Designing for residents

Building monitoring and co-creation in social housing renovation in the Netherlands

Guerra Santin, Olivia; Boess, Stella; Konstantinou, Thaleia; Romero Herrera, Natalia; Klein, Tillmann; Silvester, Sacha

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Designing for residents: Building monitoring and co-creation in social housing renovation in the Netherlands

O. Guerra-Santin[a,*], S. Boess[a], T. Konstantinou[b], N. Romero Herrera[a], T. Klein[b], S. Silvester[a]

[a] Faculty of Industrial Design Engineering, Delft University of Technology, The Netherlands
[b] Faculty of Architecture, Delft University of Technology, The Netherlands

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ABSTRACT

Large differences between the expected and actual energy consumption have been found in energy efficient dwellings. Research has shown that these differences are partially caused by occupant behaviour. The financing and payback periods of low carbon technologies are often uncertain because of the impact of the occupants on building performance. This translates into a reluctance to invest in deep renovation projects. The goal of this design-inclusive research project is to develop a solution for zero energy renovation that reduces the uncertainty on building performance cause by occupants' behaviour by reducing the uncertainty in design decisions and energy calculations. This investigation focuses on the identification of building type specific occupants and their characteristics, requirements and living practices. This paper presents the user research approach developed for the renovation process. The approach consists of statistical analysis of Dutch households, a monitoring campaign in the area of study and co-creation research through mock-ups, enactments and interviews. Case studies results are presented to highlight the effect of different household types on energy consumption and occupants' requirements, and point at the importance of taking into account household typology and socio-economic characteristics in energy calculations or building simulations, as well as occupant requirements in the design process.

1. Introduction

Renovation of the housing stock is an important item in the agenda of European countries. In the Netherlands, housing associations, which manage approximately 1/3 of the building stock, have set ambitious goals to improve the energy performance of their properties by 2020 [1]. They aim at achieving an average energy label B in the A to G energy performance rating scale, A being the highest. Furthermore, some housing associations are aiming for renovation projects with higher impacts. A number of zero-energy renovation projects have been conducted in recent years [2]. Renovation with a zero energy objective can be achieved through high envelope insulation, air tightness, triple glazing, efficient heating and ventilation systems and renewable energy installations, such as photovoltaic and geothermic. However, recent research has shown that low energy buildings do not always perform as expected [3]. Large differences between the expected and actual energy consumption have been found in dwellings with similar characteristics, some studies have reported a twofold difference [4]. These differences have been attributed to diverse factors such as rebound [5] and pre-bound effects [6], as well as on the interaction between occupants and building technologies [7]. These effects are partially caused by the different household typologies, comfort preferences and lifestyles of users. An in-depth literature review in these topics can be found in [8]. As a consequence of the impact of the occupant on building performance, the financing and payback periods of low carbon technologies are often uncertain; the periods are often longer than initially calculated. This translates into a reluctance to invest in far-reaching renovation projects by housing associations.

To address this issue, the research presented in this paper aims at developing a renovation concept for social rental multi-family housing. The concept consists of four main elements: 1) technical solution, 2) pre- and post- renovation monitoring campaigns, 3) acceptability process, and 4) business modelling. These four elements are integrated into the renovation strategy with the intention of developing a complete approach to building renovation. This paper presents and discusses the user research part of this strategy, which consists of 2) building monitoring and 3) acceptability process. The paper presents the approaches and summarises the results

* Corresponding author at: Faculty of Industrial Design Engineering, Delft University of Technology, Building 32, Landberstraat 15, 2628 CE, Delft, The Netherlands.
E-mail address: oguerrasantin@gmail.com (O. Guerra-Santin).

