publication from the Planbureau voor de Leefomgeving (PBL) (Frans Schilder 2016) it is suggested that within the present financial and legal frameworks there are enough possibilities to invest in this kind of refurbishments for *social housing corporations*. For (small organisations of) private home-owners the PBL calculated that the costs for the additional mortgage to finance the refurbishment still exceeds the prognosed savings on energy costs.

This is an important reason for the 2ndSKIN-team to focus on the social housing corporations as a lead customer group in this early stage of innovation and market development.

4.3.2 Building occupants as co-creators.

RQ3: How can residents become a driving force behind this concept? Which aspects and interventions provide added value? Can residents be involved as co-creators?

RQ4: To what extent is the energy neutrality of the 2ndSKIN - concept vulnerable to occupant behaviour?

70% tenant opt-in is needed in order to proceed with a renovation, but this is not always achieved (Sijpheer, Borsboom et al. 2016). Additionally, if a renovation does go through, rebound effects often occur afterwards, meaning that occupancy consumes more energy than predicted in calculations (Galvin 2014). The reasons are still unclear, but are presumed to lie in residents' post-renovation behaviour and interaction with their home systems (Chiu, Lowe et al. 2014). These sources concur that a careful process of resident participation ahead of renovation could address these issues.

A number of research methods were employed to develop a co-creation process for 2ndSKIN that facilitates opt-in, and to identify aspects that could influence post-renovation energy saving positively.

1. On the municipal and neighbourhood level, ethnographic research was conducted by attending and analysing a number of neighbourhood and building improvement processes. The perspectives of housing corporations, municipalities and occupants were elicited.

2. On the participation process level, case studies were conducted into three different recent participation processes, and these were analysed and described in a typology.
3. On the house and home systems level, scenario-based research was conducted with occupants of (mostly) the reference building. Several were visited in their homes, and several participated in visits to various mock-ups of a home situation as if renovated with 2ndSKIN.
4. In parallel to the studies on participation process and house and home systems level, design research was conducted via student design projects. The project produced and evaluated examples of improved process aspects and home systems interfaces. As the theme of wellbeing emerged as an important priority for tenant communication, the student design projects became more focused on it as a basis for 'pleasant living at home'.

The research resulted in theoretical and practical insights. It produced a theoretical perspective on a good co-creation process: such a process should

- address individual and community wellbeing,
- connect the levels between neighbourhood-level issues (that are most visible and easiest to talk about, e.g. a local park), to building level issues (technical and social), to home systems level (how energy-related interfaces in the home promote energy saving)
- support co-creation by means of insight and co-creation tools across the levels.

In the following, each study and its key findings are briefly described.

4.3.3 Ethnographic research on neighbourhood and building improvement processes.

The ethnographic research was conducted by attending ca. 30 events over a two-year span, preceded by a series of expert interviews (Boess 2015). The events ranged from all-day to evening events and ranged from small resident initiative events (*LSA bewonersdag, huurdersraad West*) to large events involving several stakeholders ('*Stook je rijk*'*: debate among Milieucentrum Rotterdam, Woonbond, political parties and tenants;* '*Mooi, mooier Middelland*': co-creation session among local city officials, residents and other stakeholders in a city neighbourhood).

figure 10 Mooi-mooier-Middelland neighbourhood co-creation process

4.3.4 Sample results from the ethnographic research

- To improve their neighbourhood, residents value the strengthening of the community across its diversity
- Residents value green on public squares and are eager to engage in creating it themselves
- Neighbourhood residents take the initiative in helping collect wishes and organise the improvements

During the co-creation process, nobody raises the notion of environmental sustainability

A key conclusion from the ethnographic research is that there is a gap between residents' wishes for their own community wellbeing on the one hand, and environmental sustainability on the other. The latter is only addressed when this is explicitly the aim of a consultation. When environmental sustainability is the issue, then the focus of discussions tends to be political, financial and technical. The wellbeing focus is not addressed. It can be concluded that for the case of sustainable renovation, community wellbeing should be a focus alongside the wider environmental concerns. This focus on residents' wellbeing priorities will increase the residents' motivation to agree to the renovation and to contribute in the use phase to a zero energy outcome through their daily practices.

4.3.5 Case studies on participation processes

The comparisons of processes and stakeholder analyses resulted in the identification of three types of current participation process, each one based on an observed actual process. Comparing the three processes, characteristics were identified in order to create a process description that would be optimised to support tenant opt-in, satisfaction and low-energy practices in use. The processes are compared on the characteristics of timeframe, consortium (or organisation) learning, resident learning, risks for residents, consideration of wellbeing, post-renovation low-energy practices (interacting with the home), and resident-led innovation (Table 11). From this comparison, characteristics of an optimised process are identified. The first process type could be dubbed 'showroom' figure 11. This process has been developed within Stroomversnelling in their 2014 pilot projects. In this process, a networked consortium functions in the background of a replicable process. This has two key effects. Firstly, what residents see of the process is much shorter than in the other two processes below. The residents are offered an attractive product - the future home. They are supported well and only participate a short time. Secondly, the networked learning in the background provides a great basis for product development and industrialisation. In effect, it is an industrialised process as in car production, where the finished product is in the showroom and people can select it and 'buy' it.

figure 11 'Showroom'; a demo house that can be visited by other residents

The second process type could be dubbed 'tailor' (figure 12). This process was witnessed in a 2014 large scale renovation project and is the currently most applied. In this process, organisations contact local key persons and these provide access to neighbourhood networks. A housing corporation and a builder run the process and organise an independent advice-partner for the residents. The process is organisationally replicable but inclusive of local issues (for example, it included a local park that residents cared about). Knowledge remains largely limited to this consortium. The process resembles a tailor's craft, making a product according to needs and a pattern while the customer waits for it. The product is adapted until it fits.

figure 12 'Tailor'; a resident gives us a tour around the finished renovations. This resident was a local key-person for the project, guiding it all the way through together with fellow residents.

The third observed process type could be dubbed 'grassroots' (figure 13)This process was identified from the case of grassroots initiative 'Blijstroom'. Its history was elicited through retrospective interview and its current developments followed through visits to events. Blijstroom started with a group of residents noticing something about their neighbourhood: the potential of using heat from a local pool for their houses. They sought to realise this aim, but did not reach it. Instead, this 'bottom-up' process resulted in a diversification of activities, among them professionalisation. The actors in this process founded a cooperative for solar energy and became successful consultants in sustainable renovation. It should be noted that

figure 13 'Grasroot' participants meeting

other similar observed processes did reach their original aims. This type of process is grounded in the context of the dwelling and neighbourhood and awareness of local issues. Participants adapt initial aims as they encounter barriers and form new ones as they learn. The process resembles a seed being dropped into ground that reveals its shape as it grows and interacts with the plants around it. It contains negotiations, discoveries, alternative routes.

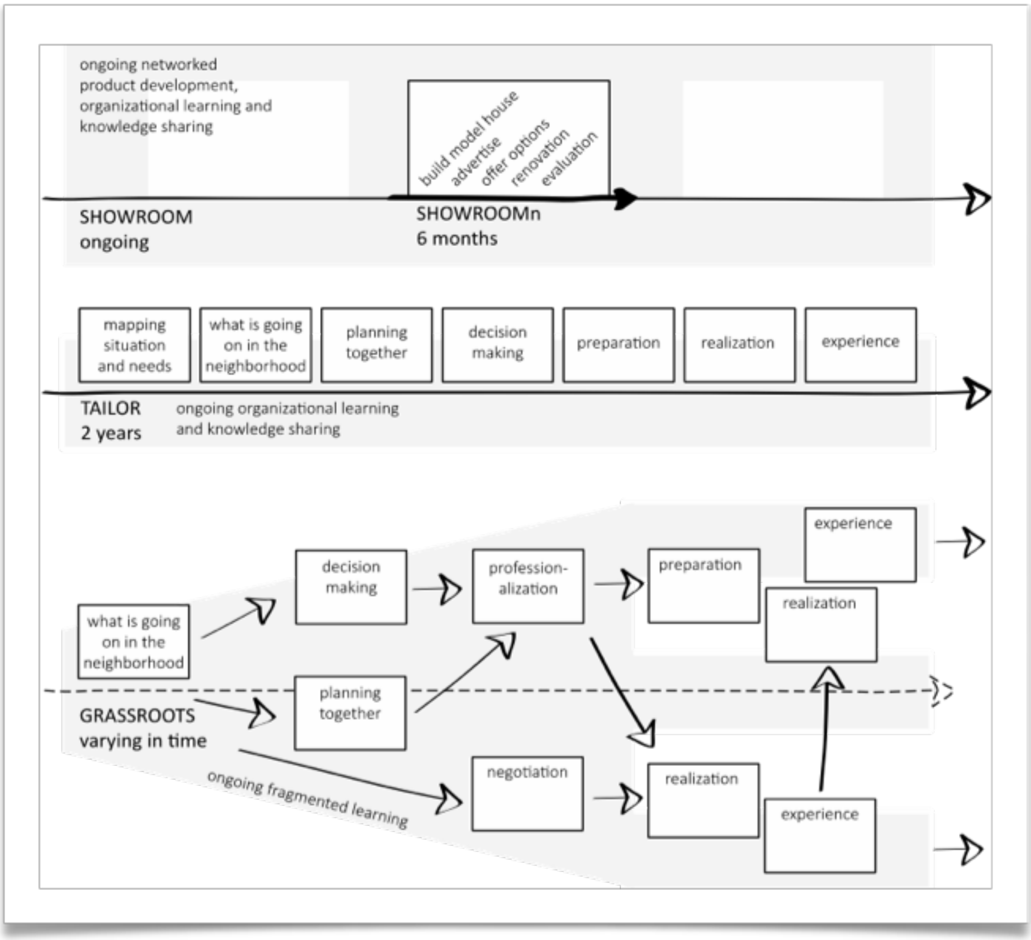


figure 14 Three types of participation processes observed

Table 11 Three types of participation processes described

Aspect	Showroom	Tailor	Grassroots	Proposed optimized process
Timeframe	short (6 months) financial and technical efficiency, minimal bother for residents	long (2 yrs) maximised co-creation of solutions, supported by lean management	long/varied obstacles due to lack of fit with corporate or municipal planning, learning takes time	of medium length (1 yr) to maximise co-creation yet achieve financial and technical efficiency
Risks for residents	low due to process standardisation	low due to support	high due to lack of support	low due to support
Consortium learning	high experiences per process are transferred in an organized way to new projects in ongoing learning	medium consortia are formed per project, knowledge transfer is limited	medium fragmented, ad-hoc consortia, but good networking and individual learning	high by aiming for knowledge transfer and inclusion of all stakeholders
Resident learning on wellbeing and energy saving	low due to short timeframe	high due to long timeframe and support	high due to long timeframe and commitment	high intensified learning, medium timeframe
Consideration of wellbeing	low due to standardisation of process	high due to relationship building	medium due to many stress factors	high by including it during all of process
Post-renovation low-energy practices (interacting with home)	uncertain due to unfamiliarity and consumer attitude	uncertain due to high satisfaction yet also unfamiliarity	likely due to immersion and commitment	likely due to immersion, commitment and support
Resident-led innovation	low due to unfamiliarity and consumer attitude	medium due to long timeframe, openness, relationship building	high due to autonomy and problem-solving	high due to openness, commitment and support

A proposed optimised process (see last column in Table 11) in which residents become a driving force is of medium length for financial viability, and starts with a community building phase also involving the municipality, to address issues the neighbourhood cares about. It should be supported by guarantees and advice for residents, as well as provide co-creation opportunities and services to understand and pre-experience post-renovation living practices. The process should be framed in terms of resident short-term and long-term wellbeing and meanings of home living, and include the post-renovation phase in terms of residents' lives alongside the building life cycle.

4.3.6 Scenario-based research on window areas and ventilation sample results

From the scenario-based research that was also conducted (see description below), key content areas for an optimised process were identified. They were, for example, to provide

- real choice, early enough, on key building measures such as window fronts
- transparent and trustworthy cost-structure scenarios
- a fair cost-distribution system, for people who currently do not use much energy, as well as for those who use a lot of energy, for example for health reasons (some conditions require a resident to heat their home to 27 degrees Celsius).
- consideration of neighbourhood issues such as a vandalised park, an unsafe pedestrian crossing or a badly-lit basement
- scenarios, experience and understanding of what ventilation does and at which specific moments it is advisable to keep windows closed.
- competent renovation execution with consideration for residents' lives, that remediates current building problems
- up-to-date home systems interfaces (e.g. control panels for ventilation) that do not overwhelm users but provide control

4.3.7 Inhabitants' disturbance and robustness & simplicity of solution

One of the starting points of the project development was that the occupant will 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.

Table 12 Levels used to distinguish the qualitative aspects

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 alive 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

4.3.8 Energy performance (Nul-op-de-Meter)

According to Marszal (2011), the most important issues to define a zero energy building are: the metric of the balance, the balancing period, the type of energy use included in the balance, the type of energy balance, the accepted renewable energy supply options, the connection to the energy infrastructure, and the requirements for the energy efficiency, indoor climate and building-grid interaction. This section discusses the issues that are relevant for the 2ndSKIN strategy.

A primary energy demand method is in accordance to the EPBD (2002) and takes into account differences between energy sources, which can help to make decisions during the design phase. Primary energy demand is the preferred metric for the balance in most methodologies, which makes comparison to other projects easier. However, for the 2ndSKIN project, we follow a method based on the more straightforward and easier to grasp zero-on-the-meter approach (Nul-op-de-Meter, NoM), since it is the approach favoured by industry and by housing associations in the Netherlands, which are the target market group. The zero on the meter approach is based on an annual balance, otherwise the zero energy targets would be difficult to reach given the differences on energy demand between summer and winter. For the zero-on-the-meter approach, the energy balance is made between the energy consumed and the energy generated.

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).

4.3.9 Occupants' behaviour

Very low and zero energy renovation projects are associated with high costs and long payback periods. The actual performance of these buildings is often unpredictable due to the

uncertainty provided by occupant behaviour (Guerra-Santin and Silvester 2016). The 2ndSKIN strategy aims at decreasing the performance gap, which is defined as the difference between the expected and actual energy consumption in buildings. This gap is created by rebound and pre-bound effects and as a consequence, it increases the uncertainty related to the return of investments in low carbon technologies. Thus, these two types of uncertainties, related to occupancy, are taken into account and integrated into the 2ndSKIN approach.

Pre-bound effect

The pre-bound effect has been defined as the situation in which, before the renovation, less energy is consumed than it is assumed. According to Sunikka (Sunikka-Blank and Galvin 2012), as renovations cannot reduce energy that is not actually consumed, this has implications for the economic viability of thermal retrofits. The expected energy consumption is, in some cases, higher than in reality because in building simulations an 'average household' and 'average building occupancy' are often employed. However, there is a large diversity in household characteristics, preferences and lifestyles of buildings' occupants, and therefore, large differences have been found between standardized occupancy patterns and actual occupancy patterns.

Rebound effect

The rebound effect has been widely studied in recent years. This effect can be defined as the increase on energy consumption in services for which improvements in energy efficiency reduce the energy costs (Guerra-Santin and Itard 2010). Rebound occurs when people compensate for efficiency improvements by increasing their spending (Herring and Sorrell 2009). In addition, it is important to consider that the rebound is in some cases, not a consequence of the user's choices or behaviour, but a consequence of new technologies.

Rebound and pre-bound effects can be minimised by knowing better the context of the users, their actual requirements and their capacity for changing behaviour. There are, thus, two main goals within the user research:

- To determine the performance of the building in relation to different types of households in order to user-proof the zero energy concept.

- To develop a protocol to monitor the energy consumption, indoor quality and user satisfaction of refurbishment projects. The protocol will be used to assess the actual performance of the building, but also to help the landlord (housing associations) and tenants (residents) to further reduce energy consumption by effectively operating the new technologies.
- to use the participation process ahead of a renovation to empower residents to contribute to the zero-energy outcome by providing them with insight and experience with home systems interfaces.

4.4 Program of requirements

In this paragraph the issues addressed in the foregoing chapters is being elaborated into a program of requirements for the 2ndSKIN product-/service to be developed.

Table 13 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 prototyping process will help to determine the values for some of the criteria, to be applied in the up-scaling.

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	oC				X
	Temperature aux. spaces	16-25	oC				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

Table 13 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 solutions.

5 Design Strategy

5.1 Methodology

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 relation between the 2ndSKIN final strategy and the prototyping is one of the main project contributions. The 2ndSkin team has realised that the direct replication of prototyping to the upscaling 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 in 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 of technologies to be implemented in the upscaling of the 2ndSKIN kin 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.

Overall, the result of the 2ndSKIN project is not a single project solution but rather an approach, highlighting the underlying argumentation line with pros and cons. In fact, the project has basically three stages:

- Prototyping with the possibility to test as many of the systems as possible.
- Upscaling prototype by using available technologies and in the same time testing basics for future more innovative solutions.
- An outlook to an improved version that includes promising technologies available in the near future.

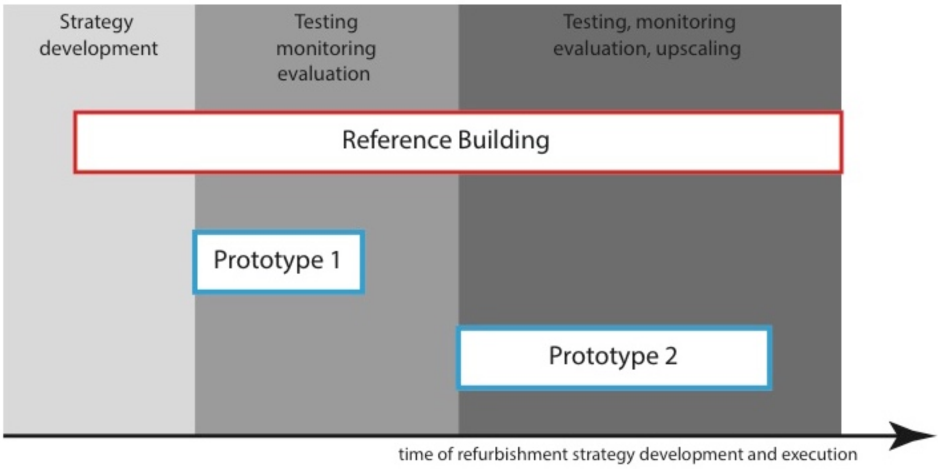


figure 15 Timeline of strategies development, showing that the reference 2ndSKIN strategy is developed in parallel with the prototypes, exploiting the input by construction and testing on prototypes.

The process of the project consists of the following steps, reflected in the different Work packages. The methodology scheme is shown in figure 16.

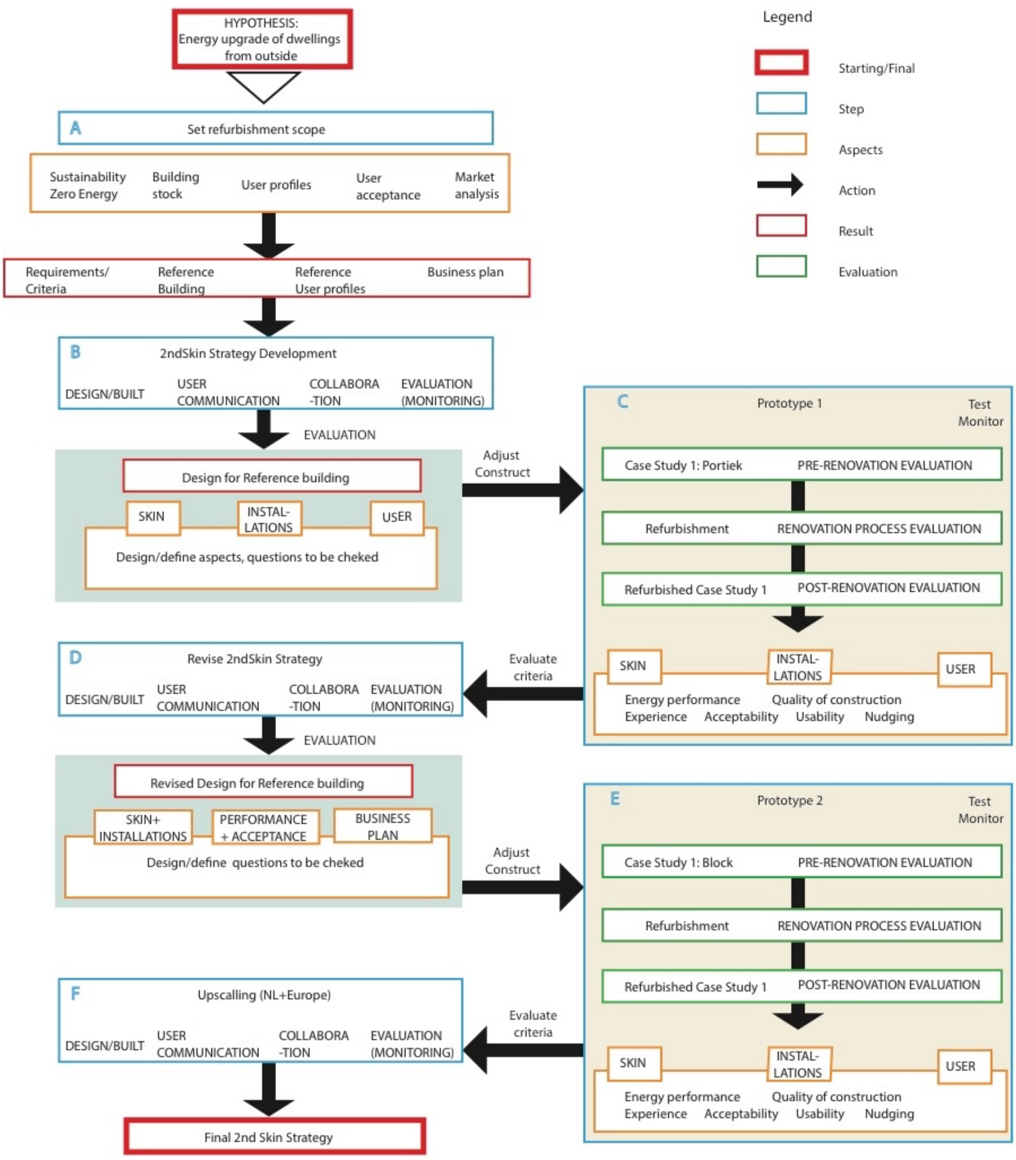


figure 16 Methodology scheme; Steps C & E, which are the prototyping are parallel with the 2ndSKIN strategy development.

