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A Design Process for a Resident-Oriented, Sufficiency-Based Energy Renovation Approach for Dwellings

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Abstract

Energy efficiency of houses is considered a key measure against climate change. However, its characteristics jeopardize effective energy savings. Firstly, the use of a relative scale to express energy efficiency, in kWh per m² floor area, neglects the impact of building size on absolute energy use. Secondly, the use of standardised norms for thermal comfort neglects how residents are effectively using the space in their homes. And thirdly, the abstraction of the social context ignores the actual and dynamic behaviour and wellbeing of the residents.

In order to put the final objective of lowering the absolute energy use in houses in the front seat of our research, without neglecting the needs of residents, we abandoned the focus on the house as the object to be optimised by improving its energy efficiency. Instead we explored the potential of energy sufficiency in dwelling (as an act) by means of the three types of interventions that are documented in literature on sufficiency. We applied the interventions of reduction, adjustment and substitution of dwelling-related energy services, especially heating and cooling, to meet the residents' basic needs such that the provided service is enough whilst avoiding too much of a service.

To do so, we firstly investigated the dynamic way of living of residents over the seasons, especially in large, underused houses, via ethnographic interviews and diaries. Then, through research-by-design we explored the potential of spatial design on dwelling and room level to stimulate sufficient behaviour of an active resident and to optimise (thermal) wellbeing of a diverse resident. These stages informed the development process of a design instrument to support architects to increase energy sufficiency in (large, underused) dwellings. The instrument was iteratively tested and optimised in four design experiments, over four subsequent academic years, with novice (student) designers.

By shifting from an object-centred towards a resident-oriented perspective we were able to develop a design process for an alternative sufficiency-based energy renovation approach. The process involves three main steps (analysis, synthesis, evaluation) and the implementation of design methods (grouping, linking and zoning and flexible spaces/places). Based on place-making (identifying places, meaning of places, meaning of spaces), energy sufficiency can be increased by reduction of space, adjustment of energy services, and substitution of active output/practices. A qualitative evaluation scheme with design criteria, boundary conditions and critical questions is provided to evaluate the impact of the renovation design on the overall energy consumption.

Introduction

In the commute to a more sustainable development of the built environment, policymakers are making strong efforts to implement energy policies that aim to improve energy performance of buildings and increase renovation rates (European parliament and Council of European Union 2010). Energy efficiency is implemented as a main strategy to reduce energy consumption and is defined as "*the ratio of output of performance, service, goods or energy, to input of energy*" (European Commission 2012). In the residential sector, energy efficiency (measured in kWh/m^2) has increased by 35% between 1990 and 2016, mostly due to improvements in space heating (European Environment Agency 2019). However, the overall energy consumption of space heating (measured in kWh) has only decreased with 4% (European Environment Agency 2019). Three characteristics of energy efficiency can be seen as important causes for jeopardizing effective energy savings.

First of all, energy efficiency is a relative measure expressing energy use on a relative scale (in kWh/m² floor area). Most energy regulations merely focus on improving the energy efficiency of houses by increasing the insulation level and the application of energy efficient heating systems and renewable energy systems, and thus disregard the impact of the house size. This brings forth a distorted perspective on the energy consumption, which is often (mistakenly) seen as interchangeable with 'efficiency'. In this sense, the relative nature of energy efficiency and the strong focus on the building envelope and the systems can be seen as important limitations to achieve effective reductions of the overall energy consumption (Granda, Lynch et al. 2008, Shove 2017, De Decker 2018). Furthermore, the definition of energy efficiency implies that the requested energy service in itself is not questioned, because in the comparison of the efficiency of houses, the same thermal conditions are assumed based on standardised norms for thermal comfort. This way, energy efficiency is more focused on decreasing energy demand than on questioning comfort demands and energy needs. Furthermore, studies on (adaptive) thermal comfort suggest that standardization of thermal conditions can induce a self-fulfilling cycle of demanding too much energy (Chappells and Shove 2004). Finally, most studies on energy efficiency make an abstraction of the social context in which it is established. Shove (Shove 2017) discusses the concept of 'purification', meaning that efficiency measures are established, isolated from social aspects and (abstracted from their context, because they need to work on their own terms. Due to this purifying nature of energy efficiency, residents' everyday behaviour and their relation with use of energy is often overlooked (Shove 2017). This abstraction makes designers expect residents to behave rationally and demand the energy service that is predefined as well as to consume it in the way that is intended (O'Brien and Gunay 2014). But neglecting the residents' stochastic nature and behaviour leads to actual energy consumptions that may be higher (or lower) than predicted (Derijcke and Uitzinger 2006, O'Brien and Gunay 2014). This is in literature well-known as the *rebound effect*, a psychological reaction, by which the demand for an energy service increases when the marginal cost of that service decreases (Guerra Santin 2013, Gram-Hanssen 2013), and the *prebound effect*, which explains how residents have a lower comfort demand because of a high(er) comfort cost (Sunikka-Blank and Galvin 2012). The latter suggest that, when higher energy costs are expected, residents heat/cool their dwelling according to what is sufficient to them and economically feasible. Whilst, as the rebound effect demonstrates, increasing energy efficiency seems to nudge residents to consume more energy than is sufficient and leads to a lower awareness of the actual energy consumption.