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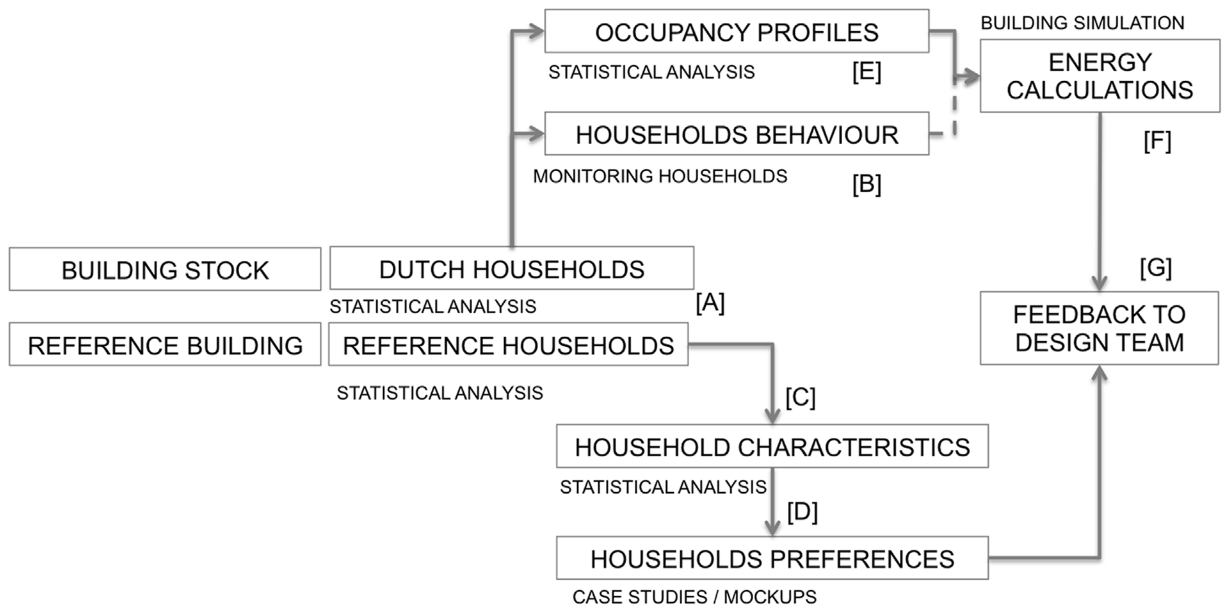

Fig. 1. Research approach.

obtained from case studies in which the approach was tested. The aim of this investigation is to contribute with a combined approach to replicate in actual renovation processes. The methods as well as results are reported in more depth elsewhere. The overall renovation strategy is further explained in [9], the technical solution in [10], the building performance in [11], and the business modelling in [12].

The technical solution consists in the façade system to be manufactured off-site and added to the buildings. Although, the description of the technical solution is out of the scope of this paper, it is important to mention that it presents challenges for tenant participation: standardization of design and home systems will create a technically and financially feasible design, but raises the question about the choices tenants would have for their specific building.

Pre- and post- renovation monitoring campaigns are intended to assess and improve the performance of the buildings. The renovation performance target has been defined as 'zero on the meter' (NOM). In the Netherlands, the concept of zero on the meter (nul-op-de-meter) is defined as a building (usually social housing renovation projects) in which the yearly building-and user-related energy consumption equals the generated renewable energy in the building and surrounding area, for example with Photo Voltaic panels on the roof [2]. The concept is based on residential buildings with 'standard' occupancy defined in Dutch norms [2]. However, actual occupancy patterns and their effect on energy consumption are currently not reflected in the 'standard' occupancy patterns defined in norms and simulation tools. Therefore, the achievement of energy targets defined by the concept (NOM) is uncertain. In addition, there is still uncertainty about the causes of rebound effects [7].

The acceptability process consists in the early involvement of the tenants in the renovation process so that they can give an input that can render the project acceptable to them. In other words, this is a participation process. Part of acceptability is that the process serves to enable tenants to understand and consider the new systems and solutions in their homes. In the Netherlands, 70% of the tenants in a building must agree on the renovation process, for it to be performed. This is not always achieved [8]. Additionally, if a renovation does go through, rebound effects often occur afterwards, meaning that the actual energy consumption is higher than predicted in calculations [13]. The reasons are still unclear, but are presumed to lie in residents' post-renovation behaviour and interaction with their home systems [14]. The current literature on good communication processes with tenants presents well-developed processes emphasizing open and timely communication, financial security, and a reliably scheduled and brief renovation process [15]. Breukers et al. [15] concur that a careful process of resident participation ahead of renovation would improve acceptability. However, the current literature on processes lacks a focus on daily living practices of tenants, both pre- and post-renovation, although these may affect energy use (pre-bound and re-bound). The acceptability research therefore adds this element by starting from the meanings that people attach to their home [15], to enable residents to find their own motivation for the renovation and to be open to the new experiences it brings.

A new business model is required for this renovation concept in order to implement and upscale the solution. Housing associations have only a limited budget to invest on their portfolio, and so, for a deep renovation, extra investments are needed. The business modelling seeks to find the best solution for the investment in the new technologies, taking into account market and occupancy uncertainties.