Industrial design phase:

- A. Setting the scope of the refurbishment strategy (WP 1.1)
- B. Design the solution based on reference building (WP 1.2, 1.3, 1.4a)
- C. Design aspects installation & installation box (WP 1.3)
- D. Test specific aspects on Prototype 1 (WP 1.4b, 1.5)
- E. Consider test results and revise refurbishment strategy (WP 1.6, 1.7)

Experimental phase:

- F. Apply refurbishment in Prototype 2-Upscalling (WP 2)
- G. Evaluate Prototype 2 and suggest upscaling methods

There are in principle two axis of the strategies development. Steps B, C, E focus on the 2ndSKIN strategy on the reference building, while steps D and F include the construction and testing of prototypes.

The design the refurbishment strategy is based on the collaboration of the different consortium members. The collaboration occurs in different levels. At the beginning of the design elaboration the 2ndSKIN team defined four themes, which were subsequently further elaborated in smaller groups, according to expertise. The themes are: a) Skin, b) Installations, c) User and d) Business plan. Next to the themes elaboration, the whole team meets regularly to exchange their result and require input from the different themes. In this way the design process is integrated.

5.1.1 A-B-C innovation status approach

The design team started with the development for the 2ndSKIN system on a project contributed by the social housing corporation Woonbron as part of the Concept House Village located on the RDM Campus at Heijsekade Rotterdam, as one of the four concepts to be tested on location which were due to be realised within 10 months after the start of the project. With limited time for the development and subjects which needed far more time than available, the design team decided to define different statuses of innovations to be applied in the series of prototyping foreseen. The statuses which was disclosed as;

Status A: Available solutions, techniques and proven models which could be combined to the desired 2ndSKIN system to enable the realisation within given timeframe, to test the system, monitoring the production and realisation of the facade as preparation to the demonstration project.

Status B: A re-design of the 2ndSKIN system with the test results of the prior model, adopting results of ongoing research and the possibilities to assimilate new products/techniques or new legislation within 3 to 5 years.

Status C: A reconnaissance of the development within the market developments, techniques and housing market with a timeframe of 5 to 10 years. These will not be of direct influence on the direct development of the 2ndSKIN faced but should be taken in account of the long term purpose of the desired upscaling of the zero energy renovation of porch apartments.

The innovativeness of the first prototyping was decided on status A.

5.1.2 From Example to Sample

Some months after the start of the project, one of the main partners, Woonbron, owner of the porch apartments at Heijsekade decided, to stop the participation in Concept House Village Living Lab and offered to sell the property to a replacement with comparable goals. This process of finding a replacement and getting permission from the Ministry of the Interior (Binnenlandse Zaken) and local authorities proved to be more time consuming as anticipated by all of the partners. This forced the project team to change strategy, instead of making a design for the Heijsekade to test the system on a project from the post-war industrialised housing systems to develop the 2ndSKIN façade with the possibility to perform the intended testing on a mock-up.

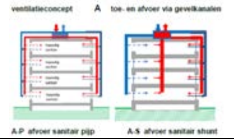
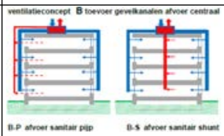
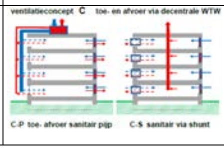
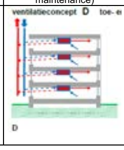
The MUWI system, as described in Table 10 combined the characteristics of most of the systems and makes 11% of the post war housing production. Frequently occurring characteristics for example are: three types of balconies, the basement with storerooms re-entrant to the façade of the dwellings, a slab extension on every floor, balconies as part of the floor introducing thermal bridges, parapet within the façade panels which stretch from floor to the ceiling and a division with kitchen at the façade and the bathroom in the centre of the dwelling joining the steering shaft.

The proposed solutions for the 2ndSKIN based on the MUWI system therefor should be feasible for most of the building systems during the period from 1946 to 1974, in this period nearly two million dwellings were realised which should be refurbished to energy neutral before the year 2050.

5.1.3 Morphological charts

The design elaboration process has resulted in a number of options on a component and sub-system level. These options, which are the result of approximately five months of design elaboration, are organised in a matrix that forms a morphological chart. Based on the systematic organisation and evaluation of options, the design team can come up with combinations for the 2ndSKIN strategy. Most importantly it provides knowledge that can be applied in different refurbishment cases, supporting the objective of larger applicability. On the next page as an example the chart of the ventilation system is shown with the assessment criteria.

Ventilation options

Ventilation	with heat recovery (WTW), Collective supply of fresh air and outlet via façade individual	with heat recovery (WTW), Collective supply of fresh air in via façade outlet collectively	with heat recovery (WTW) decentralised	with heat recovery via porch (WTW placed in traffic space for maintenance)	
					

Description	*-1= worse than reference 0= like reference +1= nearly 2nd Skin +2= 2nd Skin +3= better than 2nd Skin*				Remarks /
1) Occupancy:					
(thermal, light, moisture, air velocity) comfort	-1 / 0 / +1 / **+2** / +3 In-uit aan zelfde gevel	-1 / 0 / +1 / **+2** / +3 Overloop principe	-1 / 0 / +1 / +2 / **+3** Comfort per vertrek regelbaar	-1 / 0 / +1 / **+2** / +3 Overloop principe	
Usability (control, 'regelbaarheid')	**-1** / 0 / +1 / +2 / +3 Collectief system	**-1** / 0 / +1 / +2 / +3 Collectief system	-1 / 0 / +1 / +2 / **+3** Per vertrek regelbaar	-1 / 0 / +1 / **+2** / +3 Per woning regelbaar, per vertrek indien verdeelsysteem per vertrek wordt aangebracht (veel werk in de woning!)	
Satisfaction	-1 / 0 / +1 / +2 / +3	-1 / 0 / +1 / +2 / +3	-1 / 0 / +1 / +2 / +3	-1 / 0 / +1 / +2 / +3	
Nudging (possibilities to change behaviour and adaptation)	-1 / **0** / +1 / +2 / +3	-1 / **0** / +1 / +2 / +3	-1 / 0 / +1 / +2 / **+3** Per vertrek regelbaar, maar risico van misverstand en verkeerd gebruik. Misschien en slechter score?	-1 / **0** / +1 / +2 / +3	
Health & Safety (fire, CO2,..)	-1 / 0 / +1 / +2 / +3	-1 / 0 / +1 / +2 / +3	-1 / 0 / +1 / +2 / +3 Gevaar voor niet vervangen van filters	-1 / 0 / +1 / +2 / +3	Brandpreventie?
Flexibility (future-proofed)	-1 / 0 / **+1** / +2 / +3	-1 / 0 / **+1** / +2 / +3	-1 / 0 / +1 / +2 / **+3**	-1 / 0 / **+1** / +2 / +3	Heel lastig om dat te zeggen. Eigenlijk moet er en concrete future scenario zijn om dat te kunnen beoordelen.
Robust in use	-1 / 0 / +1 / **+2** / +3 Centraal system alleen buitenaf bereikbaar	-1 / 0 / +1 / **+2** / +3 Centraal system alleen buitenaf bereikbaar	**-1** / 0 / +1 / +2 / +3 Kwetsbaar door veel apparatuur in een woning, veel ventilatoren in de verschillende ramen	-1 / 0 / **+1** / +2 / +3 Woningsysteem alleen buitenaf bereikbaar. Is toch en voordeel voor woning coöperaties?	
2) Technology /Economics					
Energy efficiency / including 'hulp-energie'	-1 / 0 / +1 / +2 / **+3** Een wtw voor heel travee	-1 / 0 / +1 / +2 / **+3** Een wtw voor heel travee	-1 / 0 / **+1** / +2 / +3 Een wtw per vertrek	-1 / 0 / +1 / **+2** / +3 Een wtw per woning	
Air Tightness	-1 / 0 / +1 / +2 / +3	-1 / 0 / +1 / +2 / +3	-1 / 0 / +1 / +2 / +3	-1 / 0 / +1 / +2 / +3	
Robustness/Proven Technology, A available, B tested /, C still in laboratory)	-1 / 0 / +1 / **+2** / +3 A	-1 / 0 / +1 / **+2** / +3 A	-1 / **0** / **+1** / +2 / +3 B alhoewel ventilatoren en filters op zich zeer robust zijn (dus kan best +1)	-1 / 0 / +1 / **+2** / +3 A	
Possibility of integration into 2nd SKIN	-1 / 0 / +1 / +2 / **+3** Dit is 100% 2nd skin	-1 / 0 / +1 / **+2** / +3 Afvoer via shunt is ingreep in woning	-1 / 0 / +1 / +2 / **+3** Dit is 100% 2nd skin	**-1** / 0 / +1 / +2 / +3 Flinke ingreep binnen woning. niet 100% 2ndSkin.	
Maintenance centralized/ easiness of maintenance Maintenance Costs	-1 / 0 / +1 / +2 / **+3** Centraal system per travee Eenvoudig onderhoud	-1 / 0 / +1 / +2 / **+3** Centraal system per travee Eenvoudig onderhoud	**-1** / 0 / +1 / +2 / +3 Meerdere systemen per woning van binnenuit onderhouden	-1 / 0 / **+1** / +2 / +3 system per woning Eenvoudig onderhoud	
Production Cost	-1 / 0 / **+1** / +2 / +3 Centraal system per travee Veel leidingen in gevel	-1 / 0 / +1 / **+2** / +3 Centraal system per travee leidingen in gevel	**-1** / 0 / +1 / +2 / +3 Meerdere systemen per woning.	-1 / 0 / **+1** / +2 / +3 Eenvoudig systeem per woning	Moeilijk te zeggen
Conclusie	**Goede 2nd skin oplossing Slecht regelbaar Veel leidingen in gevel**	**Goede 2nd skin oplossing Slecht regelbaar leidingen in gevel**	**Goede 2nd skin oplossing Goed regelbaar Veel apparatuur in huis + kosten + onderhoud**	**Grote ingreep in woning Eenvoudig individueel systeem**	

5.1.4 Concept choice workshop and selection of concepts to test in Prototype 1

A milestone in the 2ndSKIN design development was the “concept choice method” workshop. The aim of the workshop was choosing the right combination of building and energy systems to fulfil 2ndSKIN BTA project aims. Moreover, criteria, trade-offs and questions were to be clarify.

Figure 14 The 2ndSKIN Design team during the workshop

Throughout the design investigation, as well as the options evaluation workshop, the choice of ventilation system is considered central in order to determine the refurbishment strategy.

Ventilation system

To this end, it has been decided to test two ventilation concepts in the prototype 1. The retrofitting of the other systems and components will adjust respectively. Table 14 summarises the refurbishment strategies to be constructed and tested in prototype 1. The concepts are characterised by the ventilation system.

Table 14 Refurbishment concepts based on different ventilation solutions

Ventilation system	Advantages	Considerations	SKIN
Heat recovery, collective air in via façade (selected for prototype 1))	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 (selected for prototype 1))	Ventilation system is safer and is available technology Well-known technology, robust	Limited flexibility Not expressing 2ndSKIN approach as some parts are inside the dwelling	Ducts running through facade External insulation Replace windows with HR++ Integrate air inlet/outlet at staircase
Heat recovery decentralised per room (further development needed)	Flexible Innovative	Difficult to develop such a new system and upscale it to 20 units within time available > recommendation for further development (B/C type innovation) Some rooms not adjacent to façade	External insulation Replace windows with HR++ Integrate ventilation unit into window frame or wall

Installation Box (Ventilation, Space heating and domestic hot water supply)

The Installation Box, as proposed in the TKI grand application, aimed to solve some of the obstacles which prevented the upscaling of the zero energy renovation of porch apartments and represented some of the proposed solution directions.

The size and division of the apartments, especially from the period 1946-1974, limit the possibility to introduce a state of the art installation both for ventilation system and storage domestic hot water system fully integrated in the skin. Introduction of a balanced ventilation system would take far reaching adjustments to integrate the needed piping, if possible, throughout the dwelling.

The participation of at least 70% of the owners' association or, if the object is owned by housing association, 70% of the tenants, is highly unlikely and should be considered as one of the main obstacles in the desired upscaling when a radical indoor-renovation has to take place.

By the proposed break-up between real estate and the energy supply systems and locate the equipment for as far as possible outside the dwelling, new possibilities occur.

An important improvement of 2ndSKIN will be the possibility to contract providers which can provide no "energy" but the agreed thermal comfort and air quality as stated in a service agreement, and which will own and maintain the equipment needed. The break-up gives the provider direct access to the installation which might seriously reduce the cost for maintenance because no appointment with tenants has to be made. By owning the equipment and making the system choice, it is the responsibility of the provider to make long term business plans including anticipating on chances in future energy market and energy sources. This might include the investment needed for PV panels either placed on the roof or part of the facade.

The investment needed for the zero energy renovation will by this break-up replace the investment for the equipment into a part of the service contract which might have a long term duration related to the life span of the equipment.

In an early stage of the project an estimation of the space needed per porch was made which led to the conclusion the box couldn't be situated on ground level, neither at the front nor the rear. The size of the box – based on the available components was just too dominant to be placed in the public space at street level or in the gardens at the rear. An additional problem seemed to be the distance between the box and the windows at the opposite façade, length of piping became unusable. A challenge for the project team was to come up with alternative strategies within the scope as disclosed previously.

The ideas for solutions from the workshop were further elaborated during the research of the ventilation systems and organising the ducts within the system. The roof system was preferred to the balcony option on the aspects of accessibility without intervention of the tenants and the possibility to make use of the existing shunt duct.

The balcony option could be an interesting option, if thermal bridges combined with extension of the balcony together with storage of warm water supply is needed.

Study feasibility of integration of installation in parapet

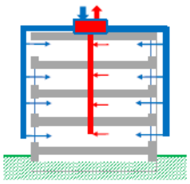
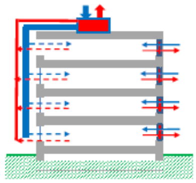
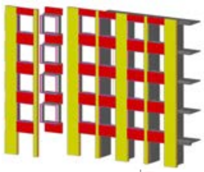
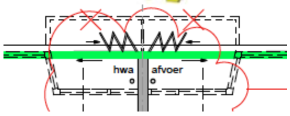
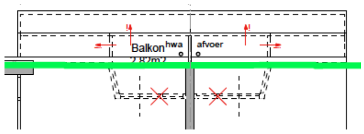
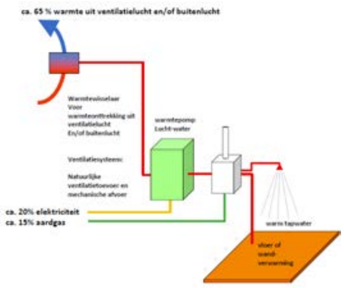
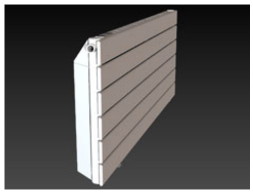
During the 2ndSKIN project, several research and design challenges of the 2ndSKIN approach were also translated into assignments for Bachelor and Master students of the Hogeschool Rotterdam and the Faculties of Architecture and Industrial Design Engineering of the TU Delft. For example, one assignment on the design of the balcony area especially focussing on senior citizens (Aghina 2015) and another on the feasibility of integration of the installation box into the parapet of the reference building was executed by Ahmed Assed, master student TU Delft Architecture, Building Technology (Assad 2016). He developed a solution for the installation box together with Rollecate (Façade Industry) and Alklima/Mitshubishi (Heatpumps). This promising solution is typical a status C innovation; not ready yet for implementation but very interesting for further R&D. One of the challenges of Assad's solution is still the boiler for the domestic hot water, to be positioned horizontally instead of the common applied vertical position.

5.2 Integrated 2ndSKIN concept

During the sessions on the morphological charts and its assessments it was decided by the 2ndSKIN-project team that when it was possible from a building-physics and financial perspective, preferably combinations of different promising options of sub-systems should be applied and investigated for getting more insights in their impacts. At this point of concept development of 2ndSKIN it wasn't possible to select one single combination of options yet for the vast array of details for the targeted building typologies.

Table 15 gives an overview of the subsystems selected for further prototyping

Table 15 Sub-systems selected for 2ndSKIN prototyping

Sub-System selected for prototyping	Option 1	Option 2
Ventilation: Option 1: Heat recovery & ventilation unit on roof, inlet in façade, extraction thru renovated shunt duct. Option 2 (De-)central ventilation and heat recovery in facade		
Façade; prefab completed façade panels		
Balcony; option 1:cut of old balconies. Option 2: + enlarged new balcony outside envelop.		
Space Heating / DHW: Individual Air-Water heat pump with buffer for domestic hot water		
Heat distribution; Option 1: use existing radiators. Option 2:Convection low temperature new radiators.		

6 Integral concept 2ndSKIN, embodiment

6.1 Developing Prototype 1 (WP 1.4b, 1.5)

In this chapter, the results from Work Package 1.4b: INTEGRATED 2ndSKIN CONCEPT (process solution), and Work Package 1.5 (PROTOTYPE REALISATION) are presented. The prototype realization refers both to the physical technical mock-up façade, and the energy calculations based on building simulations and energy audits.

6.1.1 Integration 2ndSKIN concept: co-creation sessions with occupants and participation process (WP 1.4b)

The user research developed for the 2ndSKIN project aims to identify the sources for energy performance uncertainty and to reduce it. The approach focuses on the identification of target occupants and on the investigation of their characteristics and requirements to inform the design and the energy calculation process. The user research was conducted on a series of monitoring pilots, mock-ups and case studies. This section presents the user research approach developed for the 2ndSKIN renovation process, summarising the findings of the quantitative and qualitative analysis.

6.1.2 Approach to integrate user requirements into design

This section presents user research serving two main goals: to determine the effect of household typology on the zero energy concept, and to integrate user requirements into the design of solutions. Two types of studies are presented: 1) quantitative analysis of pre-renovation monitoring campaigns and statistical data to determine occupant's behaviour and household typologies prevalent in the neighbourhoods to be renovated, and 2) qualitative research on occupancy practices and occupant preferences on the use of window areas and mechanical ventilation as an example of user interaction with a building system. Part of the results from the ventilation research are included here to illustrate their contribution.

Two aspects of occupancy are taken into account and integrated into the 2ndSKIN renovation approach:

A. Uncertainty on building performance. The objective of this research aspect is to reduce the uncertainty about the effect of occupancy often encountered in renovation projects. By reducing the uncertainty on calculated energy savings, created by differences in occupant behaviour and pre-bound effects, we will also reduce the uncertainty in the estimation of 'return of investments'.

B. Uncertainty on user-building interaction (rebound effect). Reducing energy consumption while increasing comfort can be achieved by integrating user-centred research as an instrument to feedback requirements to designers and to implement better interfaces and solutions that help users to understand and interact with the new technologies.

This research also highlights the differences between occupancy profiles from monitoring data, statistically defined household profiles and requirements elicitation. In order to determine the most effective method to define occupancy, it is important to consider the aim of the evaluation. Monitored occupancy profiles can provide detail information on the occupant behaviour of specific households. However, the behaviour will be highly determined by the building characteristics. In renovation projects when it is expected that the building properties improve, the behaviour of the occupants will certainly change. The enactment study did not result in profiles corresponding to the occupancy profiles. For example, user requirements for safety and control were shared across participants with different socio-economic profiles. Quantitative and qualitative research methods are therefore equally necessary and their integration can help to determine the occupant preferences in building renovation projects. In the pre-renovation design process, the results inform the building design and options for occupants. In a proposed renovation process, the results serve to manage expectations on energy savings

figure 17 shows the approach and research techniques used in this investigation. Statistical analysis was used to determine household typologies and the socio-economic characteristics of households more likely to inhabit the reference building. Based on the household typology, monitoring cases were studied to determine behavioural patterns of the households. In addition, based on the reference socio-economic household characteristics, qualitative studies were carried out to determine user requirements. The following sections summarise the findings from the quantitative and qualitative studies.

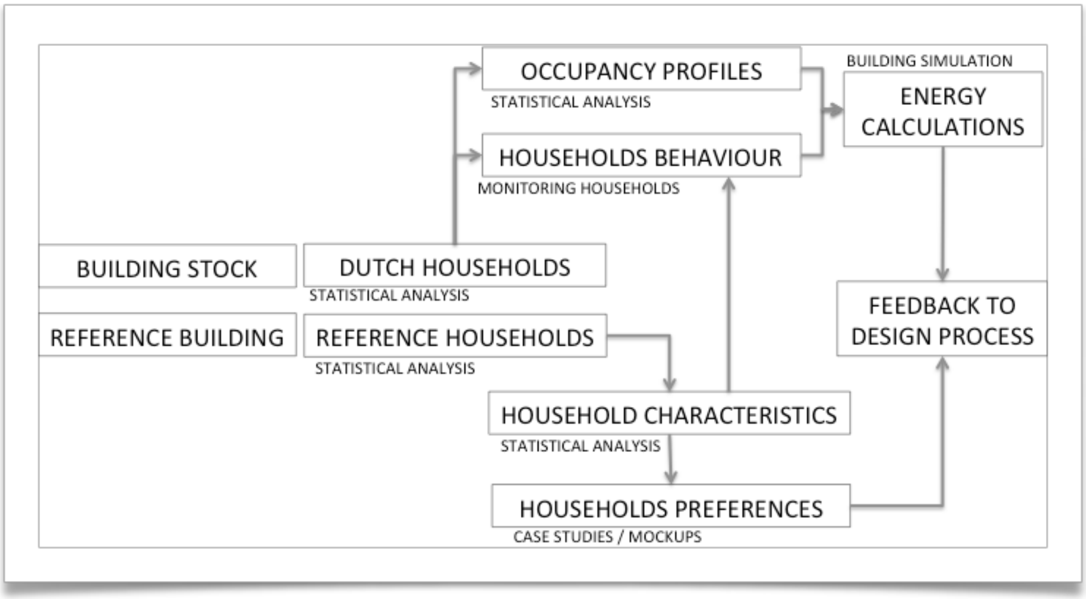


figure 17 Approaches and techniques used for user research

Co-creation sessions with occupants and participation process (WP 1.4b)

Because this research was conducted without a specific housing corporation partner, the co-creation with tenants was sought in a number of alternative ways. Interviews were conducted with reference residents in their homes, in a simulated new home environment, and in various co-design activities with students. These activities led to a critical review of the building management process and how it could facilitate co-creation possibilities for tenants. The current standard building management cycle tends to present an even distribution of phases

figure 18 The current standard building management cycle (e.g. Warmelink, 2009)

(figure 18)(e.g. Warmelink, 2009).