While views on energy efficiency have become more critical (Lutzenhiser 2014, Lopes et al. 2015, Shove 2017), the concept of energy sufficiency has gained attention as an alternative strategy to minimise energy consumption (Fawcett and Darby 2018). Energy sufficiency rethinks the quantity and/or quality of an 'energy service' in a way that a provided service is 'enough' whilst also avoiding 'too much' of a service (Bierwirth and Thomas 2019). Defining energy as a 'service' implies that there is a receiver, someone who demanded that service and who is in need for it. Darby and Fawcett introduce energy sufficiency as "*an organizing principle for achieving a 'state' in which residents' basic needs for energy services are met equitably and ecological limits are respected*" (Darby and Fawcett 2018). In order to achieve that 'state', Thomas and Brischke propose three energy-sufficient interventions: reduction, adjustment and substitution of quantity and/or quality of energy services (Thomas and Brischke 2015). Meaning, "*sufficiency may be improved by taking reduced or adjusted transformation steps according to the really needed levels of reliefs and services, as well as by taking different steps, satisfying the demands and needs in a different way (substitution)*". In their study, Thomas and Brischke consider energy consumption at household level and define it as a result of a transformation chain that transforms needs into demands and demands into energy services. This way, energy sufficiency starts from residents' needs whilst also focusing on their demands, which contradicts with energy efficiency that abstracts social aspects and fixates mostly on supply.

Implementing the three energy sufficient interventions in the design process during energy renovation of dwellings, especially if they are large and underused, can serve as an approach that challenges the current limitations of a mere focus on optimising the building envelope and systems. Firstly, *reducing* residents' needs and/or energy demand can serve as a solution for limitations brought forth by standardisation of comfort and defining a fixed energy demand. Secondly, the limiting relative nature of energy efficiency can be tackled by *adjusting* the energy service or comfort demanded to the size of the dwelling. Thirdly, *substitution* of active services with passive practices can help avoid an increase in energy consumption caused by the purifying nature of energy efficiency.

In this paper we present the development of a sufficiency-based alternative renovation approach that integrates residents' needs and behaviour and decreases the energy use of dwellings. First we present the research set-up.

Then we describe the final design approach as a compilation of principles, processes and methods for an alternative sufficiency-based energy renovation approach. The paper summarizes the research process and outcome of the PhD research by Ann Bosserez (Bosserez 2020).

Research set-up

As a starting point to introduce the concept of energy sufficiency, the dwelling is considered as an energy system composed of several (design) layers, including residents and space. Each layer affects the energy use of the dwelling in its own way. Defining dwellings as a composition of layers is first introduced by Duffy, who defined four layers (Shell, Services, Scenery and Set) and Brand added two additional layers and presents in total six 'shearing layers of change': Site, Structure, Skin, Services, Space plan, Stuff (Brand 1994). While Duffy and Brand used the layers to emphasise the longevity of each layer, we (re)define the layers in order to reveal their relation towards energy. Moreover, we expand the dwelling with one additional layer: Selves. This layer refers to residents, who also play an important role in dwellings as energy systems as they are the ones actually demanding and consuming energy. With this first exploration for rethinking the current object-centred approach for energy renovation, we aim to shift the focus on energy efficiency towards energy sufficiency whilst adopting a resident-oriented perspective (figure 1).

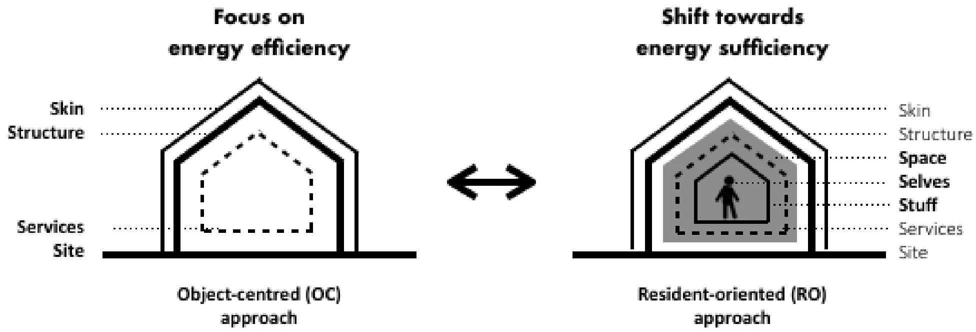

Figure 1. Rethinking the current energy renovation practice by shifting towards a resident-oriented approach.

To develop an alternative approach that integrates residents' needs and behaviour and decrease energy use of dwellings, the research was subdivided in three sub-objectives: (1) to gain knowledge on existing architectural strategies and methods that integrate residents when (re)designing dwellings and enable a dynamic way of living throughout the seasons; (2) to develop a theoretical model that conceptualises and defines the role of residents and space of dwellings in an energy-related context; and (3) to generate concrete design solutions that demonstrate how to arrive at alternative energy saving solutions that increase energy sufficiency of dwellings.

For the first sub-objective, a critical literature review was performed on existing architectural design strategies that centralise residents and integrate their needs and behaviour throughout the design process, and that allow for and enable a dynamic way of living throughout the seasons. The exploration of literature led to strategies related to climate-responsive architecture, building with adaptive ability and user-centred design/design for all. In the next section Findings, we present a conceptual framework on how these strategies can serve as support to tackle the three challenges induced by the current focus on energy efficiency.