The third element of the approach is the acceptability process and consists of two parts: firstly, working towards the go-ahead from tenants, and secondly, reducing uncertainty about tenants' pre- and post-renovation lives with their home and its systems. The first part responds to a regulation in the Netherlands that states that a renovation process cannot start unless 70% of the tenants within the project scope give it the go-ahead, in other words, accept it. This go-ahead is by no means always achieved [8]. Consequently, there is Dutch literature on good communication processes with tenants, presenting well-developed processes emphasizing open and timely communication, financial security, and a reliably scheduled and brief building period [15]. However, the well-described processes [15] lack a focus on pre- and post-renovation daily lives of tenants although, as mentioned above, these may affect energy use (pre-bound and re-bound) and expected energy savings are not achieved [2,7,13]. The second part of this acceptability process therefore seeks to engage tenants in inquiry into their pre- and post-renovation interaction with their home and its systems, of which not much is known [14]. As Strengers [16] argues, such practices are not only economic-rational, but consist of fine-grained networks of routines co-shaped and managed with certain

Table 1
Scales, topics and instruments used in the different research methods.

	Scale	Topics	Instruments
Case studies (Study of target households in similar neighbourhoods)	Urban/ neighbourhood	Acceptability of renovation process Target user practices and behaviour at home	Interviews Questionnaire surveys Observation Iterative interventions
Mock-ups (Prototypes of systems and building elements)	System/element	Interaction user-system or user-element Liveability	Interviews Observation Iterative interventions
Monitoring case studies	Dwelling unit	Thermal comfort preferences Occupants' behaviour Heating practices	Monitoring campaigns Measurements Interviews Self-reported data
Statistical analysis	Nationwide	Occupants' behaviour Household typology	Statistical analysis of Dutch dataset

competence by diverse householders and the home systems. The complexity of these practices, combined with the technical complexity of a building, result in the need for an in-depth participation process. It should start from people's experience of their home and what they do in the home daily and why [14,16]. In this research project, seeking acceptability of the concept consists of a) seeking the tenants' go-ahead for the renovation (this process is presented elsewhere [9]), and b) establishing design choices with tenants. The design choices, to be established, should later be open towards tenants' co-shaping of their home experience with the building and its systems. Many sources concur by now that this co-shaping should result in energy savings more naturally than through self-discipline via feedback systems [17,18]. Both the monitoring research and the design choices part of the co-creation research are about the dwelling and its systems, so this overlap will aid our later discussion of how they inform and enrich each other.

This paper presents the two parts of the user research to identify and reduce the uncertainty in building performance. The monitoring research focuses on the quantitative identification of building type specific occupants and on the investigation of their characteristics and requirements to inform the design and the energy calculation process, combined with qualitative interviews to understand household practices. The co-creation research focuses on the qualitative elicitation of user requirements for design choices using mock-ups and enactments. The paper summarises the findings of the quantitative and qualitative analyses. The discussion addresses how the user research unites the possibilities of automated data collection with the insights that tenants themselves develop through engagement with old and new home systems, and how these two ways of gaining insight can strengthen each other.

2. Approach

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

A Performance gap. The objective of this research is to identify and reduce the uncertainty related to the effect of occupancy. By reducing the uncertainty on calculated energy savings, created by differences in occupants' behaviour and household typology, we can also reduce the uncertainty in the estimation of return of investments.

B User-building interaction. This research aims at reducing uncertainties by integrating user-centred research as an instrument to feed back requirements to designers. Additionally, designers can implement better interfaces and solutions, and help users to understand and interact with the new technologies.

Thus, this paper presents a user research approach using diverse methods and serving two related goals: to determine the effect of household typology on the zero energy concept, and to integrate user practises and requirements into the design of solutions. Three types of studies are presented: 1) quantitative analysis of nationwide statistical data to determine occupants' behaviour and household typologies prevalent in the neighbourhoods to be renovated, and to calculate energy demand, 2) mix-methods analyses of pre-renovation monitoring campaigns to determine occupancy practices and thermal preferences, and 3) qualitative investigation on how tenants experience buildings involving user requirements elicitation from enactments with full-size mock-ups of window areas and mechanical ventilation.