These cycles are presented from the perspective of a management organisation or consortium. The residents' perspective is quite different as interviews revealed, since they view their home in terms of their routine lives and life events. The 'use & repair' phase is the main experience, whereas the other three phases are experienced as abrupt, with many unknowns yet great intensity (figure 20). Since the use phase is crucial in maintaining low-energy and dwelling satisfaction, it should receive more attention in a building management visualisation and the technical design process. For example, with regard to usability of interfaces in the home, information on energy use, and the life cycle of a building. This attention should be framed in terms of wellbeing in the home in order to connect with residents' life experience. This is relevant not only for those who deal directly with residents, but also for those involved in the technical design and management. The stakeholders should have a shared concept of the process, such as shown in figure 19. It visualises the phases but also the intensity of the process for residents. This conceivably leads to more inclusive design and management decisions that ultimately facilitate an energy-saving outcome.

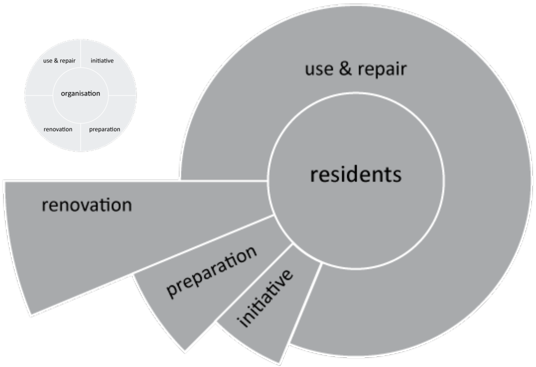


figure 19 Building management cycle in the residents' experience (compared with standard process)

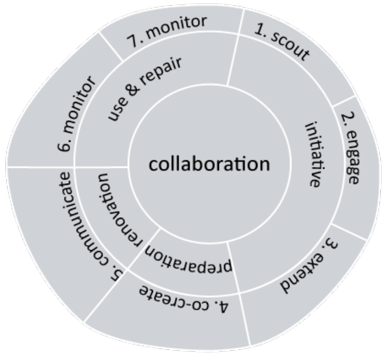


figure 20 Conceivable building management cycle that is inclusive of resident's perspective and collaboration

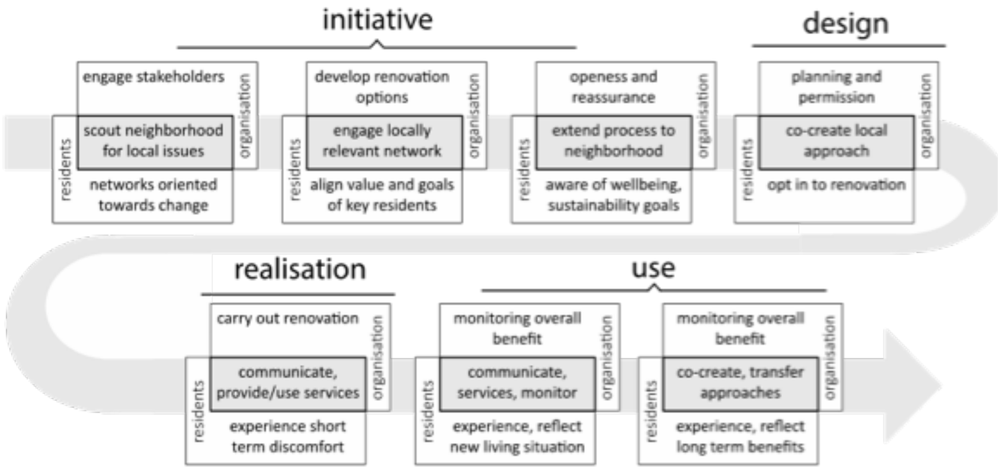


figure 21 Activities in a conceivable integrated building management cycle that is inclusive of resident perspective and collaboration

6.2 Architectural studies for the reference building

Spee Architects together with the others partners of the 2ndSKIN teams a large numbers of architectural designs for the facades of the targeted project at Heijplaat (figure 22) and in preparation of the Mock-up also for the reference building (figure 23).

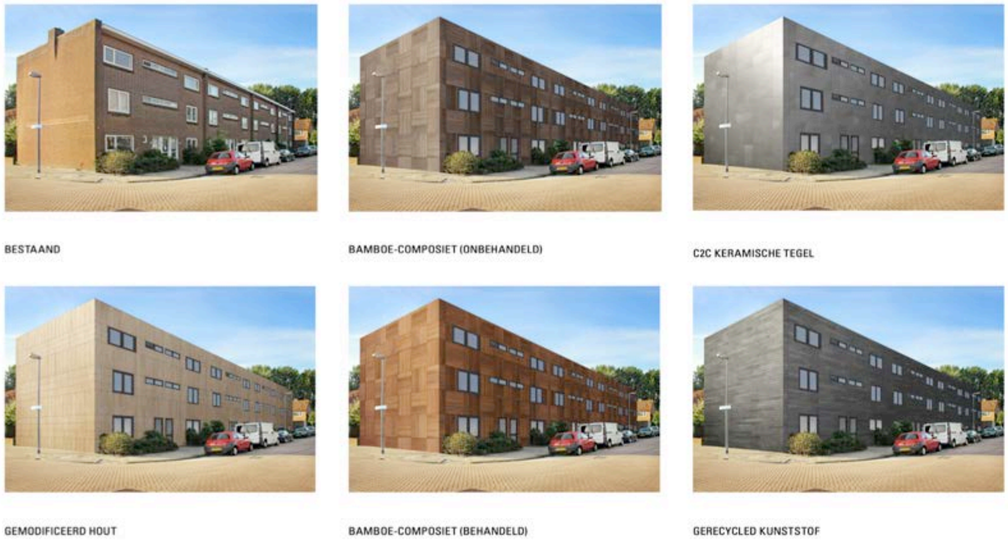


figure 22 Studies on claddings for a project at Heijplaat Rotterdam by Spee Architects

figure 23 Facade Design studies by Spee Architects (2015)

6.3 Prototype realisation: technical solution (WP 1.5) & 2ndSKIN Mock-up development steps

The mock-up design and construction included several actions, such as the design of the mock-up, the selection and delivery of products and the assembly. The façade contractor, Rollecate, had a leading role in executing the steps, with the support of the design team. The total time period, from design to assembly, was approximately four months. In a real project situation, the design period will be considerably shorter, since the details will already have been determined, but the production time will be longer, since a larger number of components will be required. As far as assembly is regarding, the two weeks of the mock-up included the construction to simulate the existing building, which will not be needed in an actual project.

Table 16 Timing of Mock-up & expected timing final production

Step	Time period	Time expected for a building project
Design / Design details	3 months (Jul-Sept 2016)	1 month
Products from suppliers and construction of components	3 weeks (Sept-Oct 2016)	6 weeks
Assembly / prefabrication	2 weeks (Oct 2016)	Depending on project size (approx. 1 week in factory and 1 week on site, per 6 apartments)

Design / Design details

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 concept is 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.

Detail design

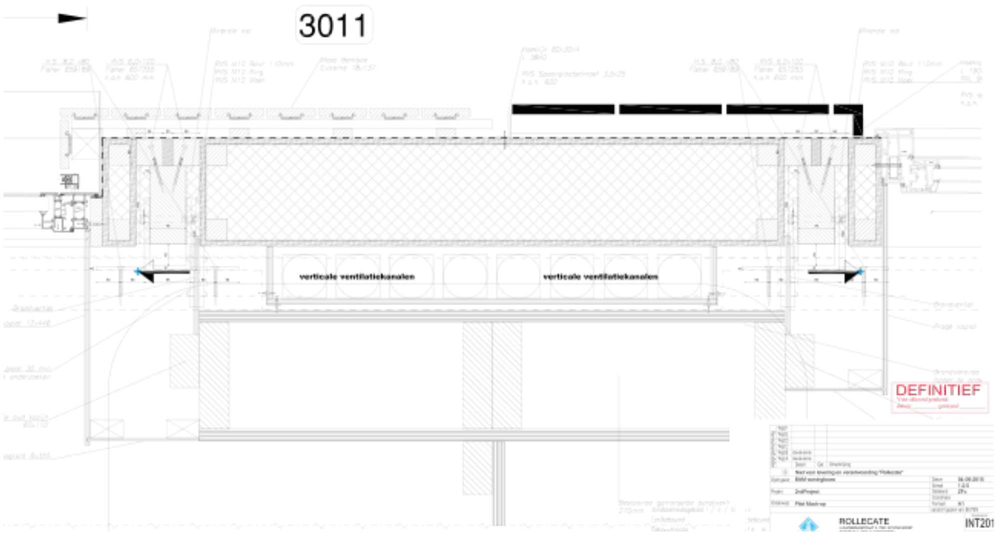


figure 24 Detail of the 2ndSKIN construction

For the mock-up to be constructed and assembled, construction details needed to be decided and designed, based on the preliminary concept for the 2ndSKIN component. Even though the basic principles remain the same, the design and construction have been further elaborated, to include details about the connection of the panels, cladding options etc. (figure 24).

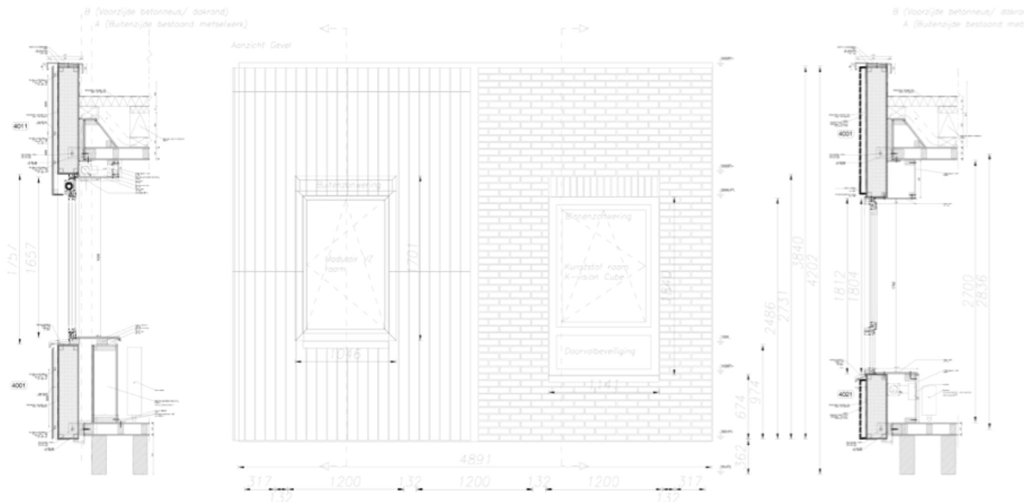


figure 25 Design for the 2ndSKIN façade fragment to be constructed as a mock-up

Moreover, the façade fragment to be reproduced as a mock-up was chosen in order provide more opportunities for checking several critical points of the construction. The final decision, as shown in figure 25, included both opaque and transparent parts, openings with different height and position (the one represented the option where parapet is present in the existing façade), roof construction and different cladding options.

6.4 Products from suppliers and construction of components

After the mock-up details where finalised, the products to be used needed to be chosen and ordered. Table 17 shows the products used for the different components.

Table 17 Mock-up; Components& Suppliers

Component	Company	Photos of Mock-up products
Sandwich insulation panels	Kingspan	 
Window frame profiles Solar screen	Alcoa	 
Pipes and ventilation inlets	Ventilatieservice	
Brick slips (Steenstrips)	Sto-Steenstrips	
Wooden cladding with supporting structure	Bambooextreme	

Due to the strict timeline and the small scale of the mock-up, the time period for ordering and delivering of the products was 2-3 weeks. Normally, for a building project, at least 6 weeks should be accounted. The materials selected for the mock-up were based on decisions of the preliminary design, such as the sandwich panels, need to test different options, such as the cladding material, and regular product suppliers. In a project situation, the choice of supplier and some of the material can be different.

6.4.1 Assembly / prefabrication

The assembly process lasted two weeks, during the first of which a timber structure was constructed to simulate the fragment of an existing building. The assembly of the 2ndSKIN components, after the products were delivered, was finished within one week and it included the following steps, as summarised in figure 26 and documented by the following pictures:

1. Construction to simulate existing building
2. Substructure: wooden posts attached to existing structure with steel U profiles
3. Central panel attached to the sub-structure, through timber sticks
4. Left and right panel attached to the sub-structure, through timber sticks
5. Airtight sealing between the panels
6. Window frame and glass placement
7. Ventilation pipes in the cavity
8. Cladding

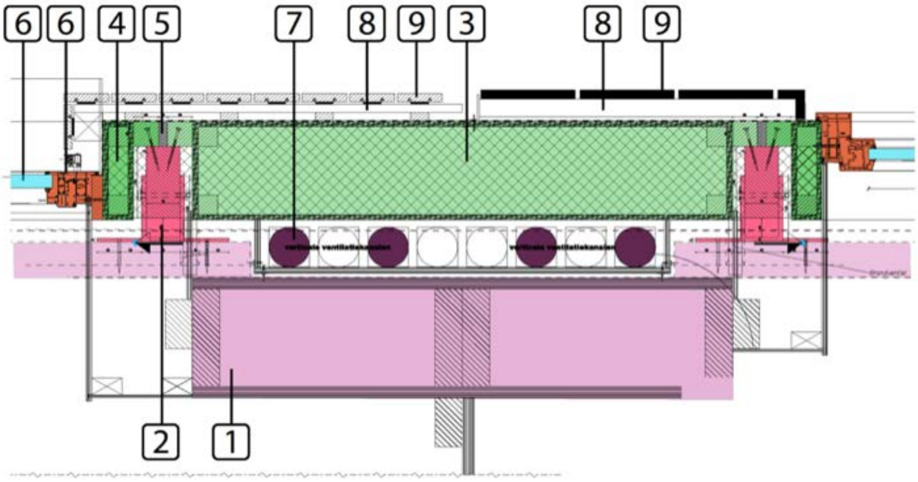


figure 26 Horizontal detail of the façade panels and connection, indicating the sequence of the mock-up components.

1. Construction to simulate existing building

2. Substructure: wooden posts attached to existing structure with steel U profiles

3. Central panel attached to the sub-structure, through timber sticks

4. Left and right panel attached to the sub-structure, through timber sticks

5. Airtight sealing between the panels

5. Window frame and glass placement

6.

7. Ventilation pipes in the cavity

8. Cladding

6.4.2 Prototype realisation: energy calculations (WP 1.5)

In this section, the results from the energy demand calculations are presented. Heating demand is calculated through building simulations based on a standard household.

Heating demand: building simulation

The dynamic building simulations were carried out with Bink software [ref]. Table 18 shows the building characteristics used as input in the building simulation model.

Table 18 Input for the building simulation software

	Specifications
Roof	Rc 4.5
Facade elements	Rc 6.5
Ground floor	Rc 3.5
Window frames	Rc 0.8
Double glazing	U 0.8 (1.135) gg o,8
Infiltration	0.4 dm3/s.m2
Ventilation system	Balanced ventilation efficiency 0.75
Heating system	24 kW central heating boiler

Each room is modelled as one thermal zone, as we wish to investigate the effect that preferences for room temperatures and spaces heated have on energy demand. The heating demand per room was calculated assuming a 100% efficiency of systems, according to the schedules defined per household profile (intermittent comfort). The system adjusts the temperature of the room according to the comfort requirements, with unlimited capacity. The comfort temperature per room is determined for an average household.

Natural ventilation is only considered for the summer period, when external temperature reaches 18oC or internal temperature exceeds 25oC. Thus, natural ventilation does not have an effect on heating demand in the simulations.

The internal heat gains are integrated into the simulation model in two ways. Artificial lighting is defined as specific artificial use patterns defined per household type, which are based on the household profiles. Internal heat gains for appliances and electric equipment are calculated based on statistical data on electricity consumption per household type in reference dwellings (WoON dataset).

Table 19 shows a comparison between the heating demand for different apartment types, since their size and location will have an effect on heating demand. Apartments type A have three bedrooms and a total area of 68 m2, while apartments type B have two bedrooms and a total area of 58 m2.

Table 19 Results building simulation; Heating demand (kWh/year)

	Standard household
A Ground floor	924
A 1st floor	801
A 2nd floor	751
A 3rd floor	641
B Ground floor	746
B 1st floor	632
B 2nd floor	868
B 3rd floor	746

Heating demand according to different technical solutions

The energy demand for a limited number of technical solutions was also calculated. The issues investigated were 1) double vs. triple glazing, 2) high vs. low infiltration rates of the Porch building entrance, and 3) low temperature heating vs. high temperature heating. The results are shown in Table 20 and figure 27 per apartment (58 m2). In figure 27, the results of the heating demand simulation are compared with the heating demand on the reference buildings, obtained from statistical data.

Table 20 Heating demand per technical solution in kWh/year per apartment

	Infiltration	Heating demand
AVG. reference building	NA	6892.1
Double glass 24 kW CV boiler	Low Qv=0,4	1035.1
Triple glass 24 kW CV boiler	Low Qv=0,4	800.9
Double glass 24 kW CV boiler	High Qv=0,8	1201.9
Triple glass 24 kW CV boiler	High Qv=0,8	962.0
Triple glass, low temperature 3 kW heat pump	Low Qv=0,4	584.6

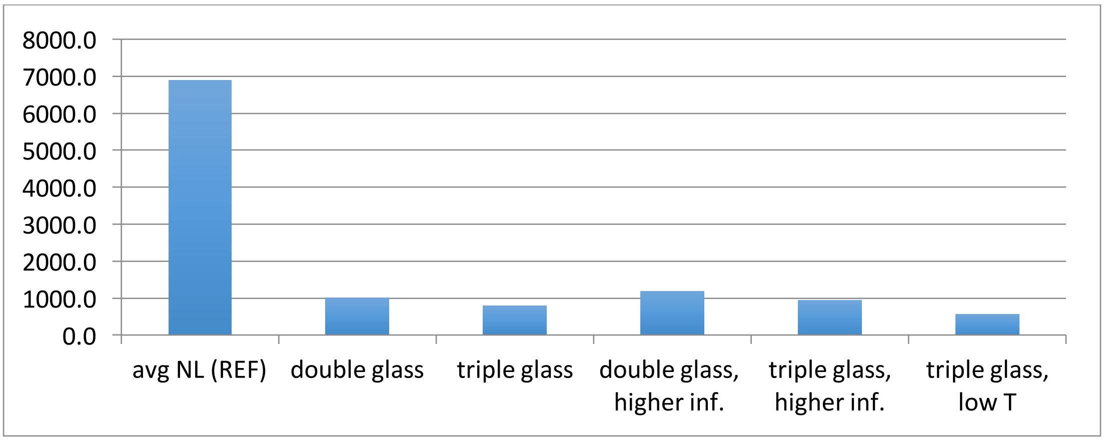


figure 27 Heating demand per technical solution in kWh/year per apartment

Energy generation

We calculate the energy generation depending on roof type and orientation of the building. Five scenarios were calculated, taking into account the orientation of the building, the type of roof, and the possibility to provide an attic for installations. The five scenarios are: North-South orientation with flat roof, North-South orientation with pitched roof, North-West orientation with flat roof with an attic for installations, East-West orientation with flat roof, and East-West orientation with pitched roof.

Calculations were made assuming the use of a CSun255-60P solar panel [20]. Each module has a capacity of 255 Wp. Results of the calculations are in Table 21. The energy generated in the roof of the building is divided by the number of apartments in the buildings. Porch apartment buildings can have either three or four floors. Given that the 2ndSKIN strategy could be applied to both possibilities, we studied the results of the calculations considering both scenarios. The energy generated per apartment can be seen in the right-side columns of Table 21.

Table 21 Energy generation per building orientation and type of roof

	Orientation	Type of roof	Number of modules	Panels installed m2	Installed capacity (kWp)	Production (kWh/year)		
						One porch building	Per unit (6 per porch)	Per unit (8 per porch)
EW_flat	East-West	Flat roof	52	84.4	13.26	10430.5	1738.4	1303.8
NS_flat	North-South	Flat roof	36	58.4	9.18	7795	1299.2	974.4
NS_flat_b	North-South	Flat roof (attic)	90	146.1	22.95	19544.5	3257.4	2443.1
EW_pitch	East-West	Pitched roof	52	84.4	13.26	*10430.5	1738.4	1303.8
NS_pitch	North-South	Pitched roof	26	42.2	6.63	*5215.3	869.2	651.9

6.5 Consider test results and revise refurbishment strategy: the technical solution (WP 1.6)

In this chapter, the results from Work Package 1.6: MONITORING OF REALISATION PHASE are presented.

6.5.1 Evaluation of mock up and installation process

The mock-up design and construction helped the team to elaborate further the 2ndSKIN design and develop detailed solutions for the production and assembly. Based on this information, the reference building design was updated (report MS 6, Dec 2015). More specifically the mock-up provided insights on the following aspects.

The installation sequence

The installation sequence on an existing building, which will be different than the one followed the mock-up, as indicated by the numbers in figure 28. In both cases the substructure with the timber posts will be first attached to the existing structure and the central panel for the opaque façade components will be attached to it, but in an actual project, the ventilation pipes will be integrated in the factory to the panel. The panels including the windows will also be assembled in the factory.

The external cladding can or cannot be prefabricated, depending on the material choice. Some finishing will probably be required on site, depending of the cladding material selection. Materials such as brick-slips need a binding mortar, which can be applied after the placement of the panels, to cover and waterproof their connection. Moreover, the internal lining needs to be placed on site, after the panels are installed. Finally, the mock-up assembly experience showed that the installation of the panels and lining can be done with two people, with the support of cranes to lift and place the panels.