For the second sub-objective, a deeper understanding of the interrelations between the resident, dwelling and energy was aimed for. As a first step to get insight in the residents' role and in existing practices of energy-sufficient living, the energy-related behaviour and (thermal) experiences of 9 residents living in 6 large, underused dwellings was investigated. An empirical ethnographic study on residents' dynamic way of living throughout the seasons was set up using qualitative research methods and following the principles of Grounded Theory (Strauss and Corbin 1990). The cases were subdivided in 3 main cases and 3 test cases. The data collection that took place between January 2017 and May 2018 was divided into two parts. Firstly, we conducted interviews on residents' actions, occupation and (dis)comfort within spaces by means of guided tours (= exploratory interviews). Secondly, supported by photographic journals kept by the residents, we conducted interviews on residents' experiences within each season (= seasonal interviews). Through reading, coding and interpreting of interviews, the empirical data collected in the 6 cases was systematically analysed. We conducted three analyses, the first two on the data from the 3 main cases, whereas the 3 test cases were used in a third analysis to challenge and test original findings from the main cases, by reflecting on how new findings agree upon, contradict or expand the results from the first and second analysis. All three analyses were performed in NVivo, following Strauss' and Corbin's three-level procedure of coding: open, axial and selective coding (Strauss and Corbin 1990).

As a second step within the second sub-objective, to increase the understanding of the role (design of) space plays within dwellings as energy systems, a spatial analysis was conducted on 3 of the 6 cases. By means of mapping, the interaction between space and residents was investigated, specifically how the spatial design of dwellings acts as a cultivator of (thermal) experiences throughout the seasons and how this can limit or increase the need for energy for heating/cooling throughout the seasons. This has led to a resident-oriented theoretical model on the interrelations between resident, dwelling and energy, consisting of a set of spatial (design) factors, sub-factors and properties and their implications on energy demand of dwellings.

For the third sub-objective, a research-by-design study was conducted on 3 of the 6 cases to develop a design approach that increases energy sufficiency in dwellings. The research-by-design study is characterised by an iterative design process of repetitive short-term cycles of analysis, synthesis and evaluation that focus specifically on spatial issues that occur during energy renovation of large, underused single family dwellings. As design support during the research-by-design the conceptual framework and the theoretical model developed in the previous stages were used together with the concept of place-making, as guiding design concepts to better centralize the resident throughout the design process. The design process and instruments that have thus been developed were iteratively tested and fine-tuned in four subsequent design experiments with novice designers (master students in architecture) in which they created designs for energy (-sufficient) renovation of large, underused single family dwellings.

The next section will present the main outcomes of the research process, with a specific focus on the final sufficiency-based design approach for energy renovation.

Findings

Conceptual framework

Application of energy-efficient measures, such as insulation and efficient HVAC systems leads to a decrease in energy demand for heating and cooling, but it also creates new challenges by generating a constant, controlled and static indoor environment (Bosserez, Verbeeck et al. 2017). Therefore, energy renovation of dwellings should lead to optimised and efficient dwellings *as well as* living environments that (1) allow variations in thermal conditions aligned with residents' (seasonal) comfort demand and according to their varying use of the dwelling; (2) respond to residents' (under)usage of dwellings and related fluctuations in their occupation of spaces on a short-term; and (3) are understandable and easy to operate and in which residents have control over the acclimatisation of interior spaces. This could be established by centralize the interaction between residents and dwellings in the design process of energy renovation. In literature different existing design strategies can be found that integrate this valuable interaction and that place residents at the centre of the design (process).

Climate-responsive architecture is a strategy that creates a strong relationship between resident, dwelling and the natural elements by generating dwellings that respond to and exploit climatic conditions in order to increase physical comfort of residents. It thus allows variations in thermal conditions aligned with residents' seasonal comfort demand. There are two main underlying principles that characterise climate-responsive architecture (of temperate climates): (1) a heating principle that collects, stores, distributes and contains heat in dwellings in winter; (2) a cooling principle that protects dwellings from overheating and where heat is extracted in summer. Various measures can be found in literature that relate either to a dwelling as a whole or to components constructing the skin of a dwelling: floor, roof, window, wall (Le Paige M. 1986, Goulding, Owen et al. 1992, O'Cofaigh, Olley et al. 1996, DeKay and Brown 2014, Looman 2017).

Building with adaptive ability is an overarching term for strategies that aim to create a living environment that responds to fluctuations in use and occupancy of spaces occurring on a long-term (e.g. empty nest) as well as on a short-term (daily, weekly, seasonally). For instance, by creating different types of spaces with varying sizes, shapes and/or positions aligned with residents changing needs in occupancy and use of space (Janssens, Bosserez et al. 2016), building with adaptive ability creates a dwelling that is adjusted *to* residents as well as a living environment that allows a more fluctuating way of living *for* residents (e.g. migrating between spaces or retracting/expanding over seasons).

Finally, *User-Centred Design* or Design for All is a design process that integrates residents when designing dwellings and aims to support them when interacting with that dwelling (Abras, Maloney-Krichmar et al. 2004, Herssens 2011). Moreover, a user-centred dwelling can be defined as a designed living environment that is efficient, comfortable as well as supportive towards residents. This way, user-centred design can serve as support to better integrate residents throughout the design process and create a living environment that supports their use and occupation of spaces and enables them to live in a more sustainable manner.

Figure 2 shows how the three design strategies can be applied on different design layers to tackle the design challenges of creating an adjusted environment that enables a dynamic way of living throughout the seasons.