Fig. 1 shows the approach and research techniques used in this investigation. Statistical analyses were used to determine household typologies and the socio-economic characteristics of households more likely to inhabit the reference building [A] a typical example of the post-war industrial build social housing stock. Based on the household typology, monitoring cases were studied to determine the specific behavioural patterns of the monitored households [B]. In addition, based on the reference socio-economic household characteristics [C], qualitative studies were carried out to determine user requirements [D]. Occupancy profiles were statistically defined [E] to calculate energy demand with building simulations [F]. The results from the energy calculations and household requirements were fed back to the design team [G]. Table 1 shows the research methods followed according to the scale in which they were carried out, the topics studied, and the instruments used. The statistical analysis of household typologies and occupants' characteristics as well as the monitoring studies are introduced in Section 4. The co-creation studies with mock-ups to understand occupants' practices in the reference building are presented in Section 5. Sections 3–5 summarise the findings from the quantitative and qualitative studies. For more detailed information about the individual research approaches, see [9–12,19–21]. The integration of the methods into the design process is explored in Section 6. A discussion and conclusions are presented in Section 7. Following sections introduce the reference building and reference households, central concepts on this study.

3. Effect of household typologies on performance

The proposed approach has been developed to be applied to specific renovation projects, since every building is different, both in terms of construction and occupants. To develop the approach, the research was based on a reference building and reference households. The selection was the result of building stock and household's typology research, as described below.

Fig. 2. The reference building.

3.1. *The reference building*

The target group for the present investigation are the massively built post-war, porch apartment blocks (portieketagewoning) in the Netherlands. 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 period 1946–1974 more than 2 million dwellings were constructed

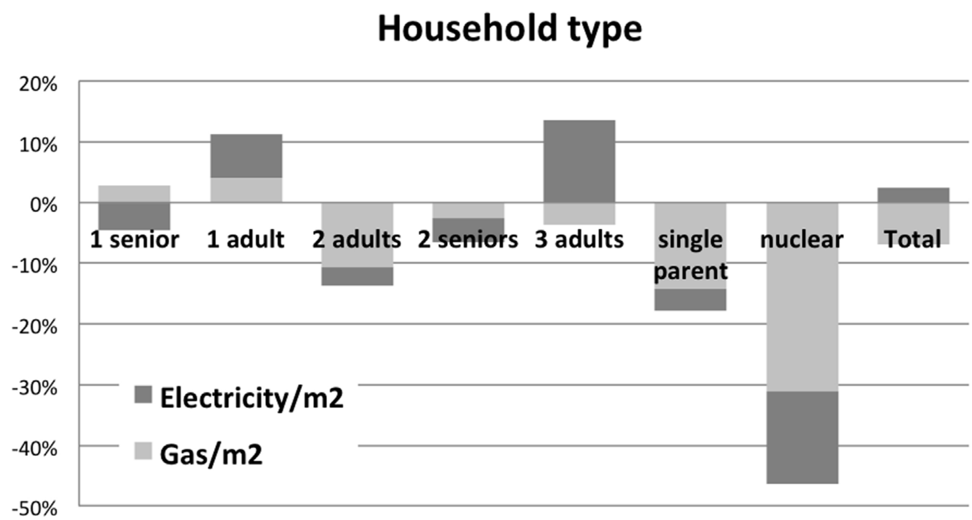

Fig. 3. Percentage of increase/decrease on energy consumption in the reference building in comparison to the total Dutch building stock.

Table 2
Energy consumption per household type (in kWh) for the building stock and for the reference building.

	Gas kwh		Electricity kwh	
	Reference	All	Reference	All
Single senior	10874	14858	1724	2162
Single adult	10450	12800	1837	2341
Adults couple	11583	16437	2338	3479
Seniors couple	12131	18335	2342	3358
Three adults	13037	18704	2726	4681
Single-parent	12976	15362	2405	3194
Nuclear family	13183	18166	2773	4309

in the Netherlands, which account for approximately one third of the residential stock. These buildings were generally poorly insulated at the time of construction and they are in need for renovation [22].

About 15% of the post-war construction was carried out in a precisely defined, modular system that was replicated for thousands of buildings. The system is characterised as non-traditional and industrialised, because prefabrication, new materials and ways of constructions were predominant [23]. However, dwellings that were not constructed with industrialised systems still show a high degree of similarity in terms of material, techniques and layout [24]. The most important building characteristics that can determine the refurbishment strategy include floor plan layout, location of utilities spaces, balcony type, wall construction, connection with the slabs, and window-to-wall ratio.

Next to literature research, an on-site investigation was carried out in the area of Rotterdam-Zuid. Through observation and documentation, different building types were categorised in terms of wall, window, roof type, balcony location, the existence and construction type of the parapet, and staircase location. 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 and have typical characteristics found in the building stock analysis.

The features of the reference building are: a mid-rise apartment block with central staircase and access in the front façade leading to two apartments per floor. The construction is characterised by massive walls with reinforced concrete slabs, brick cladding with cavity and no/little/out-dated insulation, large windows incorporating lightweight parapet and continuous floor slabs in the balconies. The floor plan and pictures of the reference building are shown in Fig. 2.