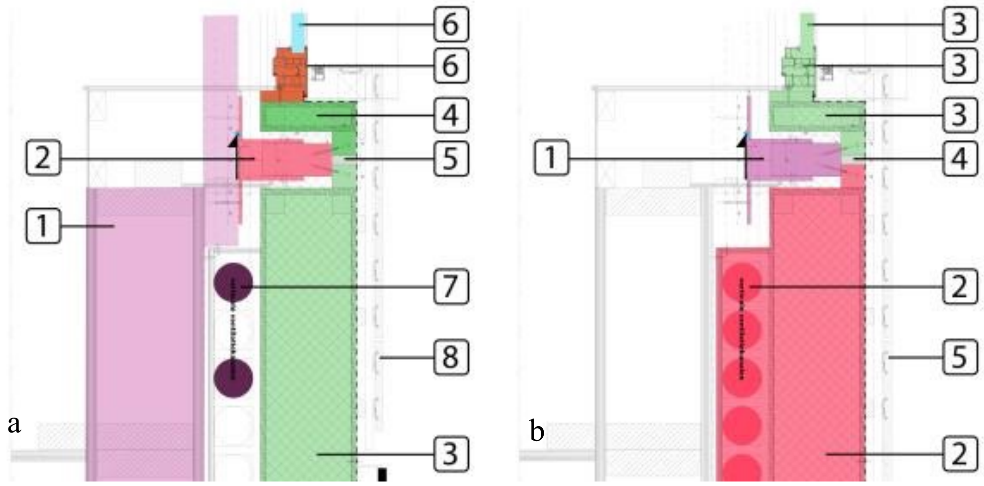


figure 28 Assembly sequence followed for the mock-up & projected sequence of 2ndSKIN on an existing building

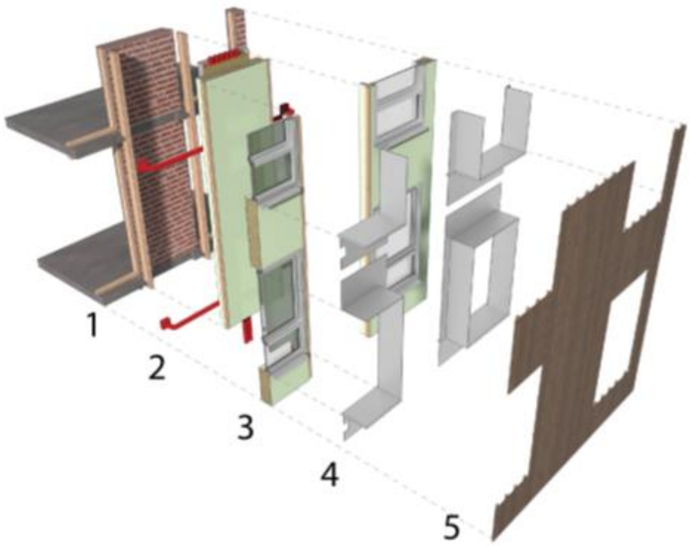
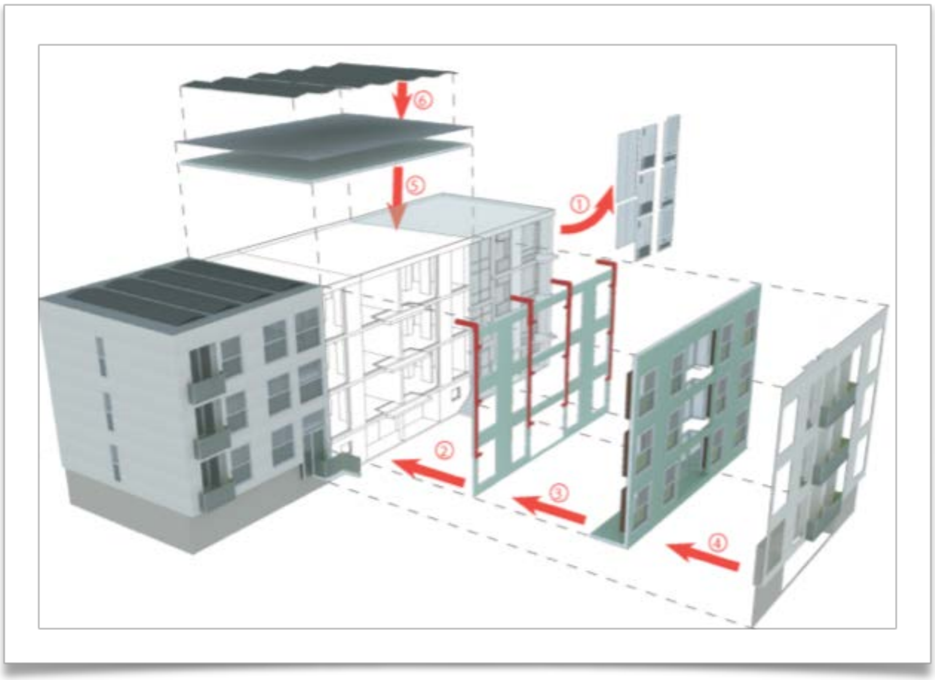


figure 29 Detailed assembly sequence of the 2ndSKIN concept on an existing building

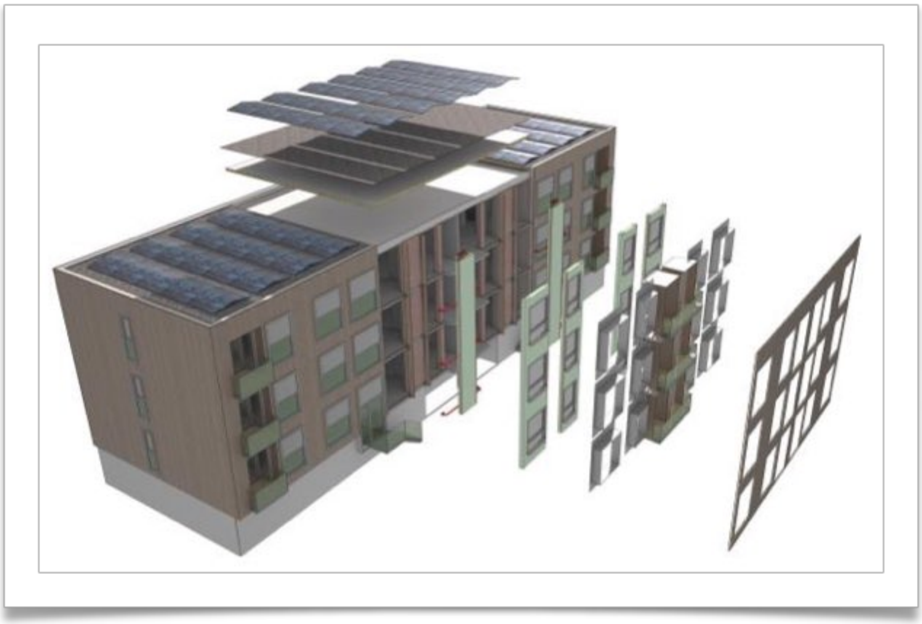
1. Substructure: wooden posts attached to existing structure with steel U profiles
2. Central panel attached to the sub-structure, through timber sticks. The ventilation pipes integrated in insulation board, are attached to the panel in the factory
3. Left and right panel attached to the sub-structure, through timber sticks. Windows and shading devices are already assembled in the factory
4. Internal lining
5. Cladding. The finishing material can vary from project to project.

More detail in sub-structure design

During the mock-up development, the team made decisions on issues such as the connections and internal finishing, as highlighted in figure 26. Based on these decisions and the installation sequence the reference building design as updated figure 30.



a. Preliminary design



b. Updated design, reflecting the installation process

figure 30 Exploded views demonstrating the installation sequence of the 2ndSKIN concept

Experience on products and delivery time

The process provided insights and experience with the products. For example, at least 6 weeks should be accounted for delivery, especially in the case of bigger projects. Additional questions raised during the production and construction resulted in changing some of the initial ideas. Even though the initial plan was for the central panel integrating the pipes to arrive on site as one piece, in order to minimise connections, the panel production company, Kingspan, specified that the maximum length of the panels can be 8m, which means that for a 3 or 4 storey building the central panel should be in two pieces. Furthermore, the integration of the pipes in the insulation was not fully explored and needs further elaboration before the panel production. Finally, in an actual building, the tolerances can be an important issue, which was not present for the mock-up. In an actual building situation, scanning of the existing building to create an accurate 3D-model, can allow for precise prefabrication of the panels.

Different parapet

A very important aspect was how the concept can be adjusted to different buildings characteristics. In the mock-up the case of different parapet was realised and tested, as shown in figure 31. The height of parapet, internal lining and ventilation inlet depend on original building.

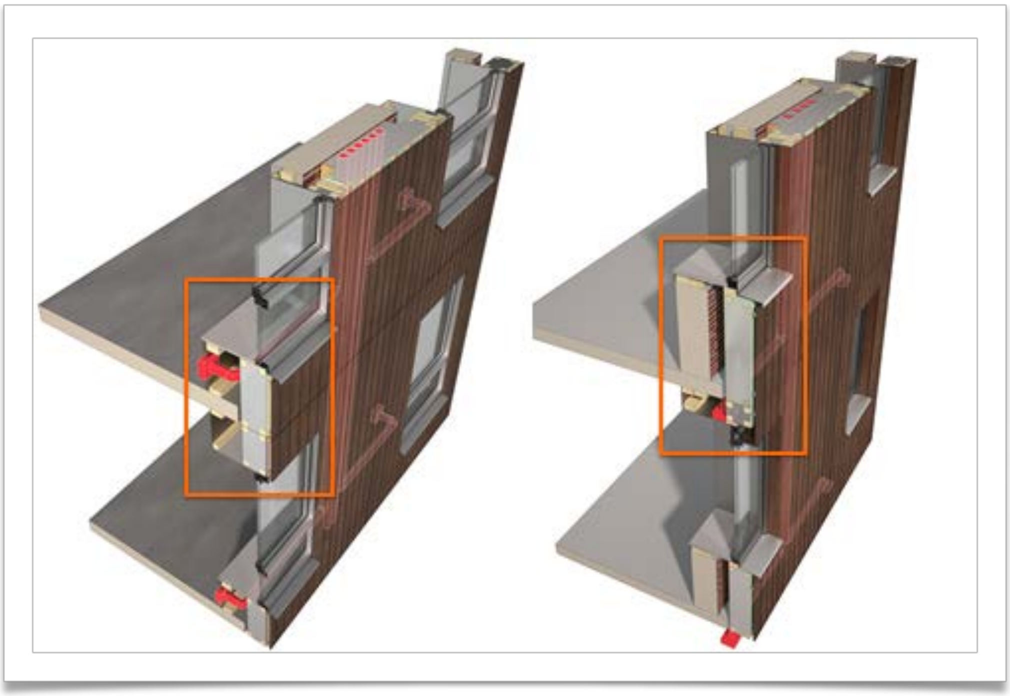


figure 31 Solution of the 2ndSKIN construction, in case there is or is not a parapet in the original façade

The above points have been incorporated in the reference building design and will be taken into account for the construction of Prototype 1, which is the next step for the 2ndSKIN project. Some adaptation may be required to the specific case study. Nevertheless, the construction of the Mock-up has proven that the 2ndSKIN refurbishment concept can be constructed and installed and can accommodate some flexibility to address variation in the building stock, such as the existence of parapet and difference finishing material.

6.6 Consider test results and revise refurbishment strategy: the role of the occupants (WP 1.7)

In this paragraph, the results from Work Package 1.6: MONITORING OF USE PHASE are presented. The results are based on two research activities: the investigation on the effect of occupancy and household typology on energy demand, and on the investigation of user requirements regarding ventilation systems and control.

6.6.1 Occupants' behaviour and household typologies effect on energy demand and NoM concept (WP 1.7a)

In this section, the results from the energy demand calculations taking into account the diversity of occupancy are presented. Heating demand is calculated through building simulations based on statistically defined occupancy patterns (nationwide Dutch household profiles). Domestic hot water is calculated based on the requirements per person based on Dutch regulations. Electricity demand is calculated based on the statistical occupancy profiles and hours of use per household type.

In order to model occupants' behaviour in the building simulations, occupancy profiles per household type have been previously defined statistically using factor analysis and ANOVA tests (Guerra-Santin and Silvester 2016). The profiles of the reference households can be seen in figure 32.

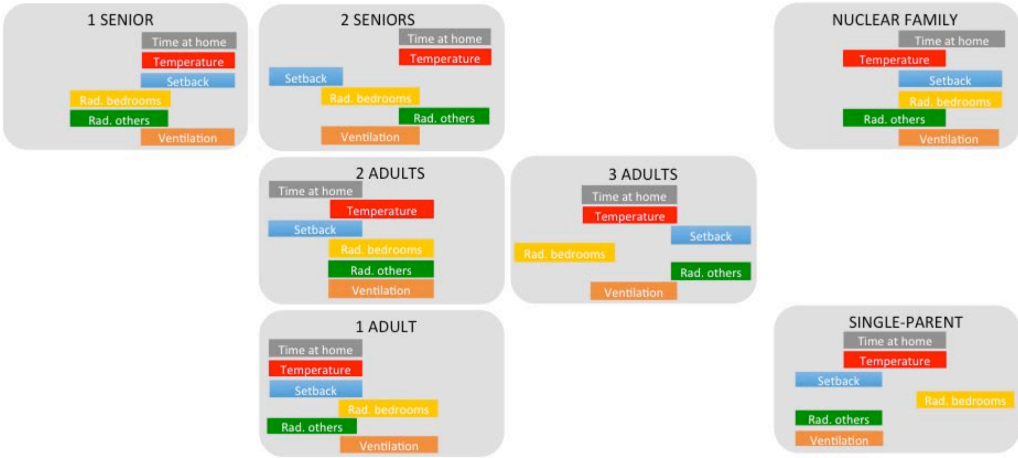


figure 32 Household Profiles, behaviours to the right are more energy intensive than behaviours to the left.

The household profiles consist on occupancy profile (presence at home) and heating use pattern (use of thermostat and radiators) per household type. From these, artificial lighting and use of appliances patterns were also developed. The least energy intensive behaviours were found in households with one adult and single parent household, while the most energy intensive behaviours were found in households with seniors and nuclear families. The calculation results for the expected building-related and use-related energy consumption per household type are presented in the following section.

Heating demand: building simulation

Building simulations of the 2ndSKIN solution were carried out with different household profiles. The dynamic building simulations were carried out with Bink software (BINKSoftware 2015) for each type of household using two scenarios: a pre-renovation state-of-the-art behaviour scenario based on the statistical analysis of the WoON dataset (WoON2012 2013), and a post-renovation scenario, also based on the statistical analysis but modified to reflect a possible rebound effect and changes in behaviour to achieve higher levels of comfort, but also reflecting a better control of the heating system, by integrating the use of setback temperatures when absent and during the night. Table 22 shows the building characteristics used as input in the building simulation model.

Table 22 Internal heat gains based on the electricity consumption (electricity kWh/m2)

	All buildings			Reference building		
	N	kwh/m2	IHG	N	kwh/m2	IHG
Single senior	6648	27.1	3.1	293	28.3	3.2
Single adult	11429	35.5	4.0	888	33.0	3.8
Adult couple	13056	35.0	4.0	329	36.0	4.1
Senior couple	8236	33.5	3.8	192	34.8	4.0
Three adults	3892	44.1	5.0	80	38.1	4.4
Single-parent	2202	35.3	4.0	185	36.6	4.2
Nuclear family	13021	36.2	4.1	227	41.7	4.8
Total	58484	34.9	4.0	2194	34.4	3.9

Each room is modelled as one thermal zone, as we wish to investigate the effect that preferences for room temperatures and spaces heated have on energy demand. The heating demand per room was calculated assuming a 100% efficiency of systems, according to the schedules defined per household profile (intermittent comfort). The system adjusts the temperature of the room according to the comfort requirements, with unlimited capacity. The comfort temperature per room is determined per household type, based on the household profiles (figure 32).

Natural ventilation is only considered for the summer period, when external temperature reaches 18oC or internal temperature exceeds 25oC. Thus, natural ventilation does not have an effect on heating demand in the simulations.

The internal heat gains are integrated into the simulation model in two ways. Artificial lighting is defined as specific artificial use patterns defined per household type, which are based on the household profiles. Internal heat gains for appliances and electric equipment are calculated based on statistical data on electricity consumption per household type in reference dwellings (WoON dataset). The gains of electricity are evenly distributed over the zones of the dwelling. Table 22 shows the internal heat gains based on electricity consumption per household.

Current occupants' behaviour

First, simulations per household type assuming pre-renovation behaviours were carried out. These behaviours were obtained from statistical data in the Netherlands and therefore, reflect the lifestyle and preferences of Dutch households (figure 33). Table 23 shows the results for heating demand for the seven household types. In addition, a building simulation with a standardised occupancy was also run.

figure 33 shows a comparison between the heating demand for different household types and apartment types. The results are shown per type of apartment, since their size and location will have an effect on heating demand. Apartments type A have three bedrooms and a total area of 68 m2, while apartments type B have two bedrooms and a total area of 58 m2.

Table 23 Results building simulation per household type and type of apartment assuming pre-renovation behaviours (heating demand in kWh/year)

	Single adult	Single senior	Adults couple	Seniors couple	Three adults	Single parent	Nuclear family	Standard household
A Ground floor	426	2002	882	1536	954	1060	1625	924
A 1st floor	398	1685	777	1335	844	803	1393	801
A 2nd floor	384	1595	719	1216	780	872	1310	751
A 3rd floor	350	1334	625	1051	688	644	1144	641
B Ground floor	385	1586	714	1212	778	866	1305	746
B 1st floor	348	1318	617	1039	680	636	1135	632
B 2nd floor	428	1864	843	1429	913	1018	1545	868
B 3rd floor	392	1555	736	1234	802	759	1315	746

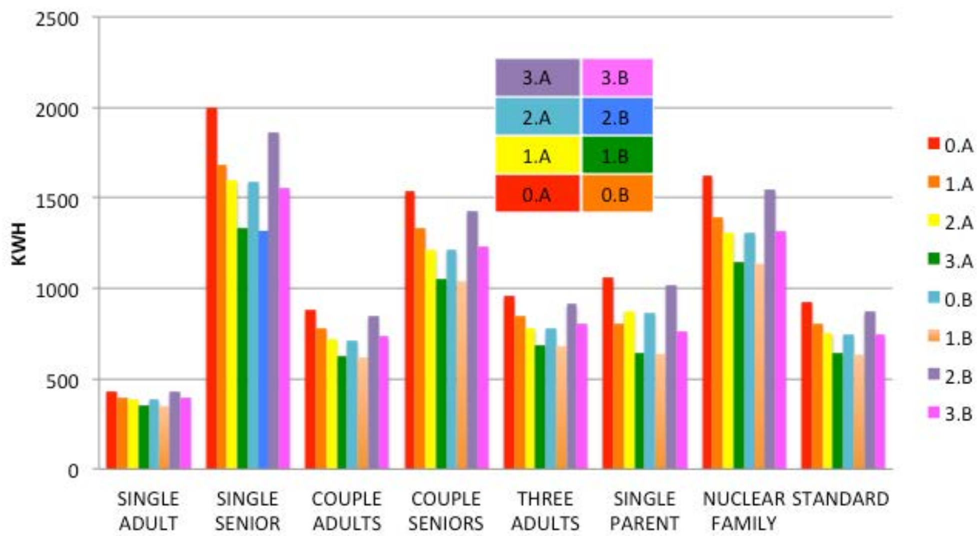


figure 33 Heating demand per household type, per apartment, assuming pre-renovation behaviour

The results of the simulations show an up to twofold difference between the heating demand of an 'standard' household, and the households with the lowest (single adults) and highest (single seniors) heating demand, highlighting the large overestimation or underestimation of heating demand when using standardised profiles. The results also showed that the heating demand calculated for single adults is 75% lower than for single seniors, while the heating demand calculated for a couple of adults is 30% lower than the demand calculated for a couple of seniors. The same difference is seen between single parent households and nuclear families. The difference in heating demand between types of apartments is larger in households with higher heating demand, for example in nuclear families, the difference on heating demand between small apartments in the middle of the building (1B, 2B) and large apartments in the ground or top floors (0A, 3A) can be up to 30%.

6.6.2 Post-renovation behaviour (account for rebound effect)

A second set of simulations per household type were carried out assuming a change on behaviour after the renovation. In this scenario, we intend to show the rebound effect that could exist if 1) people currently heating to a lower degree, increase the indoor temperature (for example, single adults), and 2) assuming a better control on the heating system, by heating only occupied spaces and using a setback in the thermostat during the night and during absent hours.

Table 24 Results building simulation per household type and type of apartment assuming post-renovation behaviours (heating demand in kWh/year)

	Single adult	Single senior	Adults couple	Seniors couple	Single parent	Nuclear family	Single parent
A Ground floor	821	1103	679	937	864	1048	1587
A 1st floor	772	1080	609	854	785	763	1330
A 2nd floor	704	1019	567	796	727	861	1335
A 3rd floor	649	914	502	718	653	609	1109
B Ground floor	735	1018	565	793	718	854	1328
B 1st floor	643	902	495	708	643	601	1099
B 2nd floor	845	1145	658	901	836	1004	1518
B 3rd floor	743	1027	584	810	749	720	1260

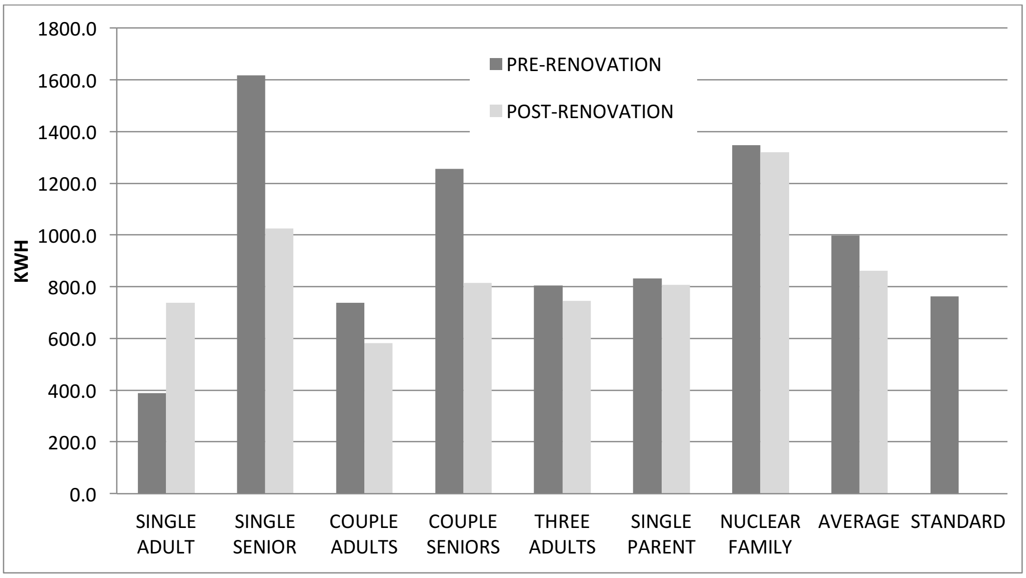


figure 34 Heating demand per household type, per apartment type. Comparison between pre-renovation and post-renovation behaviour (heating demand in kWh/year)

Table 24 shows the results of these simulations. In figure 34, we show a comparison between both occupancy scenarios per household, also showing the results with the 'standard' occupancy profile. The figure shows that energy demand decreases greatly for households with seniors (up to 40% reduction), and decreases slightly for all other households, except for single adults. Single adults were found, in the statistically developed profiles, to under-heat spaces. The heating demand for this household almost doubles. The lower heating demand of seniors is associated to a better use of thermostat setback. In comparison to an 'standard' behaviour, single seniors and nuclear families have a higher heating demand, while single adults and couple adults have a lower heating demand.