DESIGN STRATEGY	Climate-responsive architecture and thermal architecture	User-centred design process and Design for All	Building with adaptive ability
DESIGN CHALLENGES	1. Living environments that allow **variations in thermal conditions** aligned with residents' (seasonal) comfort demand and according to their varying use of the dwelling	2. Living environments that are **understandable and easy to operate** and in which residents have control over acclimatisation of interior spaces	3. Living environments that **respond to residents' (under)usage** of dwellings and related fluctuations in their occupation of spaces on a short-term
DESIGN LAYERS SKIN	• Orientation, location and materials of **thermal mass** of floor, window, wall, roof • Size, orientation and shadowing of **openings** and location of openings in relation with each other		• **Frame**-concept: skin-related element is permanent/static • **Dynamic** skin-related element (e.g. transformable skin)
STRUCTURE	• **Materiality** of the structure, such as using masonry walls, wooden ceiling, stone floors	• **Materials** of floors, walls,... to guide/nudge residents	• **Frame**-concept: structural element is permanent/static • **Dynamic** structural element (e.g. movable walls) • **Carcass**-concept where structure is fixed

SPACE	• **Spatial organisation** by **locating**, **grouping** and **zoning** of **spaces:**
	  • Heating/cooling zones
	  • Buffer space
	  • Locating outdoor rooms
	  • Clustered rooms
	  • East-West plan
	  • Deep sun
	  • Stratification zones
	  • Location next to cooler/warmer space
	  • Orientation of space: north-side and/or south-side
	• **Shape of spaces:** smaller/larger spaces, closed/open spaces, cocoon spaces
	• **Multifunctional** spaces
		• **Shape of spaces** to guide/ nudge residents	• Differences in **size**, **shape** and **location** of spaces
			• Space is liberate and becomes **adaptable, open, polyvalent** and **multifunctional** because of frame-, carcass-, and infill/support-concepts
			• **Dynamic** space-related element such as flexible (movable) spaces

SERVICES	• **Infrastructure** that serves as a **heater**		• **Frame**-concept where infrastructure/ installations are permanent and static • **Infill and support** that gathers infrastructure/installations in a 'core' • **Dynamic** infrastructure (e.g. adaptable kitchen)
STUFF	• **Materials** of interior design that create **warm** (e.g. carpet) or **cool** (e.g. marble) experiences • **Furniture** that is **heated** or serves as a **heater** (e.g. cocoon-shaped furniture)		
SELVES	• **Migration** between spaces • **Adapted** use	• **Flexible** and **adapted** use • **Simple** and **intuitive** use • Eco-**feedback** • Scripting: **stimulating** sustainable behaviour • **Nudging**	• **Migration** between spaces • **Flexible** and **adapted use** • **Transforming** spaces, structure, skin and services

Figure 2. Overview of design strategies, concepts and measures derived from literature review.

Figure 3 then presents a conceptual framework that connects the different parts of the literature study. The upper part presents on a conceptual level the limitations of energy efficiency and what opportunities energy sufficiency can offer to challenge these limitations, as discussed in the introduction. The lower part shows how designing for energy efficiency creates new challenges and how integrating the above design strategies can support a shift towards a resident-oriented design approach that enables a dynamic way of living throughout seasons. This conceptual framework is further elaborated and concretized based on the resident-oriented theoretical model on the interrelations between resident, dwelling and energy that is presented in the next paragraph.

Resident-oriented theoretical model on the interrelations between resident, dwelling and energy

An active and diverse resident acting on and in a built, spatial and natural environment

The analysis and coding of the exploratory and seasonal interviews following the principles of Grounded Theory led to insights on different levels. Through the *open coding*, we identified residents as *active*, because of their energy-related behaviour. This behaviour includes actions on the dwelling (actions on heating installations, dwelling components and alternative actions) and occupation of the dwelling (duration, frequency, mode, rate and activities). Moreover, we defined underlying drivers for this behaviour, referred to as comfort-related factors: types of comfort (psychological, functional and physical), levels of comfort (positive, neutral, negative) and subjective factors (perceptions, preferences and priorities). Because of these factors, we consider residents not only as active but also as *diverse*. In addition, we determined environment-related factors, ranging between physical, spatial and natural, and define them as affordances and/or cultivators of comfort experiences. Strong interrelations are found between spatial factors and all types of comfort experiences. Furthermore, we found that residents consider their dwelling as a living environment consisting of a collection of in- and outdoor places, opposed to a physical object or a system containing energy.

Figure 3. A conceptual framework to support an alternative energy renovation of (large, underused) dwellings.

Through the *axial coding*, we found interrelations between resident, dwelling and energy and saw that energy-related actions interfere with energy flows and determine end-use energy consumption, and that occupational patterns indicate when, where and how much energy is needed. From a residents' perspective, energy-related behaviour is about reacting and managing comfort, and not only thermal comfort. Furthermore, we found that the residents' behaviour, actions and occupancy, is seasonal and it changes along with variations in experiences of (dis)comfort. Therefore, we argue that the relation between energy and behaviour is more than interactions with heating installations in winter, and that comfort, as an energy service, is the most direct and central link to energy as it establishes the energy demand and drives energy-related behaviour. Moreover, our ethnographic study showed that the energy demand varies throughout the year because of the seasonal dynamisms in residents' different types of experiences of comfort. In addition, the dwelling-related factors shape and cultivate the residents' experiences which in turn, establishe the energy demand and in this way define the indirect relation between the dwelling and energy

Through the *selective coding*, we derived a theoretical model that represents residents' implication on energy demand. Socio-technical energy studies define the relation between residents and energy as residents carrying out single energy-related actions (e.g. opening windows, turning on thermostats) that determine and/or interfere with energy consumption. In addition, they present relations between energy and residents as a linear cause-effect relation (figure 4) in which environment-related and comfort-related factors are both seen as underlying influential drivers of energy-related behaviour (O'Brien and Gunay 2014, Stazi, Naspi et al. 2017). Meaning, the resident is interacting with installations and building components which has an *effect* on the energy consumption, while in turn, that energy-related behaviour is *caused* by comfort-related motivators and underlying drivers (e.g. environment, context, time), (Hong, D'Oca et al. 2015, Lopes et al. 2015).