3.2. Household typologies

Energy consumption in dwellings is affected by household demographics (age, gender, household composition), socio-economic level (education level, income), and lifestyle (retirement, full-time work, unemployment) [7,20]. For example, two one-person households with similar income can still have very different energy consumption levels because of age, background, employment status and health condition.

Therefore, household typologies have been defined through analysis of the Dutch building stock. The definition of the household more likely to reside in the reference building is particularly important in renovations aimed at social housing, where it is likely that the occupants hold special socio-economic characteristics in comparison to a national sample. These characteristics, such as income, employment status and background could have an effect on energy consumption and occupant behaviour. In addition, targeting a specific solution to a specific type of user can increase the acceptability of the project, because it will fit residents' needs. For example, the design of window areas could be varied depending on how much view of the street residents prefer. Additionally, it would help designers to make choices regarding the most suited solution for the renovation, and regarding which building choices to offer to the residents.

The information on household types will allow us to 1) calculate more accurately the expected energy consumption in the building, and 2) direct design decisions (for example, user-building interaction based on lifestyle).

For the determination of the reference households, the WoON dataset was used. This dataset is based on a nationwide survey carried out by the Dutch Ministry of the Interior and Kingdom Relations (BZK) and includes information regarding household composition, housing needs, energy consumption and building operation. The dataset contains the compilation of 4800 dwelling audits and over 69,000 household questionnaires, which are also linked to external data [25].

The most common household types on a national level were first 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 on energy consumption [26]. These households are: single senior, sin-

Table 3
Reference households – social economic variables and results chi-square and *t*-tests.

Chi-square and *T*-test results		
Education level (highest in household, including current level)	Low education LBO MAVO-MULO-VMBO HAVO-VWO-MBO HBO-University	χ^2 (5) = 493.6, p < .001
Ethnicity	Autochthone At least 1 western At least 1 non-western	χ^2 (2) = 990.5, p < .001
Religions and beliefs	(Roman-catholic, Protestant, Reformed church, Islam, Hindu)	χ^2 (9) = 675.7, p < .001
Health condition	Poor health condition Good health	χ^2 (4) = 427.8, p < .001
Health long-term illness, disease, disability	Poor health condition Good health	χ^2 (1) = 107.8, p < .001
Income	Continuous variable – Euro	t(3487.7) = 68.48, p < .001 all M = 55842, SD = 44825 reference M = 29256, SD = 16466
Working at home	Interval variable – frequency	χ^2 (1) = 153.1, p < .001
Lifestyle – frequency contact with friend	Interval variable – frequency	χ^2 (4) = 47.9, p < .001
Lifestyle – frequency contact with family	Interval variable – frequency	χ^2 (4) = 49.7, p < .001
Lifestyle – frequency participation in clubs	Interval variable – frequency	χ^2 (4) = 267.3, p < .001
Lifestyle – hours TV per week	Continuous variable – hours	t(2341) = 12.26, p < .001 all M = 15.44, SD = 11.4 reference M = 19.17, SD = 14.2
Lifestyle – hours sports per week	Continuous variable – hours	t(2375.6) = 2.66, p < .01 all M = 4.60, SD = 5.9 reference M = 4.23, SD = 6.4

gle adult, seniors couple, adults couple, three adults, single-parent household, and nuclear family [20].

To investigate household typologies and their effect on energy consumption in the reference building, the WoON dataset was split into a sub-dataset containing only the cases of buildings similar to the reference building. The sub-dataset contains 2194 cases.

Two analysis of variance tests were carried out to determine the differences on energy consumption for different households. The first test was carried out in the complete WoON sample, and the second test on the reference building sub-sample.

The results of the national sample test showed that gas consumption ($F(6,16080) = 659.1$, $p < 0.001$ welch statistic), and electricity consumption ($F(6,16059) = 3054.8$, $p < 0.001$ welch statistic) are statistically significantly different for all types of households. Posthoc tests showed that there were differences between all household types for electricity, and between all but the following for gas: single senior and single parent, seniors couple and three adults, and seniors couple and nuclear family.

The results of the reference building sub-set 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 also statistically significantly different for different types of households. Posthoc tests showed that there were differences between all household types for electricity but the following: adults couple and seniors couple/single parent, seniors couple and single parent, and 3 adults and nuclear family. Posthoc tests for gas consumption showed differences for all but the following: single senior and single adult/adults couple, senior' couple and adults couple/3 adults/single parent, 3 adults and adults couple/single parent/nuclear family, and single parent and adults couple/nuclear family. Table 2 shows the energy consumption per household type (in kWh/m2) for the building stock and for the reference building.