Taking into account energy demand per household type is important because, in some cases, rent could change after the renovation based on the expected energy savings. In addition, to correctly size the installations, including PVs, it is important to define more accurately the energy demand.

Domestic hot water

The energy demand for domestic hot water was calculated based on Equation 1, assuming five minutes' showers per person per day, one and a half minutes using the sink per person per day, and using the kitchen sink for one minute per household per day. Table 25 shows the results from this calculation. In addition, a scenario considering the use of a heat recovery shower (https://www.milieucentraal.nl) was also calculated. According to specifications, these systems can save up to 100 m3 gas /year per household (idem), or 30% of the energy use. In order to take into account the household size, we use the value of 30% reduction.

$$\mathbf{Q = c\ X\ \rho\ X\ (\theta w - \theta k)\ X\ q_v\ X\ t}$$

Equation 1 Calculation Domestic Hot Water
where: Q= heat demand in kj, c= specific heat of water in kj/kg oC (4.19), ρ= mass density cold water in kg/l, θw = temperature warm tap water in oC , θk = temperature cold water in oC, qv = needed flow in l/s, t = time

Table 25 Calculated energy demand for domestic hot water per household based on requirements per person

	Energy for domestic hot water per year (kWh)	Energy for domestic hot water per year incl. estimated savings (kWh)
Single adult	726.29	508.403
Single senior	726.29	508.403
Adult couple	1155.81	809.07
Senior couple	1155.81	809.07
Three adults	1680.84	1176.59
Single-parent	1680.84	1176.59
Nuclear family	2205.87	1544.11

Electricity consumption

The electricity demand for appliances, electric equipment and artificial lighting per household type was calculated based on the statistically developed household profiles (figure 32). Two scenarios were used, one with efficient appliances and one with inefficient appliances.

Artificial light

For the calculation of electricity demand for lighting, we assumed that the lights would be off in sleeping hours (24:00 - 6:00 hrs), during daylight hours (9:00 – 18:00 hrs) and when the residents are not home (defined per household type). It was also assumed that in households of more than 2 persons, more than one light would be on.

Appliances and electric equipment

We assumed that the use of appliances and electric equipment was defined by the presence of people at home. For example, a household type absent during three evening per week, was consider to only use entertainment equipment during four evenings per week.

The appliances and electric equipment were divided according to their use: 1) all day appliances such as WIFI router, refrigerator and freezer and alarm clocks; 2) short-use cooking appliances such as coffee machine, water boiler, microwave oven, toaster and kettle; 3) long-use cooking appliances such as oven, stove and cooking hood; 4) cleaning appliances such as washing machine, drying machine, dishwasher, iron and vacuum cleaner; 5) entertainment equipment such as TVs and game consoles, and 6) office equipment such as desktops, laptops, monitors and printers.

Table 26 Hours of use per appliances and electric equipment

All day appliances	Fridge Freezer WIFI router Radio / alarm clock	24 hours per day / 52 weeks per year
Others	Mobile phones	Overnight – 6 hours per day / 50 weeks per year
Sort-use cooking appliances	Coffee machine Microwave oven Toaster Kettle	10 minutes per day / 50 weeks per year
Log-use cooking appliances	Cooking hood Stove Oven	30 minutes per day / 50 weeks per year
Cleaning appliances	Clothes dryer Dishwasher Iron	30 minutes per person per week / 50 weeks per year
Cleaning appliances	Washing machine	One cycle per person per week / 50 weeks per year
Entertainment equipment	TV	Equipment on when residents at home during evenings (adults and families with children) or during all day (seniors) / 50 weeks per year
Entertainment equipment	Game console (households with children)	One hour per day (only households with children) / 50 weeks per year
Office equipment	Desktop and monitor Laptop	Equipment on when residents at home during mornings and afternoons (only adults and families with children) / 50 weeks per year
Office equipment	Printer	One hour per week (only adults and families with children) / 50 weeks per year

A series of assumptions were made regarding the hours of use. These assumptions are shown in Table 26. We only considered the use of a limited number of appliances and electric equipment to reflect the socio-economic status of the household living in the reference building. A distinction was made between efficient appliances and inefficient appliances for a selection of items: fridge/freezer, washing machine, computers, TVs and light bulbs.

Table 27 Results electricity calculations and statistical data from the WoON survey

	Efficient appliances	Inefficient appliances	WoON all buildings	WoON reference building
Single adult	1048.5	2062.9	2341.3	1837.3
Single senior	1087.7	2332.6	2162.2	1724.2
Adults couple	1629.5	2755.5	3479.4	2338.4
Seniors couple	1395.3	2737.7	3358.3	2342.3
Three adults	1958.8	3222.0	4681.2	2725.8
Nuclear family	1954.1	3229.9	3193.9	2405.3
Single parent	2301.1	3687.6	4309.1	2772.9
Average	1625.0	2861.2	3341.4	2118.6

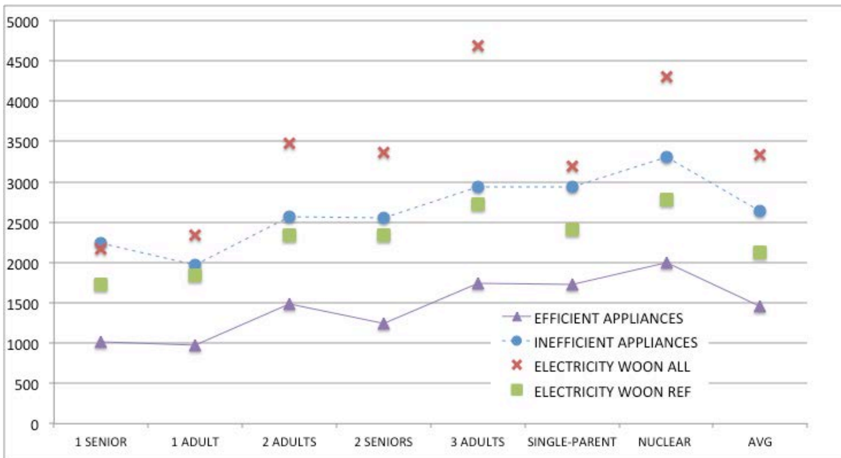


figure 35 Comparison electricity calculation and WoON statistics per household

Table 27 shows the results per household type for efficient appliances and inefficient appliances. The results show the large difference between electricity demand between singles and families. A twofold difference can be seen between single senior and single adult, and nuclear families (efficient appliances). The calculations show similarities to average electricity consumption based on statistical data from the WoON dataset (Table 27 & figure 35). The mean electricity consumption in reference buildings is, on average, between the calculations with inefficient and efficient appliances (figure 35). However, in relation to the reference building, we seem to be underestimating the electricity consumption of households without children (except single senior).

Total energy performance

In this section, we integrate the results of the building simulations with the calculation of electricity demand and renewable energy generation. Table 28 shows the energy requirements per household type.

Table 28 Energy demand per household type (average apartment) in kWh/year

	Heating demand pre-renovation	Heating demand post-renovation	Efficient appliances	Inefficient appliances	Domestic hot water	Domestic hot water incl. estimated savings
Single adult	388.9	739.0	1048.5	2062.9	726.29	508.403
Single senior	1617.4	1026.0	1087.7	2332.6	726.29	508.403
Adults couple	739.1	582.4	1629.5	2755.5	1155.81	809.07
Seniors couple	1256.5	814.6	1395.3	2737.7	1155.81	809.07
Three adults	804.9	746.9	1958.8	3222.0	1680.84	1176.59
Nuclear family	832.3	807.5	1954.1	3229.9	1680.84	1176.59
Single parent	1346.5	1320.8	2301.1	3687.6	2205.87	1544.11
Average	997.9	862.5	1625.0	2861.2	1333.11	933.18

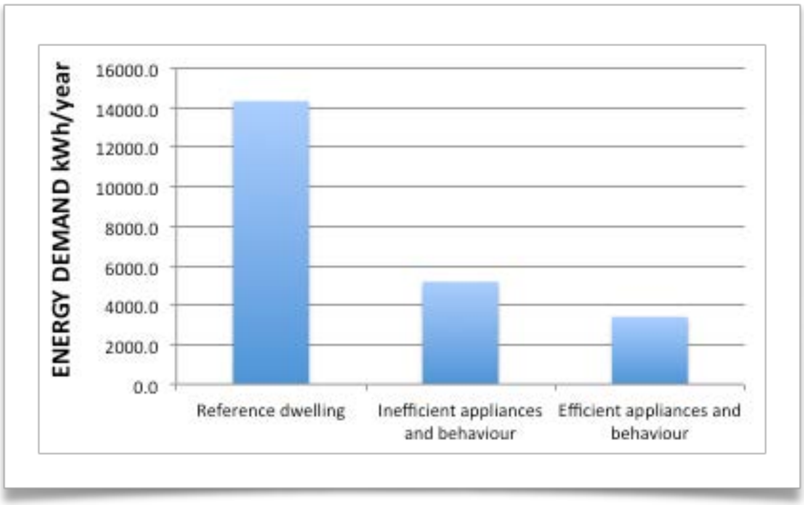


figure 36 Energy demand calculated based on inefficient and efficient appliances and behaviour in comparison to the statistical energy consumption in reference dwellings

figure 36 shows a comparison between the energy (gas and electricity) consumed in the reference dwellings (based on WoON statistical data shown), and the energy demand (for heating, domestic hot water and electricity) based on two scenarios: 1) inefficient appliances and behaviour, and 2) efficient appliances and behaviour. Inefficient appliances and behaviours is based on the electricity demand calculated using the energy consumption of inefficient appliances, and the pre-renovation behaviour defined previously. Efficient appliances and behaviours is based on the electricity demand calculated using the energy consumption of efficient appliances, and the post-renovation behaviour defined. The figure shows that the energy demand of the 2ndSKIN technical solution (i.e. only renovation without behavioural change or change for more efficient appliances) is reduced by 57%. If we also consider a scenario with improved appliances and behaviours, we reach a reduction on energy demand of 83%.

figure 37 shows the energy demand for heating (simulated in Bink), domestic hot water (estimated) and electricity (calculated based on appliances power and hours of use) per household type in the two scenarios mentioned before. To the right of the figure, we show the renewable energy generated on site according to roof type (PVs in the roof of the porch building) per apartment, according to the possible roof scenarios shown in Table 29 & Table 30

The figure shows that only in the best case scenario for energy generation (a porch building with only 6 apartments, and with the possibility to build an attic structure to support the PV panels), the energy generated barely covers the energy demand when domestic hot water and electricity are considered, considering the energy efficient scenario. Considering the inefficient scenario, the best-case energy generated covers half of the demand. In all other roof scenarios, the energy generated only covers the heating demand in all cases, except in four-storey buildings with North-South orientation and pitched roof. Table 29 shows the area of PVs necessary to reach the zero-energy target for each of the porch-building's roof scenarios.

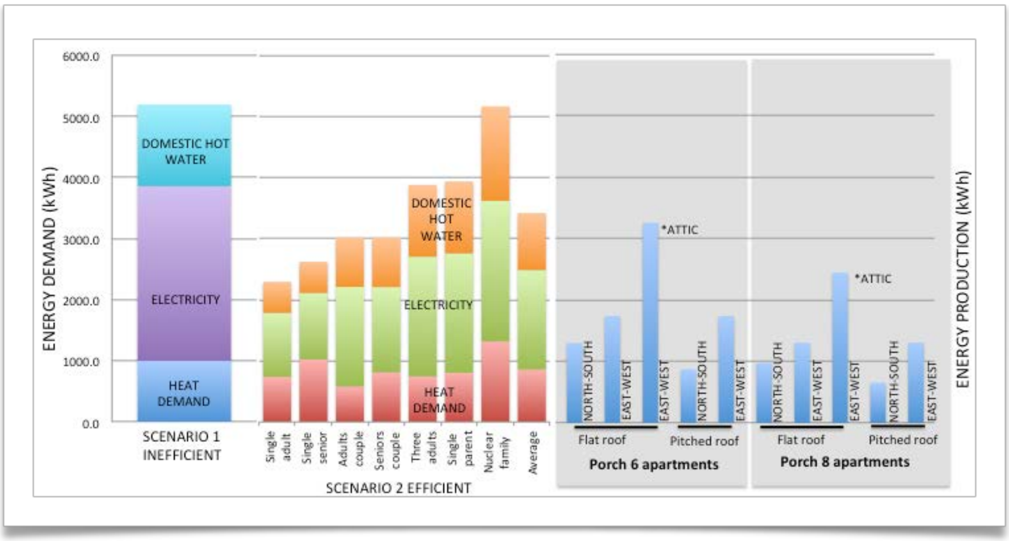


figure 37 Energy demand and production per apartment

Therefore, extra surface of PV panels is necessary to achieve the zero-on-the-meter solution. Façade surfaces could potentially be used to cover the rest of the energy generation required. However, this possibility would depend on the orientation of the building.

Table 30 shows the energy generation bases on wall surface area. The results show that the energy demand can only be met with the provision of an attic (north-south orientation) on up to three levels porch buildings. For an east-west orientation, the total energy demand can be almost met with the energy production on-site for buildings with three levels (six housing units). To cover the energy demand of north-south orientations without attic provision, and porch buildings with four levels, an extra surface of 12-20 m2 of panels is needed.

Table 29 Required surface of PV panels to cover the average energy demand, per building/roof scenario

	Production (kWh/year)		Energy gap (kWh/year)		Surface needed (m2)	
Scenario	Per unit (6 per porch)	Per unit (8 per porch)	Per unit (6 per porch)	Per unit (8 per porch)	Per unit (6 per porch)	Per unit (8 per porch)
EW_flat	1738.4	1303.8	1682.23	2116.83	13.62	17.14
NS_flat	1299.2	974.4	2121.43	2446.23	15.89	18.32
NS_flat_b	3257.4	2443.1	163.23	977.53	1.22	7.32
EW_pitch	1738.4	1303.8	1682.23	2116.83	13.62	17.14
NS_pitch	869.2	651.9	2551.43	2768.73	19.11	20.73

Table 30 Total energy production and surplus energy (in bold) per building/roof scenario

	Energy produced in walls surfaces (kWh/year)		Total energy (kWh/year) Walls and roof		Energy gap (kWh/year)	
Scenario	Per unit (6 per porch)	Per unit (8 per porch)	Per unit (6 per porch)	Per unit (8 per porch)	Per unit (6 per porch)	Per unit (8 per porch)
EW_flat	814.97	611.23	2553.37	1915.03	867.26	1,505.60
NS_flat	440.67	136.01	1739.87	1110.41	1,680.77	2,310.22
NS_flat_b	440.67	136.01	3698.07	2579.11	**-277.43**	841.52
EW_pitch	814.97	611.23	2553.37	1915.03	867.26	1,505.60
NS_pitch	440.67	136.01	1309.87	787.91	2,110.77	2,632.72

6.6.3 Occupants’ acceptability of solutions and user requirements (WP 1.7b)

In order to determine the key contents of tenant communication in a conceivable ongoing building management cycle that is inclusive of resident perspective and collaboration, literature research was combined with primary research with residents. The current literature on good communication processes with tenants presents well-developed processes emphasising open and timely communication, financial security, and a reliably scheduled and brief renovation process (Breukers, Summeren et al. 2014). This research adds three main new findings to the current literature. The findings were generated by consulting additional literature and conducting interviews and role play enactments with residents. Firstly, a good way to promote acceptability of solutions among residents is to start from the meanings that people attach to their home living (Després 1991, Moore 2000, Chiu, Lowe et al. 2014). This enables them to find their own motivation and to be open to new experiences. The core meaning for the purposes of this participation process can be defined as "pleasant living at home". The research with residents revealed the aspects connected to this core meaning (figure 38): the home is a reflection of ideas and values, the home facilitates activities and life style, the home supports healthy and comfortable living, the home systems are manageable, home-living is worry-free, and residents have a grip on their future. An open and transparent collaboration should be built around those meanings. The collaboration should address the levels from neighbourhood down to interfaces in the home. Secondly, an additional key way to promote acceptability is to acknowledge the specifics of each porch building and household and not assume acceptability of a standardised ideal solution. Participants may mistrust proposals because they have witnessed badly done renovations previously (several we spoke to, quite recently). Homes may currently have specific problems (such as leaks) that residents want addressed. Older residents, for example, may need a visual connection with the street, and may need a higher temperature in their home than others. A sophisticated concept should differentiate between these different situations and needs. Thirdly, residents may have vague ideas about what systems such as ventilation will do for them, so the specifics of how new home systems will affect residents' lives should be addressed. Residents often respond with suspicion and rejection to suggestions of required behaviour change (such as keeping windows closed in winter). Specific effort is required to enable residents to pre-experience the wellbeing of the new situation in a trustworthy way. For example, by experiencing life activities in full size mock-ups, by going through the steps of how the renovation will affect their own specific home (for example, things in it), and by understanding the new data-related possibilities of home systems. Rather than nudging residents to change behaviour, this pre-experiencing will enable them to connect with shifts in life practices that new systems will entail. The pre-experiencing should be connected with a focus on their life situation and values.

The meanings of living pleasantly at home were identified, starting from literature definitions of meanings and values of the home (Moore 2000, Chiu, Lowe et al. 2014). The specifics of how the values are expressed in home living were then extracted from the research data: the case studies, the ethnographic studies and the interviews with residents in the role enactment studies. The research did not enquire directly into values but into scenarios of home living. Residents themselves provided statements expressing the values. The findings address different scales, from home systems, the home as a whole, the building, to the neighbourhood. The cycle of use and repair, preparation and renovation is conceptualised as a change process throughout which the values should be taken into account. They can in fact become the overall framework through which change is managed.

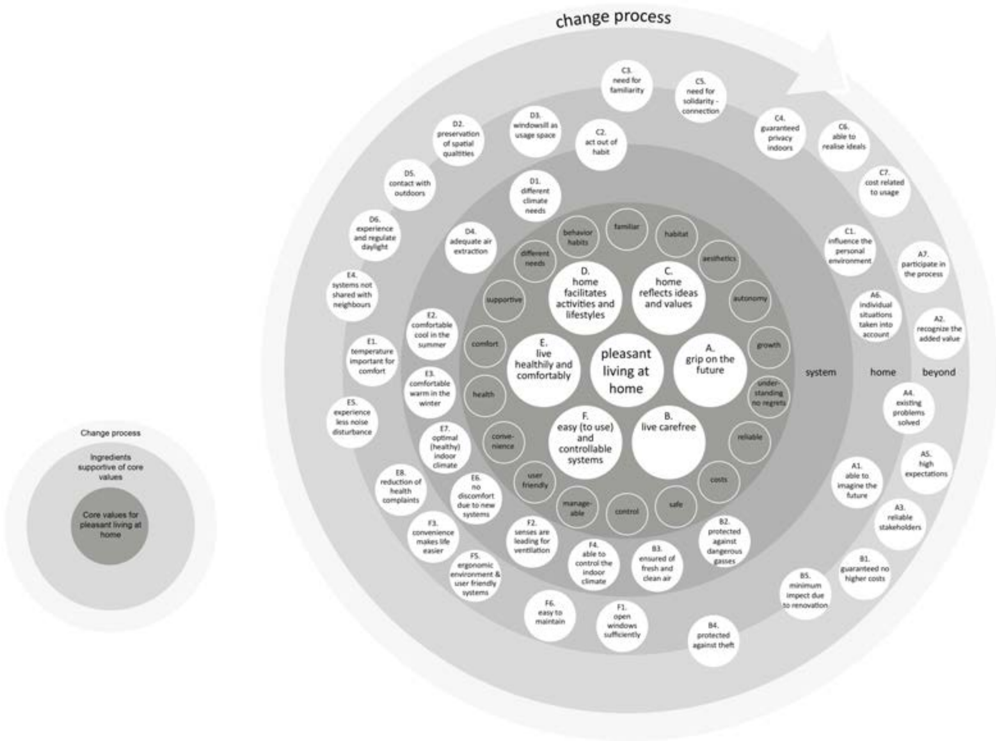


figure 38 The Circle of Values, with the core values of 'pleasant' living at home at the centre and its ingredients around it.

7 Experimental design phase: Apply refurbishment in prototype 2.0

In this chapter, the results from Work Package 2.0: RESEARCH LOCATION are presented.

First a brief description is given of the selected location for the prototyping 2.0. In parallel with the technical fine tuning of the 2ndSKIN solution for the selected complex the occupancy aspects, like acceptability, participation and the expected effects of the behaviour on the energy use are further investigated in relation with the prototype 2.0.

7.1 Research location for Prototype 2.0

After the prototyping with the Mock-up and test locations for the occupancy aspects, the findings and the 2ndSKIN proposition were pitched for several social housing corporations. Because of the withdrawal of Woonbron earlier in the project, the 2ndSKIN team had to find another social housing organisation willing to join the development of 2ndSKIN. The aim was to scale-up the prototyping to a real life testbed situation of about N=20 dwellings. The 2ndSKIN approach was presented to Vestia, Havensteder, Woonbron and Waterweg Wonen.