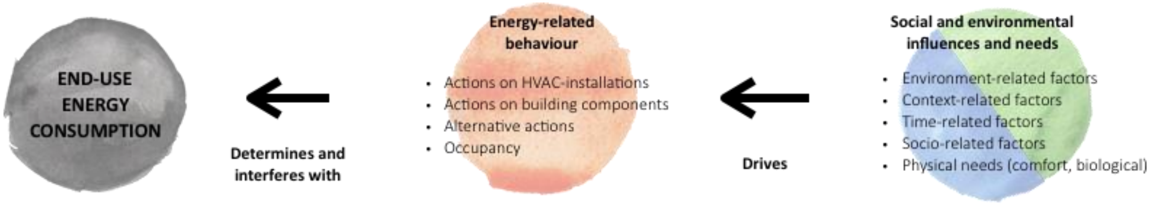

Figure 4. The relation between residents and energy as presented in socio-technical energy studies based on literature (Hong, D'Oca et al. 2015, Lopes et al. 2015, Stazi, Naspi et al. 2017).

However, our analysis showed that residents' behaviour is far more complex and nuanced than carrying out actions that consume energy. The relation between residents and dwellings is closer to a circular process (figure 5) with residents and dwelling being 'interrelated', meaning, residents are shaping the environment and vice versa. More specifically, when residents manage their comfort, they 'transform' their environment, and in turn, that environment acts on residents and then (re)shapes their comfort, that implies a 'continuing process'. Consequently, rather than adopting a linear perspective and defining a cause-effect relation (as e.g. in Lopes et al. 2015), we derive a circular process in which we consider residents, dwelling and energy as 'interrelated' and part of a holistic entity. Moreover, a holistic entity that changes throughout the year and is characterised by seasonal dynamisms. Furthermore, in literature, comfort gains a more centralised position concerning interrelations between residents and energy, however with a strong focus on thermal comfort (Chappells and Shove 2004). As stated by Shove, providing energy for residents is not about consuming energy in its purest form, it is about energy as a service and the outcome of that service, where comfort acts as one example (Shove 2017). Based on our empirical study, we agree and also find that comfort is the central link between residents and energy rather than energy-related behaviour. Nevertheless, exploring their energy-related behaviour remains important as it provides us with insights on how residents manage their comfort which uncovers their comfort needs and if the living environment is cultivating experiences of (dis)comfort.

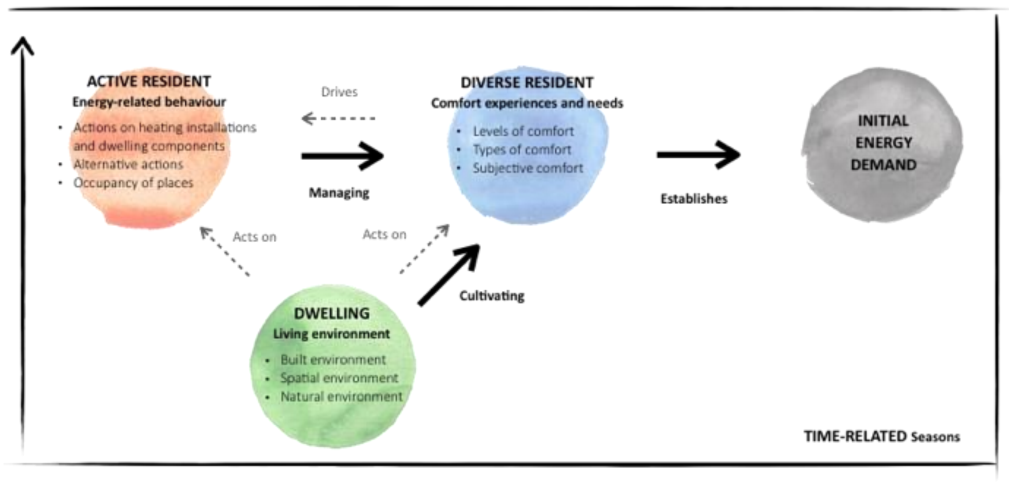

Figure 5. The relation between residents and energy based on data analysis of the empirical studies.

The role of spatial design within dwellings as energy systems while inhabited by dynamic residents

As stated in the previous paragraph, we consider residents as an influential and determining layer (selves) that is part of dwellings as energy systems. But, dwellings are composed of several other 'energy' layers (site, skin, structure, services, spaces), each with their own relation and influence on the energy demand of dwellings. Socio-environmental studies centralise architectural qualities and services that dwellings provide in order to optimise comfort, such as a physical home providing warmth, or an opening affording daylight and circulation. During our spatial analysis process, on the contrary, we centralised the residents' thermal experiences and we focused on how the design of spaces, more specifically, the dimensions, connections and organisation of spaces, acts as a *cultivator* of experiences of comfort rather than only providing comfort, as a service, through its architectural qualities. For instance, a window *allows* the sun to radiate in a space (architectural quality), but it *cultivates* a feeling of warmth in summer or coolness in winter (experience) and in this way responds to residents' thermal needs (comfort service). We argue that architectural elements, that construct physical spaces, can provide warmth (or daylight and so on), but without considering how this quality is *experienced* by a resident, in a certain season and space, we cannot ensure it will provide comfort. Therefore, we believe that *spatial design*, composed of individual architectural elements, not only *affords* certain functions but also *cultivates* experiences (figure 6). We learned from the findings that the lived (thermal) experiences of the residents are not always what is intended by the designers, who often only consider architectural factors as affordances of thermal comfort, not cultivators of thermal experiences. The findings show that when the residents (re)act on their thermal experiences, it can either limit the energy demand or lead to an increase in energy consumption, depending on the link with the spatial design. Therefore, we argue that acknowledging the design of spaces as cultivators of thermal experience is important, especially when determining the energy demand. This because of the potential the spatial design has to limit the energy demand, and thus, it is needed to adopt a resident-oriented perspective by centralising the residents' lived experience when designing.