Fig. 3 shows the differences (in percentage) on energy consumption between households living in the reference building in comparison to all Dutch households. The differences on energy consumption among the household types in the reference building are not as large as in the national sample, and the energy use tends to be lower in the reference building (with two exceptions: single households and three adult households). These results suggest that the effect of household type may be smaller in the reference building than in other building types. The reasons might be that the households in these apartments tend to have lower incomes.

To determine the prevalence of specific types of households in the reference building, a Chi-square test was used. 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', 'nuclear family, "two adults" and 'two seniors' ($\chi2(6) = 1231.97$, $p < 0.001$). In the following sections, we further explore the effect of household typology on energy demand.

4. Effect of occupants on building performance

In this section, we present the results of the investigation on the effects of household typology and occupants' behaviour on energy performance. Firstly, we investigate the socio-economical characteristics and lifestyles of the reference households. Based on these characteristics, the case studies of further sections were selected. As a second step, we briefly introduce the household profiles defined statistically for the Dutch population, and use the resulting heating and occupancy patterns as input for building simulations. Further, a occupancy monitoring campaign was carried out in the area of study (Rotterdam) to further understand occupants' behaviour and heating practices on households with determined characteristics. From the monitoring campaign, heating and occupancy profiles were defined for each household, and compared to the statistical

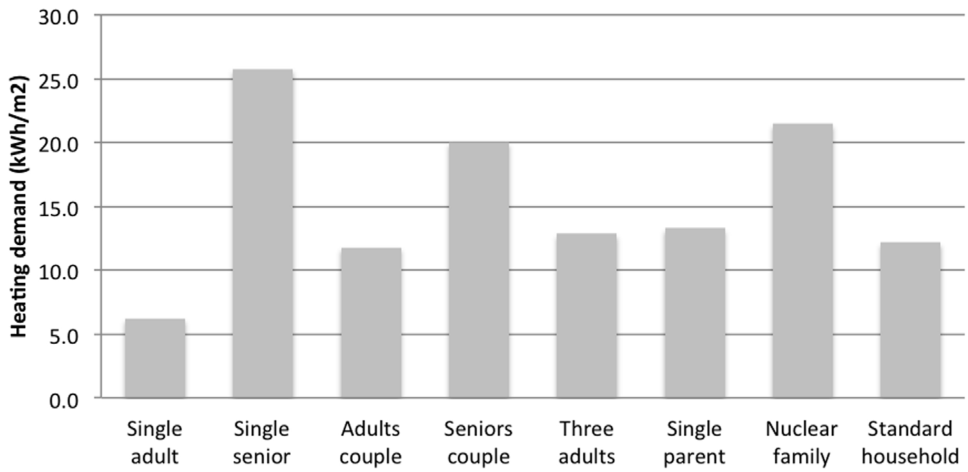

Fig. 4. Heating demand per household (kWh/m^2).

Table 4
Socio-economical characteristics of households in the reference building.

	More likely	Less likely
EDUCATION	Lower education	Higher education
LAND AND ETNICITY	Non-western background	Dutch background
LIFESTYLE	To watch more hours TV per week	To work at home To spend time doing sports Less likely To have frequent contact with family and friends To be part of a club
HEALTH CONDITION	To have poor health condition To suffer a disability	
RELIGION	Islamic, Hindu	Roman-catholic, Protestant, Reformed Church

Table 5
Dutch household profiles.

	Comfort (evening) temperature (°C)	Setback (night/absence) temperature (°C)	Average day temperature (°C)	Radiators bedroom	Radiators others
Single senior	24	21	22	Semi-open	Semi-open
Single adult	17	10	13	Semi-open	Closed
Adults couple	20	15	18	Semi-open	Semi-open
Seniors couple	23	19	20.5	Semi-open	Open
Three adults	20	16	18.5	Closed	Open
Single-parent	20	15	18	Open	Closed
Nuclear family	20	16	18.5	Open	Semi-open

profiles. The integration of these results and their feed back to the design team is presented in Section 6.

4.1. Reference household characteristics

To identify the characteristics of the reference households beyond composition (household size, age and presence of children and seniors), Chi-square tests were performed to identify other socio-economic characteristics. The WoON sample was split into reference building and non-reference building with the previously mentioned building characteristics. With the Chi-square tests we investigated whether certain social and economic characteristics would be more likely to appear in the households living in the reference building. Chi-square tests were also used to determine the lifestyle of the households living in the reference type building and to determine the presence at home and other habits that might be useful to define occupants' profiles. The variables used in the statistical analysis are shown in Table 3.