Waterweg Wonen in Vlaardingen invited the 2ndSKIN to execute a feasibility study for the zero-energy refurbishment for a complex of porch apartment buildings south of the Bilitonlaan in Vlaardingen.

A small complex of 12 dwellings at the Soendalaan is selected for the feasibility study and potential location for the prototype 2.

The complex in Vlaardingen is designed by the architects Neischke and Snijders in 1951. The complex is built according the Simplex building method.

7.2 Apply refurbishment in prototype 2.0: Occupants aspects: acceptability and participation (WP 2.2a)

In parallel with the development of the feasibility plan for Waterweg Wonen further research was executed on the occupancy aspects this paragraph, the results from Work Package 2.2: OCCUPANTS' ACCEPTATION, PARTICIPATION AND BEHAVIOUR are presented.

7.2.1 Occupants aspects: acceptability and participation (WP 2.2a)

To ensure acceptability of solutions to residents, participation activities should address the levels from the neighbourhood, to the building, to interfaces in the home. A process should start from the meanings that people attach to their home living, acknowledge the specifics of each porch building and household, and address the specifics of how new home systems will affect residents' lives. Approaches were developed to elicit these aspects in a participation process. Firstly, the approaches are described. They are intended for use in a participation process. Secondly, sample results are presented that were obtained with this approach. The sample results provide insights for specific design recommendations.

The exploration of understandings and preferences with regard to the home and its systems was conducted via 'role play enactments' plus in-depth interview, which means that participants are asked to act out typical living scenarios in a mock-up of the renovated home (Boess, Saakes et al. 2007, Halse, Brandt et al. 2010, Boess, Pasman et al. 2011). A full size realistic environment is useful in order to increase the validity of the insights. This is because product use is situated and happens in ways that people cannot recall and describe fully outside of the context of use (Boess and Kanis 2008). The research produces qualitative insights that reveal actual interactions that people have with their home. This in turn provides a basis for design recommendations. Two full size, adaptable mock-ups were realised as examples for elicitation tools in within the participation process. Their usefulness was tested by using them to elicit meanings, experiences and new practices from residents.

figure 39 Full size, flexible mock-up of window area to accommodate user experiences

Firstly, a full size, flexible mock-up of the window area of the renovated home was built (figure 39). The mock-up could be adapted flexibly and quickly to accommodate experience issues being discussed. This is in contrast to a mock-up built to research technical building issues as is customary in technical design. The window area was chosen because it addresses many issues that residents care about: the interaction with windows, and the connection with outdoors (the view, use of outside spaces like balconies, use of indoor spaces like window sills). Eight participants in total, most of them reference residents, participated in the research for an average of 1 hour each.

figure 40 Residents interacting with the window area mock-up; a senior resident assessing the view and a young resident acting out the window opening action.

Secondly, a full size mock-up of an entire home was realised, though in a condensed form. It served to represent the ventilation system in connection with various life situations in the home: cooking, eating, showering, entertaining, and sitting. The ventilation system was chosen as a focus because earlier research showed that this is what residents know least of, and are most suspicious about. Eight participants in total, all of them reference residents, participated in the research for an average of 1.5 hours each.

figure 41 Floor plan of full size mock-up of entire home in condensed form, view into the sitting room area, with interviewer and research participant experiencing the influx of air into the room

7.2.2 Sample results

The research with the full size mock-ups resulted in the following sample results on acceptability of solutions, presented here in abbreviated form.

Table 31 Sample results on acceptability of solutions

Aspect	Findings
Influence	Tenants want to be able to influence the ventilation system but do not want to be forced to deal with it intensively. Household members may have different air quality preferences.
Benefit	Tenants expect and hope for the air to be fresh, and for good air humidity and temperature, also in the summer.
Ease of interaction	Interfaces should have minimum settings needed, be easy to understand and located near thermostat, kitchen, shower and/or close to the front door out of sight. Senses are used to check system functioning (sound, airflow).
Safety and control	Tenants expect to be able to turn the system off in case of emergency (pollution emergency, not unlikely in the industrialised west of the Netherlands), when on holiday, when the system produces unwanted noise.
Trust	Tenants want to be certain of a healthy and hygienic environment. Some distrust air quality from the roof inlet, or the hygiene of the ducts. They expect systems to be serviced.
Balcony	Tenants view a balcony, as a private outdoor area, as essential, especially senior tenants. Senior tenants want the balcony to be easily accessible. and provide a good balance between privacy and contact. They want to be wind-protected.
Windowsill	For seniors the windowsill should not be too deep because they want to be able to sit close to the window yet not exposed to view. Others appreciate a deeper windowsill.
Façade	Tenants want to have a good climate in the common spaces. They do not want a decrease of indoor floor space due to a change in the façade.
Windows	Residents want no reduction of amount of glass surface. All want to be able to fully open the window. Windows should be easy to open and clean for senior tenants. Residents want to ventilate (naturally) at night while feeling safe. Offer a small window besides the regular window.
Window coverings	Shading should be considered to prevent overexposure when looking at a screen. Coverings are seen as essential for privacy, against cold and draught in the winter and against heat in the summer. Offer an insect screen optionally.

7.2.3 Occupants aspects: occupants’ behaviour effect on zero energy strategy (WP 2.2b)

RQ4: To what extent is the energy neutrality of the 2ndSKIN - concept vulnerable to occupant behaviour?

Rebound effects often occur after a renovation, meaning that occupancy consumes more energy than predicted in calculations (Galvin 2014). The reasons are still unclear, but are presumed to lie in residents' post-renovation behaviour and interaction with their home systems (Chiu, Lowe et al. 2014).

Besides monitoring of actual energy use before renovation (to assess pre-bound effects), the interaction with home systems has been presumed to affect residents' behaviour (Chiu, Lowe et al. 2014). Residents often mistrust and misunderstand home systems interfaces, our case studies and ventilation research showed. For this reason, it is advisable to collaborate with residents well ahead of the renovation to understand and future practices involving home systems interfaces.

Future research should also address the interfaces themselves. Currently they are mostly designed for a phenomenon called 'resource man': a presumed rational decision maker who is mostly interested in numerical data and precise, controlled living circumstances (Strengers 2014). Few households actually correspond to this stereotype. It is therefore necessary to continue to innovate on interfaces in the home that harmonize with actual living practices (Pohlmeyer 2012, Boess 2017).

Design research

Because there are few design solutions currently addressing actual living practices, additional research was conducted through several student design projects to generate such design proposals. During the research period, several student projects were conducted to initiate proposals for this. For an example, see figure 42. Some student projects presented unrealistic ideas that addressed 'resource man' (Strengers 2014). Other student projects presented novel ideas for interfaces in the home that they also evaluated and that fit home living practices.

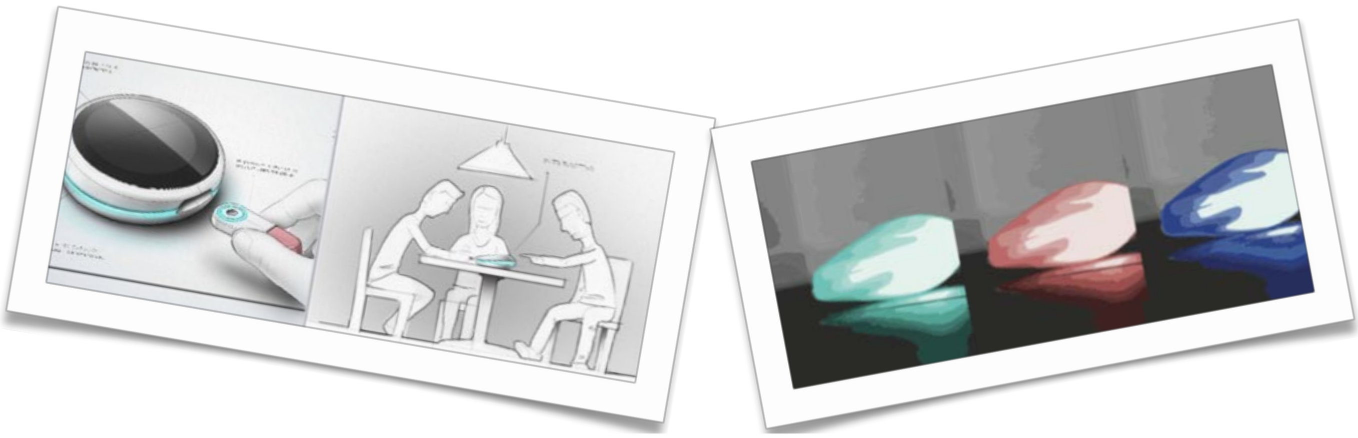


figure 42 Exploration of the realism of interfaces for living practices. Left picture: an unrealistic idea in which residents organise their lives and dinner time around energy numbers. Right picture: a realistic idea in which an interface enables residents to understand what their home systems, in this case heating, are doing, in a way that is a natural part of home life.

7.3 Apply refurbishment in prototype 2.0: Occupants aspects: occupants’ behaviour effect on zero energy strategy (WP 2.2b)

In this chapter, the results from Work Package 2.2: OCCUPANTS’ ACCEPTATION, PARTICIPATION AND BEHAVIOUR are presented.

7.3.1 Results from monitoring campaigns in reference households

Occupancy profiles per household have been previously defined statistically using factor analysis and ANOVA tests (Guerra-Santin and Silvester 2016). However, the statistically defined household profiles were based on a national sample, and thus, they might differ from the patters occurring in the reference building. In this study we investigate the possibilities to employ monitoring data from a campaign carried out in the region of study, to determine to what extent monitoring actual occupancy patterns in social rented housing in the Netherlands differ from those defined statistically from a national sample. The investigation focused on the study of households' occupancy patterns of 1) a nuclear family with children, 2) a single-parent household, and 3) a three-adult nuclear family.

Table 32 Main characteristics of monitored dwellings

	Dwelling 37	Dwelling 38	Dwelling 39
Type of dwelling	Semi-detached	Semi-detached	Semi-detached /conversion (old church)
Size	88 m2	96 m2	117 m2
Systems	Central heating, room radiators, programmable thermostat	Central heating, room radiators, programmable thermostat	Central heating, room radiators, smart thermostat
Type of fuel	Heating, cooking and domestic hot water on gas.	Heating, cooking and domestic hot water on gas.	Heating, cooking and domestic hot water on gas.
Other features	Individual meter Vents above windows Double glazing Floor insulation	Individual meter Vents above windows Double glazing Floor insulation	Individual meter Vents above windows Partial double glazing Floor insulation
Household size, ages	3 54, 46, 19	2 53, 15	3 54, 47, 15
Occupation	Employed, unemployed, student	Employed, student	Employed, unemployed, student
Attitudes	Environment over comfort or cost	Comfort over environment or cost	Cost and comfort over environment

Seven households were invited to participate. Their main socio-economic characteristics were: partially employed or unemployed, and living in social housing (low income). Their contact information was obtained from a database at TU Delft containing information on possible participants for research projects. While all households were willing to participate in the project, only three were monitored due to scheduling problems (some were leaving for the Christmas holidays, while others were too busy at the time). Table 32 shows the main characteristics of the three monitored households and dwellings.

Analysis and results from the monitoring campaign are reported in Guerra-Santin, Romero Herrera et al. (2016). While these households are not those identified as more likely to live in the reference building, we focus on the effect of socio-economic characteristics on behaviour compared to a national sample.

Sensors were deployed to collect indoor climate data (temperature, relative humidity, CO2 level) as well as contextual data such as sound, light and movement. To collect personal information about thermal comfort, the Comfort Dial (CD) was used (Cuerda, Guerra Santin et al. 2015, Guerra-Santin, Romero Herrera et al. 2016). The temperature of room radiators was monitored to further investigate the use of the heating system. During interviews, the residents were asked for a walkthrough of their homes providing descriptions and re-enactments on the way they usually control their indoor environment and on their daily practices related to energy consumption.

The results showed that the occupants' thermal comfort does not always correlate with actual room temperatures.

The average comfort votes in the houses were 4.1 and 3.7 for a mean temperature of 18 degrees in Dwelling 37; 3.3 and 3.3 for a mean temperature of 21.6 degrees in Dwelling 38 and 4.7 and 4.8 for a mean temperature of 18 degrees in Dwelling 39. A mean vote of 4 would indicate a neutral comfort feeling; comfort votes between 3 and 5 would indicate thermal comfort (slightly cool to slightly warm). The results showed that the occupants in the dwellings were on average comfortable. This contrasts with the difference in the average temperature between Dwellings 37 and 39 (18 degrees) and Dwelling 38 (21.6 degrees). This indicated that the occupants in Dwelling 38 prefer warmer temperatures. However, a correlation between indoor temperature and thermal comfort votes was only found in Dwelling 39 (person 1: $r=0.67$, $p<.001$; person 2: $r=0.64$, $p<.001$). The lack of correlation in Dwellings 37 and 38 could be attributed to the activity and clothing of the occupants. In Dwelling 37 the residents reported using extra clothing and sofa throws to keep warm.

The results were further analysed in relation to the occupants' lifestyle and attitudes. The analysis showed that the three households have different occupancy and heating patterns at home, even though their socio-economic situation is similar (see top of figure 43, figure 44 & figure 45). Nuclear households in CP37 and CP39 have similar comfort preferences but their occupancy patterns are different. These differences could be related to the difference in household composition; in CP37 there are three adults, while in CP39 there is a child. The single-parent household CP38 showed different comfort preferences and attitudes than the other two households.

Occupancy profiles

The occupancy profiles obtained from the monitoring campaigns were examined next to the household profiles previously defined through statistical analysis of a Dutch national sample. The comparisons are shown in figure 43, figure 44 & figure 45.

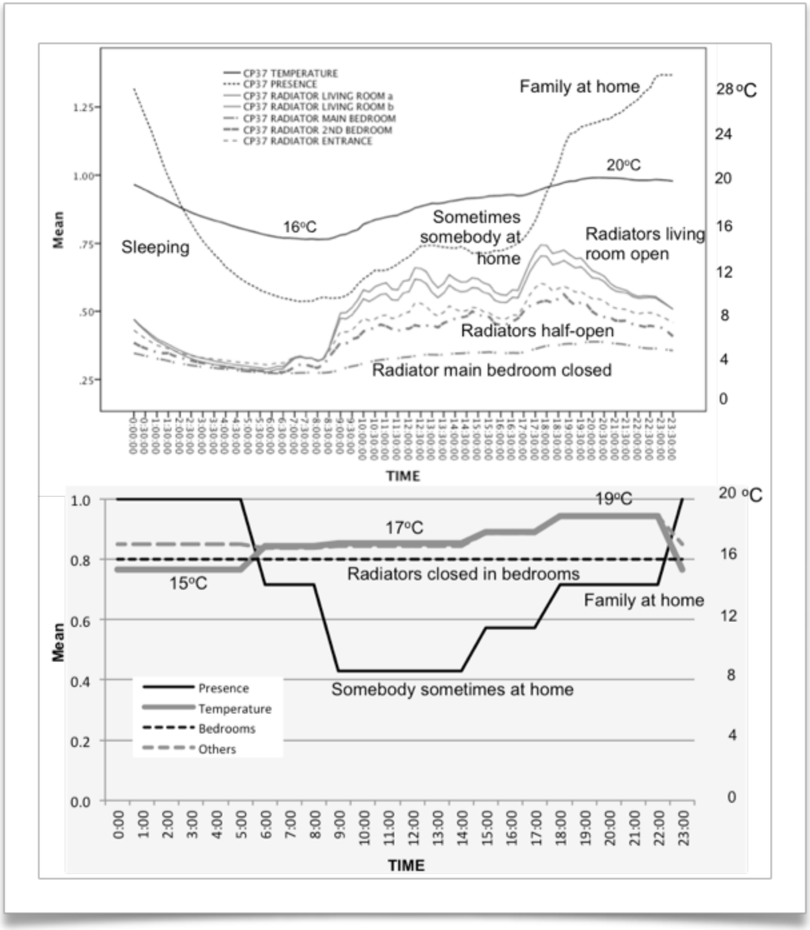


figure 43 Occupancy profile for CP37 and statistical profile for three adults' households

The analysis of the three monitored households highlighted some differences between the monitored data and the statistical data. These differences are mostly seen in comparison between the Single-parent household profile and the CP38 dwelling. Although the presence at home is similar, the temperature preferences are much higher in the monitored household. The difference found in the comparison between CP37 and the 3 Adults household profile is based on the radiator setting in ‘other rooms’. This difference could be caused by the attitude of the household CP37 towards environment care. The comparison between CP39 and the Nuclear household profile showed similarities in presence, thermostat setting (temperature in living room) and use of radiators.

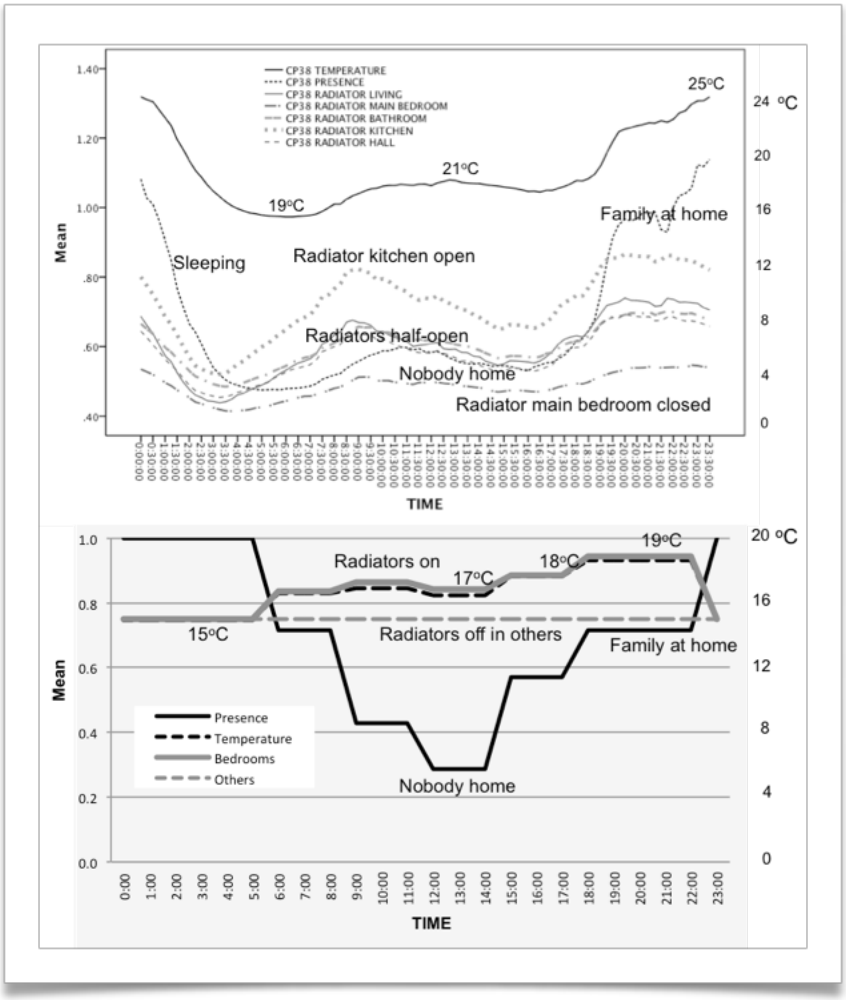


figure 44 Occupancy profile for CP38 and statistical profile for single-parent household

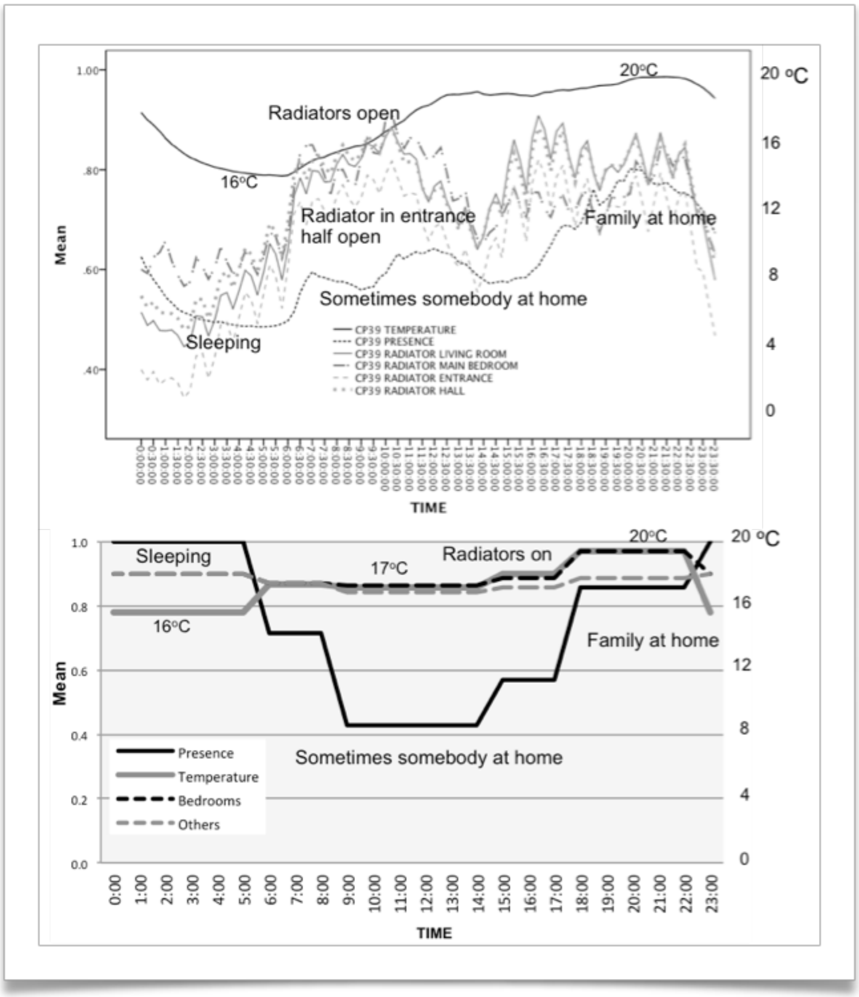


figure 45 Occupancy profile for CP39 and statistical profile for nuclear household

7.3.2 User requirements

Household practices and user interaction with the home and its systems affect energy consumption in dwellings (Guerra-Santin and Itard 2010). Balcony and window areas and ventilation systems were taken as two example areas to explore in adapting housing to users' needs (Aghina 2015). Balcony and window areas are important to residents because they are highly aware of them and they help provide well-being to a large degree. Ventilation systems and their interfaces, in contrast, are often incomprehensible to users and not always well-adapted to their needs. Prospective users are often unaware of the fact that indoor mechanical ventilation is a widespread and well-established technology. The two areas are explored via enactment-based user experience research with parts of the target design in the intended context of use. The outcomes of this research should contribute to enabling future residents to use their home in such a way that it promotes their wellbeing, while also saving energy.