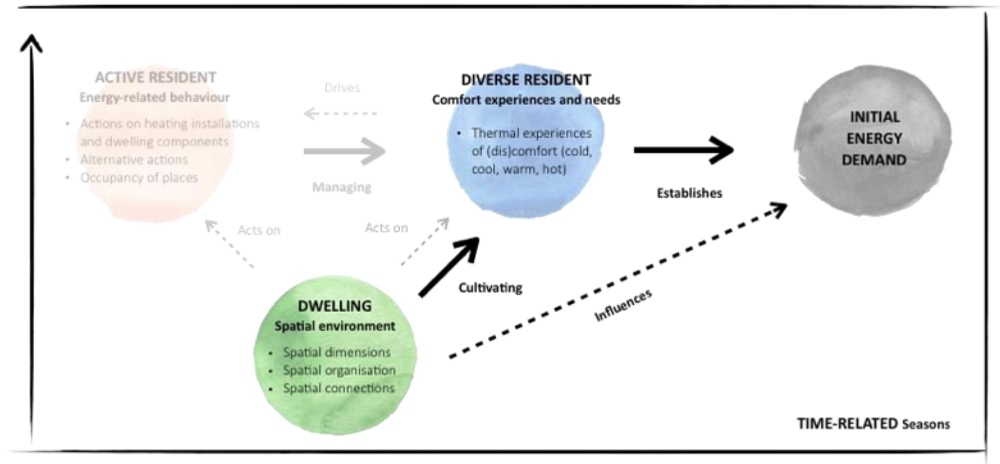

Figure 6. The relation between spatial design and energy demand based on the spatial analysis as part of the empirical study.

Principles, processes and methods to increase energy sufficiency in dwellings

With the conceptual framework and the resident-oriented theoretical model on the interrelations between resident, dwelling and energy as design support, a research-by-design study was performed in which energy renovation concepts were explored for 3 of the 6 cases. This resulted in generic solutions to increase energy sufficiency and in a design process to generate solutions. This approach has been tested in four subsequent academic years by master students in architecture in the context of a design assignment in which they had to redesign a large, underused single family dwelling into a zero energy dwelling. They were provided with different design steps and methods that thus iteratively could be tested and fine-tuned. This then resulted in the alternative design approach that is presented in figure 7. It consists of design principles, processes and methods to support architects to shift towards a resident-oriented perspective for energy renovation and minimise energy use of dwellings by increasing energy-sufficiency.

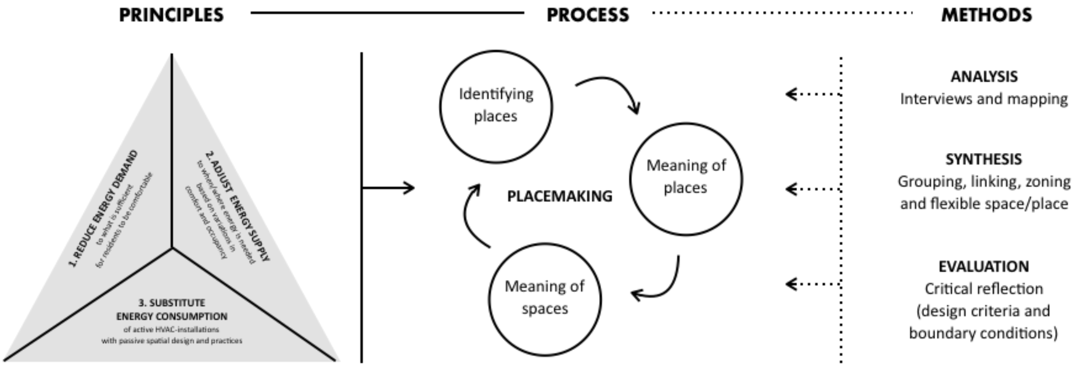

Figure 7. Principles, processes and methods to shift towards a resident-oriented perspective and increase energy sufficiency during energy renovation.