The results of the statistical tests are shown in Table 3. The households in the reference building are more likely to have lower education, a foreign background, have contact with friends less often, participate less often in activities outside the home, sport less often, have a non-Christian religion, have a lower health condition, and be less likely to work at home compared to households in other type of buildings. We can therefore conclude that we are more likely to find minorities and elderly people in the reference building (Table 4). These characteristics should be considered for energy calculations as well as in the selection of low carbon technologies such as ventilation systems and their interfaces.

4.2. Effect of household typology on energy demand

Building simulations are used, during the design process, to calculate the energy demand of a building, and to size the installations. Building simulations have however, shown large differences in comparison to observed energy consumption [27]. One of the

Table 6
Main characteristics monitored households.

	Dwelling 37	Dwelling 38	Dwelling 39
Type of dwelling	Semi-detached	Semi-detached	Semi-detached/conversion (old church)
Size	88 m^2	96 m^2	117 m^2
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

Table 7
Main characteristics of participants in ventilation study.

Participant	Age	Gender	Important aspects	Background	Household size	Building characteristics	
1	50+	Female	Environment, costs, control	NL	1	Porch building	Central heating
2	60+	Male	Health	NL	1	Porch building	Central heating
3	50+	Male		NL	1	Porch building	Central heating
4	50+	Female, male	Health Comfort	Indonesian-NL	2	Porch building	Central heating
5	±25	Male	Safety	NL	3	Porch building (previously)	Central heating
6	±25	Male, female	Habits, usability, safety, ease	Moroccan	2	Two-under-one-roof dwelling	Central heating
7	±25	Female	Different requirements	Turkish (raised in NL)	5	Gallery building (four levels)	Central heating
8	±25	Female	Ease, value	NL	2	Porch building (owner)	Central heating

reasons for the differences has been attributed to the standard occupancy profiles usually employed in practice [28].

In this section, we define statistically Dutch occupancy and heating profiles that better reflect the use of building systems.

Occupancy and heating profiles per household were defined using factor analysis and ANOVA tests [20]. The statistically defined household profiles can be used in initial stages of the renovation design process, or when information about prospect residents is not available.

Building simulations with Bink software [29] were carried out based on the reference building for each of the seven household typologies defined in Section 3.2: single senior, single adult, adults couple, seniors couple, three adults, single-parent household and nuclear family. The main information from each household profile used in the building simulation software can be found in Table 5. The results from the building simulations can be seen in Fig. 4. The results show large differences on the heating demand of different households. For example, single adults' heating demand is one fourth of the heating demand of single seniors, while the heating demand of a single-parent household is half the demand of a nuclear family.

4.3. Effect of socio-economical characteristics on heating practices

The statistically defined profiles from the previous section were based on a national sample, and thus, they might differ from the patterns occurring in the reference building caused by the specific situation of the household. In this section we investigate the effect of socio-economical characteristics and thermal comfort preferences on heating patterns. We define heating patterns as the thermostat and radiators settings for every hour on a standard week, as well as the specific practices that the occupants follow to either save energy or manage indoor temperatures at home. For this analysis, we employed monitoring data from a campaign carried out in the region of study (Rotterdam). In addition, with this analysis, we seek 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.

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 University database 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 6 shows the main characteristics of the three monitored households and dwellings. Detailed analysis and results from the monitoring campaign, based on the monitoring data collection and analysis in [30,31] are reported in [21].

For the monitoring process, a mixed methods approach was used, which consisted in the use of quantitative data from building monitoring, and qualitative data from interviews with the residents.

The Mixed Approach for Sustainability Labs [32] is used to investigate pragmatically, the technical and social aspects of practices