Based on the household typologies defined above, a number of methods were applied to research user requirements. In this paragraph we present a role play enactments study that was used to understand the user perspective of ventilation systems. In this method, participants are asked to enact and explore their possible behaviour in scenarios that apply to their everyday life, while being asked to 'think out loud' for communication with the researchers. This technique, enables participants to contribute their reactions and reasoning to the researcher's observation. System use should be studied in a realistic context (in this case, a mock up renovated flat corresponding in key aspects to the residents' own home) because product use is situated: use unfolds in ways that people cannot fully analyse or re-tell outside of context. A mock-up flat was created that consisted of an interior space furbished as a flat, in which parts of a new ventilation system were simulated with which users could interact (figure 46).

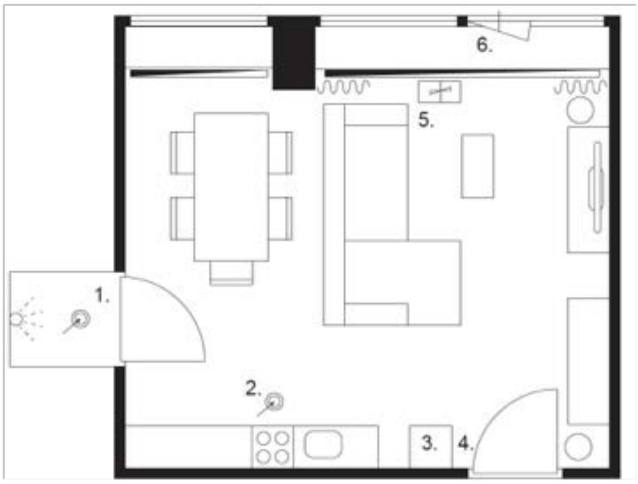


figure 46 Mock-up of flat in an experimental space

Among the elements used to simulate the situation were: a custom-made window to be opened like a normal side hung window; a ventilation control panel simulated on a tablet, air inlets indicated with print-outs on the side walls and under the radiator; air inlet simulated with a fan hidden behind a crate (figure 47); air outlet indicated with prints in bathroom and kitchen; thermostat indicated with paper print-out on the wall.

figure 47 Air inlet simulated with a fan hidden in crate

A total of eight participants, selected based on their socio-economic characteristics, took part on the study. All participants lived in the reference building type (porch building), except for one participant living in a gallery building, all in the Netherlands.

The study consisted of three parts taking about two hours per participant: introduction, acting out scenarios and in-depth interview. First, the participants were introduced to the research. They received an introduction to the proposed building systems and renovation process and the consequences of the renovation for them, for example the energy payment system and the deeper windowsill.

The proposed ventilation system was a passive ventilation system with shared heat recovery per porch, providing standard air changes per hour in line with Dutch regulations. A mock up control panel was used to study the interaction of the users with the system and their view of it. The panel had four settings: 1) absent (minimal amount of ventilation); 2) normal occupation; 3) maximum; and 4) automatic (regulated with a CO2 sensor). In addition, the ventilation inlet was mocked up under and behind the radiator. The participants were provided with 16 everyday or common scenarios to choose from as applicable to themselves. In each scenario they were asked to act out, with support by the research assistant, what they would do in their home given that the new ventilation system existed. The 16 scenarios were: just being at home, going on holiday, coming back from holiday, cooking for visitor, having visitors, visitors leaving, going to sleep, waking up, taking a shower, cleaning a stained carpet, painting something in the house, wondering whether ventilation performs correctly, having pets, being at home during warm weather, having hay fever symptoms, and smoking. Last, a semi-structured in-depth interview was conducted about their perspective on their home and a renovation process.

Analyses of the data were carried out with reference to self-determination theory and meaning of home (Guerra-Santin and Tweed 2015). A categorisation of the themes revealed in the data was carried out using grounded theory procedures. Each category was then analysed more closely to understand reasons for actions and statements. After this, the themes and connections between them were again checked against the literature (Guerra-Santin and Tweed 2015)

Resident requirements

The results were divided into requirements for renovation process and outcome. Regarding the renovation process, tenants have a need to have a grip of the future: they want reliable stakeholders, a guarantee of no higher costs, and minimum impact of the renovation. Regarding requirements for the renovation outcome, tenants want it to facilitate activities and lifestyles, provide health and comfort, and an easy to use and control system. Based on these findings, a series of recommendations were formulated and fed back to the design process. Examples of these recommendations are summarised in Table 33.

Table 33 Examples of main recommendations from enactments

Influence	Tenants want to be able to influence the ventilation system but do not want to be forced to deal with it intensively. Household members may have different air quality preferences.
Benefit	Tenants expect and hope for the air to be fresh, and for good air humidity and temperature, also in the summer.
Ease of interaction	Interfaces should have minimum settings needed, be easy to understand and located near thermostat, kitchen, shower and/or close to the front door out of sight. Senses are used to check system functioning (sound, airflow).
Safety and control	Tenants expect to be able to turn the system off in case of emergency (pollution emergency, not unlikely in the industrialised west of the Netherlands), when on holiday, when the system produces unwanted noise.
Trust	Tenants want to be certain of a healthy and hygienic environment. Some distrust air quality from the roof inlet, or the hygiene of the ducts. They expect systems to be serviced.
Balcony	Tenants view a balcony, as a private outdoor area, as essential, especially senior tenants. Senior tenants want the balcony to be easily accessible. and provide a good balance between privacy and contact. They want to be wind-protected.
Windowsill	For seniors the windowsill should not be too deep because they want to be able to sit close to the window yet not exposed to view. Others appreciate a deeper windowsill.
Façade	Tenants want to have a good climate in the common spaces. They do not want a decrease of indoor floor space.
Windows	Residents want no reduction of amount of glass surface. All want to be able to fully open the window. Windows should be easy to open and clean for senior tenants. Residents want to ventilate (naturally) at night while feeling safe. Offer a small window above the regular window.
Window coverings	Shading should be considered to prevent overexposure when looking at a screen. Coverings are seen as essential for privacy, against cold and draught in the winter and against heat in the summer. Offer an insect screen optionally.

7.3.3 Conclusions occupancy aspects

The investigation reported in this section highlight the effect of different household types on energy consumption and occupants' preferences. Three types of investigations were presented in this paper: statistical analysis of a national Dutch household survey, longitudinal monitoring data of three case studies in the Netherlands, and enactment research with mock-ups of parts of the target design. The statistical analysis aimed at investigating trends on energy consumption and occupants' behaviour, thus these results can be generalised to the Dutch population. The analysis of the monitoring data of the three case studies and the enactment research aimed to investigate in more depth the relationship between lifestyle and household type and occupants' behaviour as well as requirements. These results, specifically the results of the monitoring (e.g. thermostat settings) are tied to the specific monitored cases and should not be generalised to the population.

This research showed that:

- different households have statistically different energy consumption, even when corrected for building type (reference building);
- there are significant differences between the energy consumption of average Dutch households and Dutch households living in the reference buildings;

- the lower than expected energy consumption of the occupants of the reference building could challenge the return of investments,
- occupants of a specific type of building (the reference building) have different socio-economic characteristics than the national average;
- similar household types might have different behavioural patterns based on lifestyle, attitudes and preferences and;
- the differences in lifestyle, attitudes and preferences depend not only on household typology but also on socio-economic characteristics;
- trust, usability and variation in preferences are likely to affect resident willingness to agree to renovation and their energy consumption later;
- types of profiles differ for energy monitoring and requirements elicitation.
- These results highlight the importance of taking into account household typology and socio-economic characteristics in energy calculations or building simulations as well as user requirements in the design and renovation process.

This research also highlighted the differences between occupancy profiles from monitoring data, statistically defined household profiles and requirements elicitation. In order to determine the most effective method to define occupancy, it is important to consider the aim of the evaluation. Monitored occupancy profiles can provide detail information on the occupant behaviour of specific households. However, the behaviour will be highly determined by the building characteristics. In renovation projects when it is expected that the building properties improve, the behaviour of the occupants will certainly change. The enactment study did not result in profiles corresponding to the occupancy profiles. For example, user requirements for safety and control were shared across participants with different socio-economic profiles. Quantitative and qualitative research methods are therefore equally necessary and their integration can help to determine the occupant preferences in building renovation projects. In the pre-renovation design process, the results inform the building design and options for occupants. In a proposed renovation process, the results serve to manage expectations on energy savings.

7.4 Apply refurbishment in prototype 2.0: The physical aspects of the 2ndSKIN (WP 2.3)

7.4.1 Adaptations of the reference design

The main development with regards to the technical design is regarding the 2ndSKIN design adaptation for a potential prototype building.

Reference building

Prototype 2.0 Vlaardingen

figure 48 Main adjustment of 2ndSKIN reference design for the potential Prototype 2.0 location

The key points that needed to be adjusted to make the reference design applicable to a different building were the roof type and connection, the window and balcony solution.

Roof type:	Windows	Balcony
Detailing for insulation	Size of windows	Type
WTW units position on the roof or the attic	Parapet	Size
Pipes connection	Ventilation outlet	Thermal bridging
PV area and orientation	Inlet / outlet location	
	Zones for ventilation pipes	

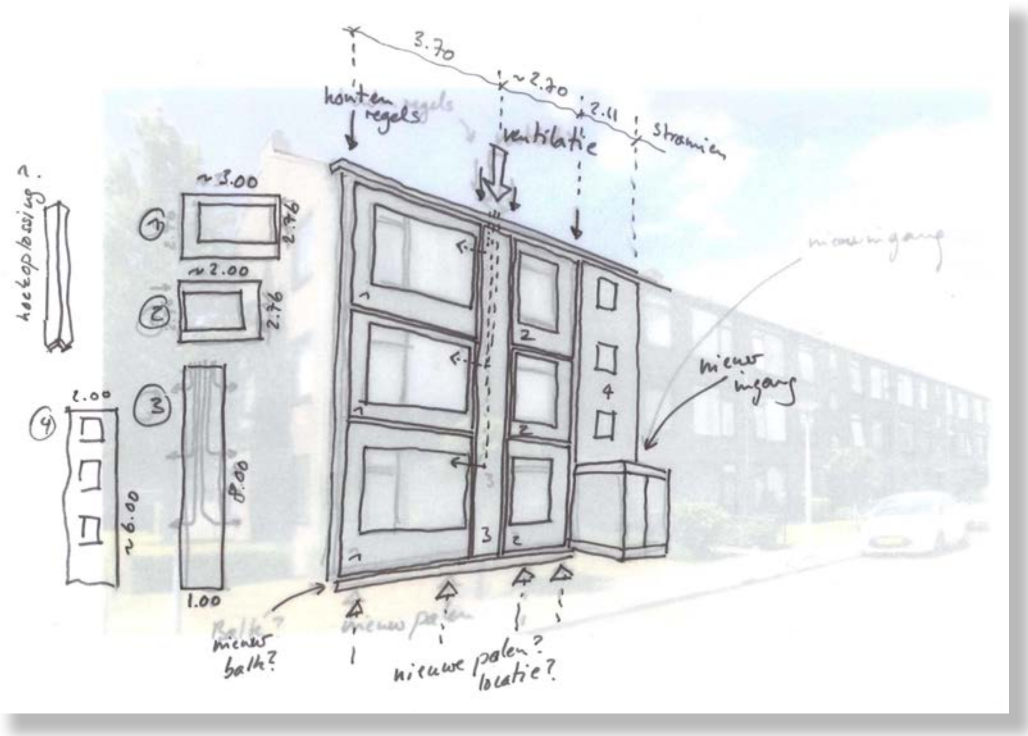


figure 49 Basic design for the 2ndSKIN panelling for the Prototype 2.0 in Vlaardingen

The design elaboration resulted in three design variations of the reference 2ndSKIN design. They are based on the 2ndSKIN integrated, prefabricated panel, but the application method and the treatment of the existing façade changes, depending on the housing association objectives.

The next step was to calculate the costs of the different 2ndSKIN options and to compare them with the traditional skin-renovation approach. (see Table 34). The different options are regarding the façade, roof, balcony, ventilation and heating.

Table 34 Alternative 2ndSKIN solutions for further discussion

	Facade	Roof	Balcony	Ventilation	Installations
1	2ndSKIN panels additional foundation	Attic floor insulation	Maintain	balanced ventilation	Balanced ventilation with heat recovery, 200 litre boiler & PV panels
2	2ndSKIN panels Remove old brick-layer	Insulated roof	Remove old, replaced by new balcony		Balanced ventilation High Efficient Furnace Central Heating (Gas), PV panels
3	2ndSKIN panels with ventilation channels & new windows & cladding integrated	Replacement by insulated roof panels			

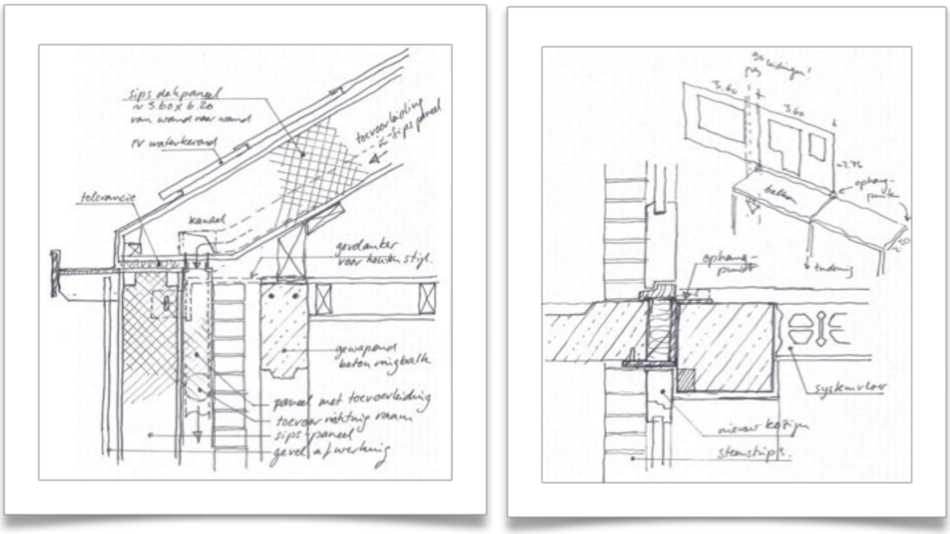
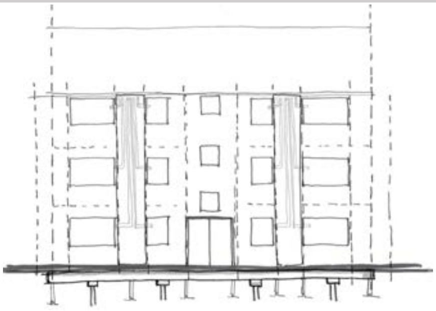
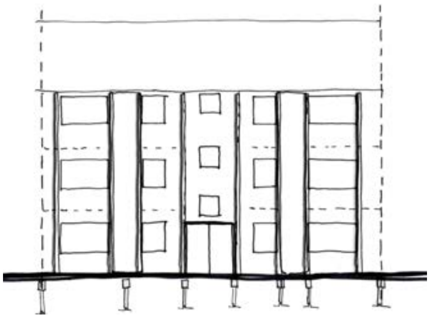
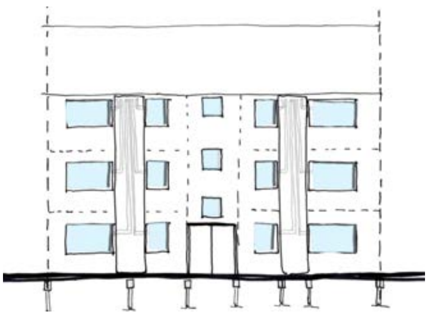


figure 50 Some detail studies of the roof connection (left) and the new balcony construction (right) for the potential Prototype 2 complex in Vlaardingen.

Table 35 2ndSKIN options explored for the Simplex System in Vlaardingen (potential prototype 2 location)

Façade solutions Simplex system Vlaardingen	Measures	Cost price Bivalent* (k€ incl. VAT)	Cost price All-electric** (k€ incl. VAT)
	• New foundation • Wooden sub frame • 2ndSKIN a-panels (integrated ducts) • 2ndSKIN b-panels with glazing, frames and cladding	102	108
	• Removing old brick façade • Wooden sub frame • 2ndSKIN a-panels (integrated ducts) • 2ndSKIN b-panels with glazing, frames and cladding	103	109
	• 2ndSKIN-panels (integrated ducts) • New glazing + frames • Bricklayer cladding	99	104

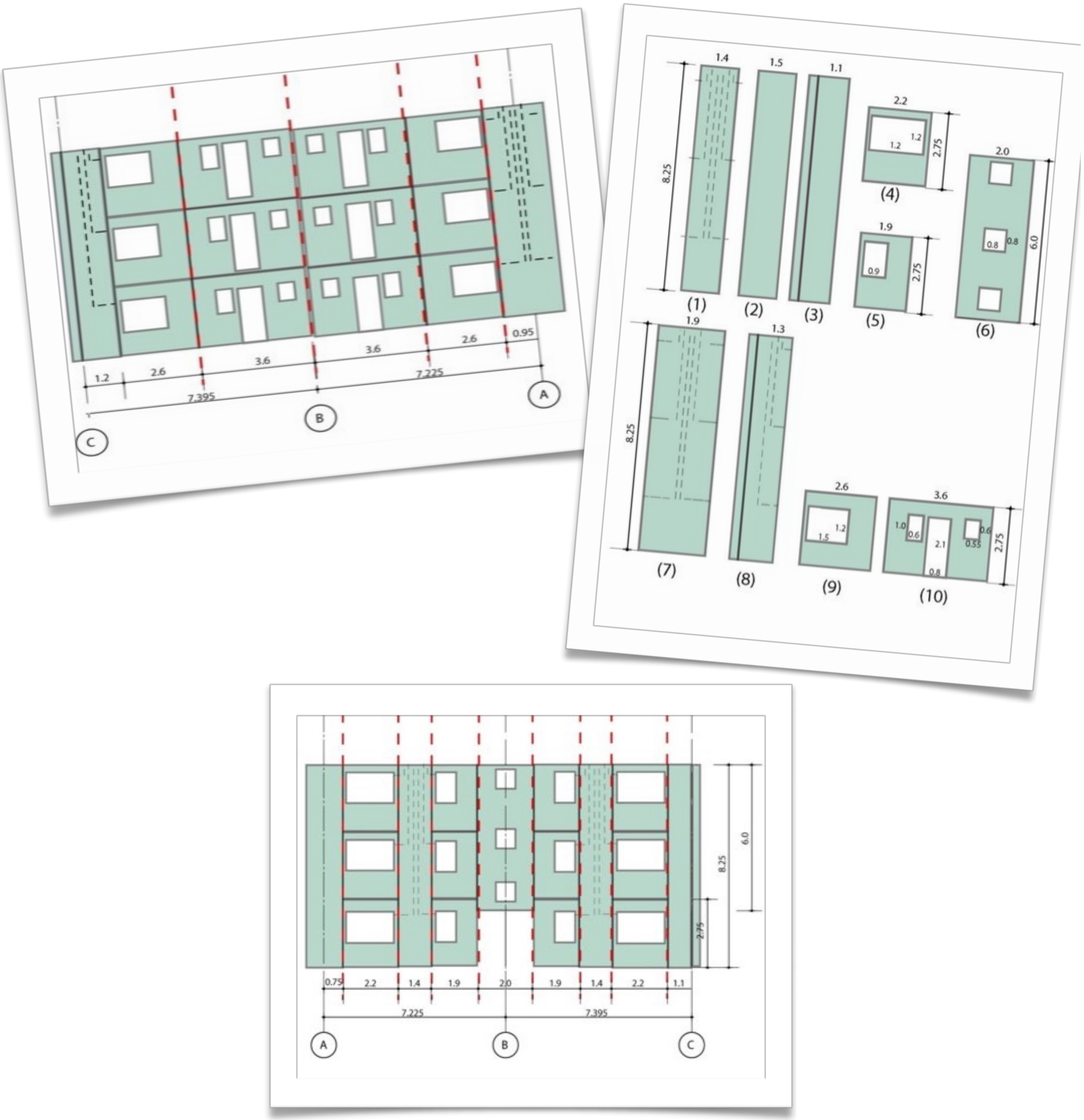


figure 51 Facade panels layout and sizes

7.4.2 Energy demand Prototype 2.0

The energy calculations for the prototype 2.0 were based in the building simulation of the reference building, but corrected for area. Table 36 shows the energy heating demand per household type and the average of all households. Table 37 is presenting the calculations of the energy production possibilities with the available roof surface for PV for the North-South-orientation of the prototype location and a calculation with an additional 1 m2 in the south oriented façade.

Table 36 Energy Heating demand per household type and the average of all households

	Scenario 1: Inefficient appliances			Scenario 2: efficient appliances		
	Heating demand pre-renovation	Inefficient appliances	Domestic hot water	Heating demand post-renovation	Efficient appliances	Domestic hot water incl. estimated savings
Single adult	328.1	1740.6	612.8	623.5	884.7	429.0
Single senior	1364.7	1968.1	612.8	865.7	917.7	429.0
Adults couple	623.6	2325.0	975.2	491.4	1374.9	682.7
Seniors couple	1060.2	2309.9	975.2	687.3	1177.3	682.7
Three adults	679.1	2718.6	1418.2	630.2	1652.7	992.7
Nuclear family	702.3	2725.2	1418.2	681.3	1648.8	992.7
Single parent	1136.1	3111.4	1861.2	1114.4	1941.6	1302.8
Average	842.0	2414.1	1124.8	727.7	1371.1	787.4
Total energy demand Average Household			4380.9			2886.2

Table 37 PV Energy production versus energy demand for the WWW-prototype location Soendalaan, Vlaardingen.