Underlying principles to increase energy-sufficiency

Similar to the principles of energy efficiency known as the Trias Energetica (Duijvestein 1996) three underlying principles, based on the concept of energy sufficiency support the alternative approach:

1. **Reduce energy demand** to what is sufficient for residents to be comfortable. We noticed that residents only occupy smaller areas (places) within existing spaces, which are often dispersed throughout the spatial plan. This leaves a large quantity of space un(der)occupied, especially in large and underused dwellings. By creating a smaller, more compact heated volume with less un(der)used space, the quantity of space, and in turn energy-service, can be reduced to what is sufficient for residents to occupy/dwell in.
2. **Adjust energy supply** to when/where energy is needed based on dynamisms in comfort needs and occupancy. We found that residents have a dynamic way of living throughout the seasons because of variations in comfort needs and fluctuations in occupation of places in time and space. Therefore, the energy needed to be comfortable is not constant but rather varies between places and across seasons. By (only) providing energy when/where it is needed, depending on the dynamisms in comfort and occupancy, the quantity/quality of energy services can be adjusted, and a more sufficient energy demand is established.
3. **Substitute energy consumption** of active HVAC-systems with passive design and practices. Residents' energy-related actions and spatial design both interfere with energy flows. Consequently, both behaviour by residents and design of spaces can increase and decrease the additional use of HVAC-installations. By enabling sufficiency-related behaviour and relying on the design qualities of spaces, existing internal and external energy flows can be exploited and passive practices and design can be stimulated.

A process to shift towards a resident-oriented perspective

To implement these principles while exploring energy-sufficient solutions, the approach includes a three-step-process based on *place-making*. The aim of place-making is to guide architects to create places and design spaces in which the residents' behaviour and experiences is centralised. As place-making draws from a theory of 'experiences, place and space', it supports the integration of residents (selves) and spatial design (space).

A first step in the process is **identification of places** which aims to first explore and then consider residents' energy-related behaviour in places. When identifying places, we explore *functions* and *activities* of places based on which we can distinguish living places with a higher comfort demand (places) from more practical places with a lower comfort demand (non-places). This way, we get to know the amount of space that is occupied and needed for residents to be comfortable, based on which we can reduce the (quantity of) space that is to what is enough. Furthermore, we explore *duration*, *frequency* and *mode* of occupancy in places, based on which we determine if/when energy is needed and/or if more/less energy is needed to be comfortable. This way, we know when and where energy-services are needed and in turn, we can adjust the energy supply to a quantity that is sufficient for a certain place and/or at a certain time. In addition, we explore *actions on HVAC-installations*, *dwelling components* and *alternative actions* based on which we can distinguish active actions that increase energy consumption from passive actions that decrease energy consumption. This way, we can substitute use of active HVAC-installations or existing inefficient behaviour with more sufficient practices.

A second step in the process is establishing **meaning of places** which aims to first analyse and then integrate residents' comfort demand which varies in time and space. We analyse nuances in the *levels of thermal experiences* (cool, warm, dynamic, static) and other types of comfort (e.g. light/dark, open/closed, connected/disconnected) based on which we can determine the quantity and quality of comfort demand in each place and time (e.g. more/less, type of warmth). This way, we gain insight in possible variations in the energy demand to which we can respond by **adjusting** the energy supply to what is sufficient in a certain place or time.

A third step in the process is exploring **meaning of spaces** which aims to first determine positive and negative qualities of spaces and then build on the problems and potentials related to the spatial design. We explore *organisation* (external orientation, stratification, internal position), *dimensions* (size and shape) and *connections* (degree of separation/connection and degree of openness/enclosure) of spaces based on which we can determine the positive/negative qualities of spaces. This way we gain insight in the potentials (cultivating comfort/enabling sufficient actions) and problems (cultivating discomfort/enabling inefficient actions) of the spatial design and build on this to enable (more) sufficient actions, cultivate experiences of comfort and avoid discomfort by means of passive design.

Methods that support a resident-oriented design process for energy sufficiency

We also developed and tested several methods to support architects in each step of a resident-oriented design process for energy-sufficiency, including analysis, synthesis, evaluation.

Methods for the analysis phase to collect, process and analyse data on residents and their interaction with space in an energy-related context. The collection of data is supported by **semi-structured interviews,** a qualitative method, which includes questions on the residents' energy-related behaviour and comfort experiences in each space and throughout the seasons. The interviews can be conducted by means of a guided tour throughout the living environment, with repetitive questions in each place or space. This in order to engage residents with the architectural space they act in/on and to collect more nuanced data because responses vary in each space. To process and analyse the data, we introduce **mapping**, a visual method that shows the collected data on 2D/3D graphic maps of the dwelling. The graphic maps serve as references frames for comparing data on space and the social entity intertwined with it. A wide range of maps can be created on behaviour, experiences and spatial design of each place, for resident and in each season. Based on these maps, we can search for links and patterns on the relation between residents, space and energy.

Methods for the synthesis phase to build on insights gained during analysis phase and find spatial solutions that increase energy-sufficiency. **Grouping of places** can serve as a design method to respond to a dispersion of (un)occupied places throughout the dwelling volume. By grouping places and reorganising them according to the characteristics of occupancy and related energy/comfort needs, a small(er) and more compact heated volume can be created in order to reduce energy demand. For instance, creating a dwelling volume that consists of a group of places located in a compact, heated winter-side and another group of places located in an open, cool summer-side, and in between a buffer space connecting both sides. **Flexible places and spaces** can serve as a design method to respond to residents' dynamic way of living throughout the seasons in order to create a more adaptive living environment that is based on an adjusted energy supply. First, by creating flexible *places*, spaces can be designed that have opposite spatial characteristics and in turn cultivate different (thermal) experiences of comfort between which residents can migrate according to their needs. For instance, a high-ceilinged and large space that cultivates a cooler experience in summer in contrast with a lower and smaller space that cultivates a warmer experience for winter. Secondly, by creating flexible *spaces*, spaces can be designed that residents can adapt and/or change according to their varying comfort needs and fluctuations in occupancy. For instance, spaces with movable walls allow residents to compartmentalise heated places in winter while in summer creating an open floorplan focused on passive cooling. **Zoning and linking of places** can serve as design methods to exploit (existing) internal and external energy flows and stimulate sufficiency-related actions in order to substitute active energy use by passive design and practice. First, by means of zoning, (groups of) places can be strategically positioned in the existing space plan and/or in relation to internal/external thermal conditions. For instance, centralising a group of heated/warm places to which energy is provided in a more constant manner. Another example is thermal stratification that positions places that need to be warm on a higher level in a space/dwelling. Secondly, by means of linking, an open/closed/flexible connection can be created between (groups of) places. For instance, infrastructure (e.g. built-in closets) and buffer spaces (e.g. hallways) that serve as a closed connection between heated and unheated places. Another example is creating an open/flexible connection between two places in order to stimulate cross-ventilation for passive cooling.

Methods for the evaluation phase to reflect on the impact of a design solution on the energy use of a dwelling and residents' comfort experiences. Quantitative evaluation of the impact of sufficiency-based design solutions on the energy use is quite difficult. Therefore, **a qualitative evaluation** scheme with design criteria, boundary conditions and critical questions is developed to serve as a reference frame for a critical reflection by comparing the existing situation or an energy-efficient scenario to the alternative energy-sufficient scenario.

- **Design criterion 1:** The design intervention limits the energy demand compared to the existing situation and/or a design based on an object-centred approach. Example of a question: Does the design intervention lead to heating/cooling a space less often?
- **Design criterion 2:** The design intervention limits the use of active HVAC-installations compared to the existing situation or a design based on an object-centred approach. Example of a question: Does the design intervention cultivate a warm/cool thermal experience by harvesting internal/external passive energy flows?
- **Boundary condition 1:** The design intervention avoids thermal discomfort and possible other types of discomfort. Example of a question: Does the design intervention cultivate a (thermal) experience of comfort that aligns with the residents' individual needs in that place in summer as well as in winter?
- **Boundary condition 2:** The design intervention avoids inducing inefficient behaviour that counteracts the increased sufficiency. Example of a question: Does the design intervention avoid stimulating energy-related actions that bring forth unneeded energy losses and/or gains?

Conclusions

The main objective of this research was to develop a renovation approach that integrates residents' dynamic needs and use of space and decreases the energy use, while still optimising comfort. At first sight it might seem as if the developed approach brings a limited level of novelty as it makes use of well-known architectural strategies such as climate responsive design, which includes passive strategies. However, the design experiments in which we positioned the alternative energy-sufficiency design approach in relation to the current energy-efficiency design approach in various ways, taught us a lot about the limitations of the current design approach as promoted by energy regulations, as well as how both approaches can support each other. In the design experiments we have implemented both approaches in various ways: resident-oriented instead of object-centred, resident-oriented combined with object-centred, resident-oriented versus object-centred. When implemented as separate independent approaches, we learned that the object-centred designer groups were able to increase the energy efficiency of dwellings by implementing high insulation levels and energy efficient HVAC systems, but their design could not respond to changes in (energy) needs of residents. For instance, they often created open floorplans (highly popular in modern dwellings), thus inducing residents to heat the entire dwelling. On the other hand, the resident-oriented designer groups were able to create solutions for an energy sufficient way of living. However, they struggled with optimising the building skin and systems without counteracting the energy sufficient way of living. For instance, they integrated movable walls that enables residents to heat spaces more flexibly, but also added floor heating which jeopardized the first intervention. However, we also found that both approaches can support each other, as they address different design layers. Energy sufficient interventions are mostly related to the spatial design of the dwelling, whereas the promoted energy efficient measures are mostly related to the skin and systems. In the last design experiment, we forced the designer groups to firstly optimise the spatial design of the dwelling based on the residents' needs and the energy sufficient design principles and only after finalizing this, they were allowed to implement high insulation levels and energy efficient HVAC systems, while paying attention not to nullify the effect of the energy sufficient design choices. This led to final dwelling designs with highly reduced floor areas, highly optimised floor plans and highly flexible spatial design, that met both the energy sufficient and energy efficient design principles. Throughout the tutoring of the students and through discussions with architects, we noticed that architects will need educational support and training to gain a deep(er) understanding of limitations and opportunities of 'efficiency' and 'sufficiency', as most energy-related architectural education at this moment is focused on the adoption of an object-centred, efficiency-focused approach. However, as the sufficiency approach brings together well-known and widely applied architectural strategies, such as climate-responsive architecture, architects are capable to increase energy-sufficiency in a dwelling to some extent without fully comprehending/implementing the alternative approach. And from conversations with practicing architects, it appears that, as this approach strongly addresses their skills as designer, it is much more appealing to them than the current energy efficient approach that is promoted by the energy regulations with its strong focus on optimising the energy performance characteristics of the building skin and the systems, which by architects is often perceived as a fully technological approach rather than a design approach.

Finally, it can be seen as a threat that the approach is based on/designed for the renovation of large, underused dwellings. However, there is an opportunity to use (part of) the approach for new built construction, as relevant insights on residents' behaviour and needs can still be gained and integrated in the synthesis phase. Furthermore, the approach is designed to anticipate differences in households which provides the opportunity to apply it to different social profiles. In general, a fundamental aspect of the approach is to respond to changes in residents needs/occupancy by creating a flexible environment, which can be applied on short-term (e.g. seasons) as well as long-term (e.g. life-phases). And, while most resulting designs are developed for a specific household, the solutions are often temporary and/or reversible, and thus can be adapted if the dwelling would be inhabited by a different household.

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