Scenario	Production roof (kWh/year)	Energy produced in walls (kWh/year)	Total energy walls and roof (kWh/year)	Energy demand (scenario 2) (kWh/year)	Energy gap (kWh/year)	Missing panels
NS_pitch	1757.05	1274.16	3031.21	2,886.16	-145.05	-1.09
NS_pitch + 1 m	2082.43	1274.16	3356.59	2,886.16	-470.43	-3.52

7.4.3 Evaluation feasibility scan Simplex Building System in Vlaardingen (July 2016)

Several design, engineering and cost calculation sessions were organised to create a technical sound and cost efficient – zero-energy- solution for the selected complex of the social housing organisation Waterweg Wonen. Table 35 on page 82 is showing the state-of-the-art in July 2016. The overall conclusion was that the prices of different 2ndSKIN refurbishment options, ranging from k€99 to k€109, were still too high for making the step towards upscaling. The 2ndSKIN team decided that more steps on integration of the different components and the accomplishing business development were needed before upscaling is feasible.

At this moment in the project BAM Woningbouw decided to end the project. The additional R&D, prototyping and business development needed towards upscaling did not fit in the project as being contracted with TKI/ENERGO and the partners.

8 Business model

8.1 Possibilities for new business models and upscaling

Status Industry consortium (consultation round)

An interview round was conducted amongst the 2nd SKIN industry partners

- BAM Woningbouw Rotterdam (general contractor)
- Giesbers & van de Graaf (installation contractor)
- Ventilatieservice (ventilation contractor)
- Bart Spee (architect)
- Rollecate (façade contractor)

The results of this consultation round at the end of 2015, were presented back to the consortium and used as a starting point to discuss the business strategy.

Results:

The outlook on the market is favourable, as long as zero-on-the-meter concepts can be offered at a reasonable price. This is the consortium's opinion, but it is also the conclusion of the business developer from separate interviews with market representatives.

The consortium needs more clear leadership and focus, especially on the subject of business development. Much of the work of the consortium has been of a technical nature, discussing design and technologies. The question of how to commercialise the concept has been mentioned over the past project period, but has not been treated in a structured manner.

The biggest current challenge is, to really "cross the tee's and dot the i's", in other words fill in all details and work towards a feasible concept in the range between 45k€-60k€. This means in particular: doing a cost price calculation and calculate the exact energy performance of the concept.

Strategy: the path from project orientation to product orientation; counterproductive incentives in traditional project orientation

It has been generally observed that within the traditional project approach, the incentives are pushing partners in a wrong, ineffective direction. In the traditional, project-oriented working culture in the construction industry, a new value chain is composed for every new project. Although more innovative contract forms are upcoming, this is still mostly done by selection based on price alone. For every new project, an architect or a general contractor (or a combination of those) will determine what will be built, and then the sub-contractors are selected based on who can deliver the specified goods as cheap as possible. Whenever subcontractors deliver or built something extra on top of the contract specifications, they will charge additional costs (meerwerk). Because (sub-)contractors in times of crisis never know if they will have another job after the current one, they will have an incentive to maximize the amount of work they do within the current project (in terms of materials, hours etc.). The incentive to maximize individual workloads has a ballooning effect on total project price. This is further increased because of the additional fees for risk coverage and overhead that subcontractors generally add to their bids. This is a barrier that in general hinders innovation adoption in the construction industry, and it has a quite tangible effect on the current phase of the 2nd SKIN project.

It was discussed with the consortium that, to achieve significant cost price reductions, a radical alternative way of cooperating and calculating would be needed. This new way of working is characterized by:

- Transparency in cost structures between the partners
- Sharing of risks and overhead
- Sharing total project revenues
- Cooperation agreement that stretches beyond the one-off project scope
- Over time, collectively attracting new financial sources

In fact, this new way of working resembles more closely partners setting up a new start up than the traditional configuration of partners in a construction project. In this way, all partners have a clear incentive to make their workload in a project as small and efficient as possible, since that will generate more overall revenue to be distributed among the partners. However, it does require an increased amount of trust, that everyone is working just as hard at keeping costs down. A new contractual agreement is being proposed, to match the redistribution of risks and revenues.

There is also a mental challenge the consortium has to overcome, as it requires them to step away from what has become an intuitive reflex, the search for 'meerwerk', and to learn how to make a profit from 'minderwerk'.

Exploit the scale of market potential beyond the current project scope

An essential part of the mind shift from project orientation to product orientation is to learn to think in terms of large scale. Within the traditional project orientation, the partners would calculate their price for the given job, and would only actually take it if it would generate a profit within the scope of that project. If the job is to renovate 6 houses, it will be calculated for 6 houses. This was in fact how the renovation of the 6 houses at Concept House Village was calculated and why it had to be cancelled. This way, investments in innovation will only happen if they have a full return on investment within the current project. Additionally, economies of scale of e.g. large scale procurement are never really exploited.

It was discussed with the consortium that the business case for 2ndSKIN needs to be calculated for 1000 houses, not for 6 or 10. The leap of faith that the partners have to take is that for a normal calculation, there is already an actual customer, whereas in this case, they have to trust that the market is there – and it is, but just not as present as it would normally be.

The calculation of the 2ndSKIN approach for 1000 houses opens up new ways of innovation, especially of the renovation process. Economies of scale that are expected are:

- High volume procurement contracts with suppliers
- Reduction of errors
- Redesign of the building process (from traditional on site production to prefabricated plug- and-play units)

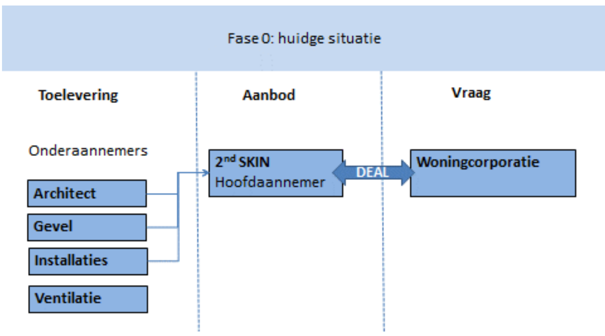
Concluding:

There is a substantial market for 2ndSKIN, but it can only be unlocked if the consortium embraces the new product way of thinking, exploits all potential economies of scale of the market and lowers cost price to the acceptable range of € 45.000 till € 60.000. More than anything, that is a mental challenge.

8.1.1 Business models in phases

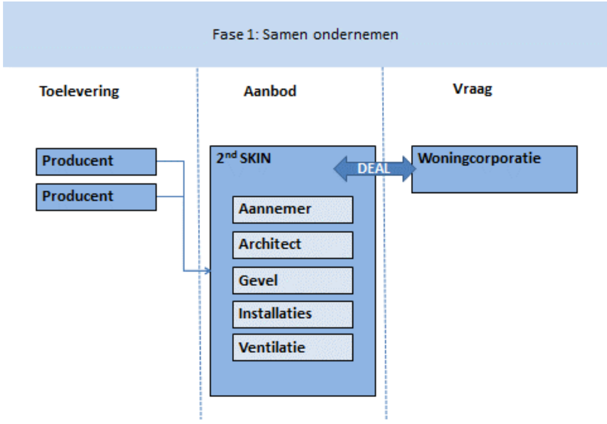
Phase 0: traditional setting

This setting will be used around the pilot project.



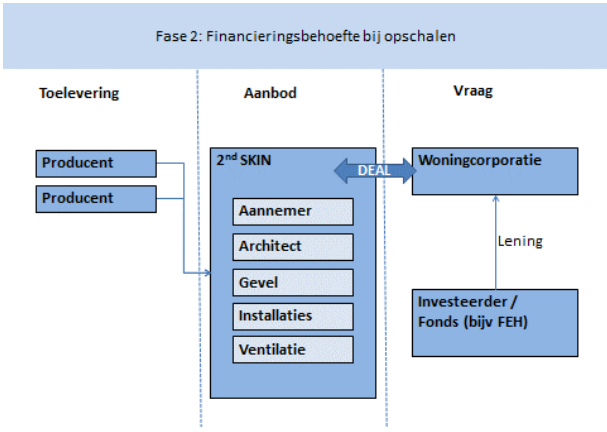
Phase 1: Joint entrepreneurship

Parallel to the acquisition and production of a pilot project, project partners will negotiate a new partnership agreement that is more suitable for a large scale concept such as 2ndSKIN. This agreement ensures that costs and revenues from the development and commercialisation of the concept are shared equally, thus giving the right incentives (as mentioned earlier in this document).



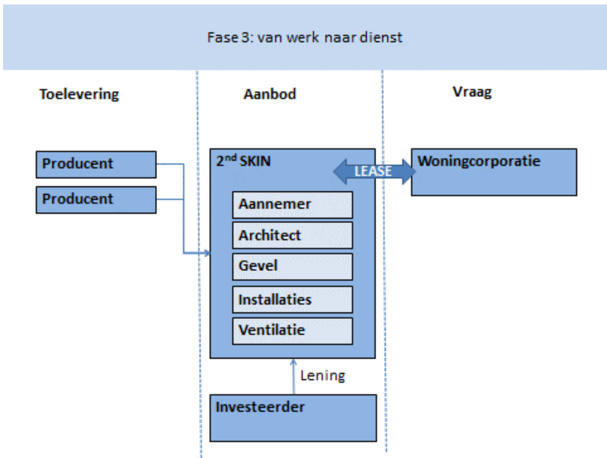
Phase 2: Scale up with external financing

In this phase, additional financial partners are required by the demand side for additional liquidity.



Phase 3: from product to value delivery (leasing facades)

Over time, the consortium itself will also incorporate a financial partner, allowing the consortium to offer the value on e.g. lease conditions.



9 Evaluation, conclusions & recommendations

This 2ndSKIN project as contracted in the TKI/ENERGO agreement consisted of two phases. In the first, industrial development phase, orientation and analysis of the project was completely executed. Resulting in a program of requirements and wishes both from a technical as from a user acceptance point of view. Furthermore, the 2ndSKIN façade concept designed and prototyped in the format of a mock-up assembled in Staphorst by Rollecate. The 2ndSKIN prototype is evaluated and the findings are integrated in the design and approach of the solution for the reference building.
The first phase of the project showed that with the 2ndSKIN approach zero-energy refurbishment is possible for the porch apartment buildings till 3 layers, but is still critical on the use of inefficient electric appliances by the households and the orientation of the complex in relation with the possibility of generating PV-electricity. It is being expected that with the constant improvement of the efficiency of the PV modules and the uptake of energy efficient domestic appliances the 2ndSKIN approach can turn into an ‘energy positive’ solution.
The second phase, experimental phase, is partly executed. On request of the social housing organisation Waterweg Wonen, the 2ndSKIN approach is being applied to a potential location in Vlaardingen for the upscaling phase. Both technical fine-tuning as the energy simulations are performed. Furthermore, cost calculation sessions were done for different options to validate the financial viability for up-scaling.

Unfortunately, the TKI subsidized 2ndSKIN project is finished earlier than planned. The reason for this early end includes the changed starting points and goals in the project together with the present market situation and the associated long-term responsibility for the products and services under development. At the start of the agreement the objective was formulated to develop a concept vision for the energetic renovation of porch apartment buildings by means of a pilot project, aiming at a performance level "energy neutral". This ambition is translated into a zero-on-the-meter-concept (NoM) where the technical installations would be integrated in the façade of the building and therefore would be more accessible in the future for maintenance and replacement.

Due to the withdrawal of the social housing organisation Woonbron Rotterdam, as a participant, there was no short-term pilot project available. In addition, turbulent developments in the context of the 2ndSKIN and more general the NoM (zero-to-the-meter) approach of porch apartments make it hard to achieve a financial affordable solution already.

The 2ndSKIN project team was forced to acquire pilot projects in a competing market situation and by the lack of a real life testbed the consortium was not able to validate the knowledge and solutions developed within the formulated TKI-agreements.

The demand for zero-energy refurbishment solutions is still limited and only actual for a small number of the social housing organisations. Zero-energy refurbishment will only be considered for complexes where there is certainty that they can be operated for another forty years. This again depends on the location, layout and structural quality and popularity of the neighbourhood. The main owners of the porch apartments, the social housing organisations seems to be in favour of a stepwise energetic upgrading of their stock to be able to profit from future technical and innovative developments.

After a series of calculation sessions, the developed 2ndSKIN concept with the application of innovative, available technology and proven building processes, showed still to be financially unfeasible for up-scaling in the present market. In addition, the calculation methods relating to the energy performance compensation (EPV) based on the number of square meters of living space per apartment is not favourable for this type of housing. Because of the small number of square meters per apartment, the EPV will be relatively low compared to terrace –single family-houses. This study indicates that the high investment needed together with the relatively low EPV cannot make zero-energy refurbishment (NoM) profitable already.

Other consortia are also working on concepts for the zero-energy refurbishment of porch apartments. These solutions are also not viable and financeable yet based on the EPV legislation. This study also shows that the energy demand is strongly related to type of occupancy. This makes it quite hard to guarantee zero-energy performance for decades to come by the suppliers of zero-energy refurbishment. This would lead to undue risks for the 2ndSKIN partners in a 2ndSKIN *pilot* project.

The 2ndSKIN studies conducted have provided many insights into the possibilities and limitations of the project. We recognize that it needs still a series of prototypes to be develop and validate a high level of industrial production and the associated reduction in costs. Within the limited context of the present project, defined in the TKI-subsidy agreement, it is not possible to reach this level of industrialisation and cost reduction already. More steps are needed than being expected at the start of the 2ndSKIN project.

The main conclusions and recommendations of this project are:

- A zero-energy refurbishment of porch apartment buildings is possible already with the technologies and building processes available in the market.
- The investments needed for 2ndSKIN approach are still too high to be an affordable solution for the porch apartment buildings.
- Long depreciation periods for the refurbishment investments (30 to 40 years) is considered too long and is blocking implementations of innovations within that depreciation period.
- The 2ndSKIN approach needs a different and high level of supply chain integration than used in the building industry to date and reconsidering the organisation of and leadership in this type of innovation processes is needed.
- The knowledge institutes can play an important role in validating the present solutions and develop new innovations for future improvements of the 2ndSKIN approach.
- For a successful product development, the involvement of global operating suppliers is needed to reach the economies of scale and the cost reduction for the 2ndSKIN approach.
- The application of the 2ndSKIN product and the provision of services can be done by the regional and local operating -often small- and medium sized – enterprises.

The TU Delft is creating the possibilities of executing a demonstration project. This follow-up is planned to start during the first quarter of 2017 and will be co-funded by EIT Climate KIC. The aim of this phase in the development of 2ndSKIN is to demonstrate the feasibility and acceptability of the 2ndSKIN product solution in a real life setting and furthermore to demonstrate and validate the business model for a financial feasible exploitation of this type of zero-energy refurbishment in the Netherlands and Europe.

10 Appendices

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10.2 Scientific 2ndSKIN publications

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O. Guerra-Santin & S. Silvester (2016): Development of Dutch occupancy and heating profiles for building simulation, Building Research & Information

10.3 Experimental design phase: Monitoring protocol (WP 2.6, 2.7)

In order to determine the actual performance of the renovated building, it is necessary to determine the performance of the building before the renovation, so that we can establish the efficiency of the technologies installed. In addition, it is necessary to determine the performance of the refurbished building before occupancy, in order to ensure the quality of the construction process. Building envelope testing methods will be suggested depending on the time scale and the frame of the construction process timeline. Given the fact that the acceptability of the renovation process is one of the goals of the 2ndSKIN, the construction phase of the renovation process should also be investigated. The nuisance, indoor air quality and noise level of the process would be monitored and evaluated.

The monitoring process should not just assess energy use, but is also a valuable opportunity to continuously engage residents in dialogue and in fact co-creation. If the co-creation phase is limited only to the moment a renovation is planned, it misses out on the learning and innovation that residents can contribute and receive in the meantime. A housing corporation should have an ongoing 'new possibilities' project with residents. Such an ongoing project will make it much easier to start new renovation projects with residents.

A number of instruments needed for the data collection have been developed or modified to fit the project. These include:

- background (initial) user questionnaire
- previous home operation questionnaire
- home operation questionnaire (seasonal)
- thermal comfort, indoor air and satisfaction questionnaire

The monitoring protocol for the 2ndSKIN project has been divided in: pre-renovation phase (current situation of the building), renovation phase (installation of the 2ndSKIN), and post-renovation phase. A number of interventions to investigate and increase the usability of the building will take place during the post-renovation phase. These phases are specified below.

10.3.1 Pre-renovation phase

1.1 Installation meters and sensors
Installation of energy meters (and sub-meters)
Installation of indoor environment sensors
Installation of building operation sensors
Testing of data collection meters and sensors
1.2 Investigation household
The occupants will be asked to answer an initial questionnaire about: • Household characteristics • Attitudes, actions toward energy savings • Household lifestyle (incl. health) Approximately one year before the envisaged start of renovation, the collaboration with residents should be started (see also diagram above), and a contact/info point for collaboration set up that the researchers have access to. The collaboration should start with the engagement of local key persons and networks. Any trust issues (e.g. with the housing corporation) should be righted first. Besides the actual renovation project, residents' priorities in their surroundings (house/social/area) should be addressed early on (e.g. noise, greenery, pets etc) because these are often residents' first priority. For the building/home, the process should facilitate real bottom-up choices.
1.3 Appliances and electronic audit
The team will carry out an audit of the appliances and electronics in use in the three apartments.
1.4 Energy metering
Energy (sub)metering should be done at least of gas and electricity per apartment. Ideally, the sub-metering should be made for: • Domestic hot water • Space heating • Ventilation • Auxiliary systems
If individual (per apartment) metering and data logging is not possible before the renovation, energy readings would be taken weekly either by the residents or by a team member of 2ndSKIN (this could be an opportunity for informal contact).
1.5 Measurement of indoor parameters

The indoor parameters to monitored are: • Temperature • Relative Humidity • CO2 concentration level • Natural lighting • Noise As a minimum, Temperature and Relative Humidity should be measured.
1.6 Investigation of subjective comfort
Subjective thermal comfort will be investigated either with TU Delft Comfort dial or comfort questionnaire. Subjective lighting level, noise and air quality will be investigated with a questionnaire.
1.7 Investigation of building operation
Sensors to determine the use of the heating system and window opening behaviour could be installed if the pre-renovation phase is during the heating period. Sensors include: • Window opening • Radiators use (temperature) • Presence If the construction program or the time schedule does not allow installing sensors, building operation will be investigated through (retrospective) questionnaires.
1.8 User acceptability
Possibly measure 'liveability' beforehand (including satisfaction) in order to be able to compare. Collaborate with residents in understanding current quality of home living practices (comfort, health, values), discover and rehearse the implications of a renovation for future quality of home living practices, across levels from neighbourhood down to interaction with home systems interfaces.
1.9 Development of intervention
Present building process as one integrated consortium. Set up contact with occupants via information evening(s), website, mailings, visits. Set up contact point permanently staffed by building consortium ('bouwbureau'/model apartment/escape apartment)

10.3.2 Renovation phase (installation of 2ndSKIN)

2.1 Measurement of indoor parameters
Regardless of the occupant staying in the building during the renovation, indoor parameters would be measured to assess the renovation process and the possibilities for occupants to stay during the scaling up. The sensors used during the pre-renovation monitoring will be used during this phase, containing: • Temperature • Relative Humidity • CO2 concentration level • Natural lighting • Noise In addition, additional noise and dust sensors will be installed.
2.2 Installation process
The renovation process will be assessed in two issues: • Safety (for users), acceptance and time. Current protocols from BAM could be used to assess the safety of users and workers. • Selected stakeholders could be interview to further assess the efficiency of the process.
2.3 Performance of building envelope
A pressurisation test and/or infrared thermography survey will be carried out to determine the performance of the building after the renovation process. These tests could be performed by the 2ndSKIN team or by an external assessor.
2.4 Performance of building systems
The commissioning of the building systems will be followed and documented by the 2ndSKIN Team
2.5 User acceptability
The renovation process should be entirely predictable for residents well in advance, specific issues for each residents should be taken into consideration. Execution should be done in a competent and considerate way. The occupants will be interviewed regarding their satisfaction with the renovation process.

10.3.3 Post-renovation phase

3.1 Installation meters and sensors
Installation of energy meters and sub-meters (if not installed before)
Re-installation of indoor environment sensors
Re-installation of building operation sensors
Testing of data collection meters and sensors
3.2 Investigation household (only if different occupants)

The occupants will be asked to answer an initial questionnaire about:

- Household characteristics
- Attitudes toward energy savings
- Household lifestyle (incl. health)

3.3 Appliances and electronic audit - update

The team will update the information regarding the appliances and electronics in use in the three apartments.

3.4 Energy metering

Energy (sub)metering should be done at least of gas and electricity per apartment. Ideally, the sub-metering should be made for:

- Domestic hot water
- Space heating
- Ventilation
- Auxiliary systems

3.5 Measurement of indoor parameters

The indoor parameters to monitored are:

- Temperature
- Relative Humidity
- CO2 concentration level
- Natural lighting
- Noise

The equipment should be already available from previous phases

3.6 Investigation of subjective comfort

Subjective thermal comfort will be investigated either with TU Delft Comfort dial.
Subjective lighting level, noise and air quality will be investigated with a questionnaire.

3.7 Investigation of building operation

Sensors to determine the use of the heating system and window opening behaviour will be installed (if not previously installed) or re-installed according to the new situation of the building. Sensors include:

- Window opening
- Radiators use (temperature)
- Presence

3.8 User acceptability

The building owner should incorporate the monitoring, use and repair into the regular communication with residents. Resident spokespersons and networks should continue to be contact points. Case study research of the use and repair phase provides important insights for optimisation of the results of this and other renovation projects.

10.4 SBRCURnet / Knowledge dissemination

The link to the SBRCURnet knowledge webportal is:

https://www.kennispartnerhub.nl/home

10.5 Link to the 2ndSKIN visual

HFB has made a visual for the 2ndSKIN approach in which the stepwise refurbishment towards ‘Nul-op-Meter’ (Nett Zero Energy) was illustrated. (in Dutch).

https://www.youtube.com/watch?v=mm_2D2cZRoM