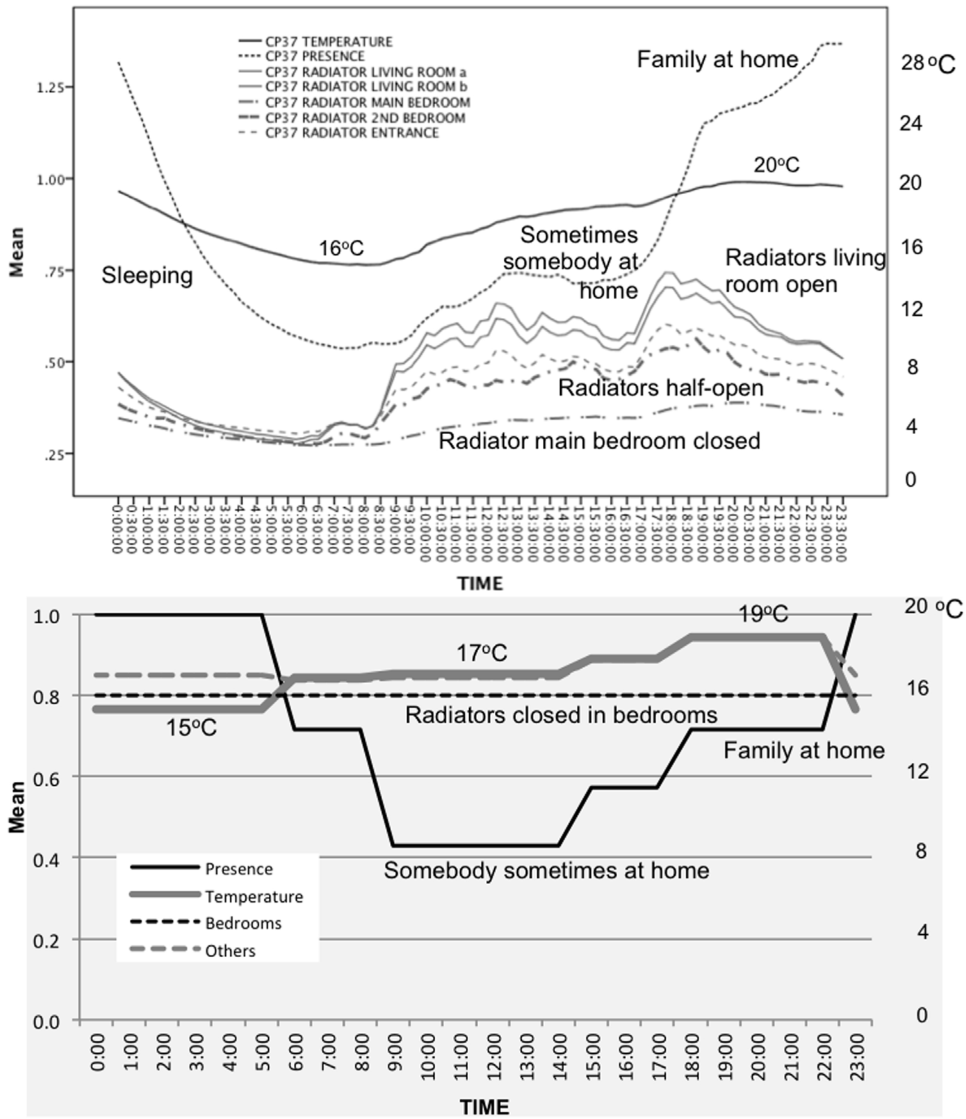

Fig. 5. Occupancy profile for Dwelling 37 and statistical profile for three-adults-household.

in qualitative and quantitative manners [33–36]. The methods can be integrated at different stages in the research process including data collection, data analysis and data interpretation. Qualitative and quantitative data can be mixed in three different ways: by connecting (having one data type build on the other), by merging (to compare or relate results from both data types), or by embedding (to explain one data type results by the other) [32]. In the building monitoring process, the qualitative analysis is embedded within the quantitative analysis to explain and validate the occupancy and heating patterns derived.

For the monitoring campaign, 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 [21], with which the occupants could self-report their thermal comfort on the seven-level ASHRAE comfort scale. 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. This technique is a situated and embodied 'telling' activity that enables users to participate in understanding and communicating their daily practices [37].

Occupancy and heating patterns were created for the three households. These patterns show the thermostat setting, the thermostat setback setting, the radiators' setting in different rooms, and the presence of the residents and home. The patterns are shown in Figs. 5–7 (top).

The results from the analysis of the self-reported thermal comfort votes showed that the occupants' thermal comfort does not always correspond to actual indoor parameters (indoor temperature and relative humidity). The average comfort votes in the houses were: 4.1(father) and 3.7(mother) for a mean temperature of 18 °C in Dwelling 37; 3.3(father) and 3.3(daughter) for a mean temperature of 21.6 °C in Dwelling 38 and 4.7(father) and 4.8(mother) for a mean temperature of 18 °C 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. The contrasts is on the difference in the average temperature in Dwelling 38 (21.6 °C) when compared to Dwelling 37 and Dwelling 39 (18 °C). This indicated that the occupants in Dwelling 38 prefer warmer temperatures.

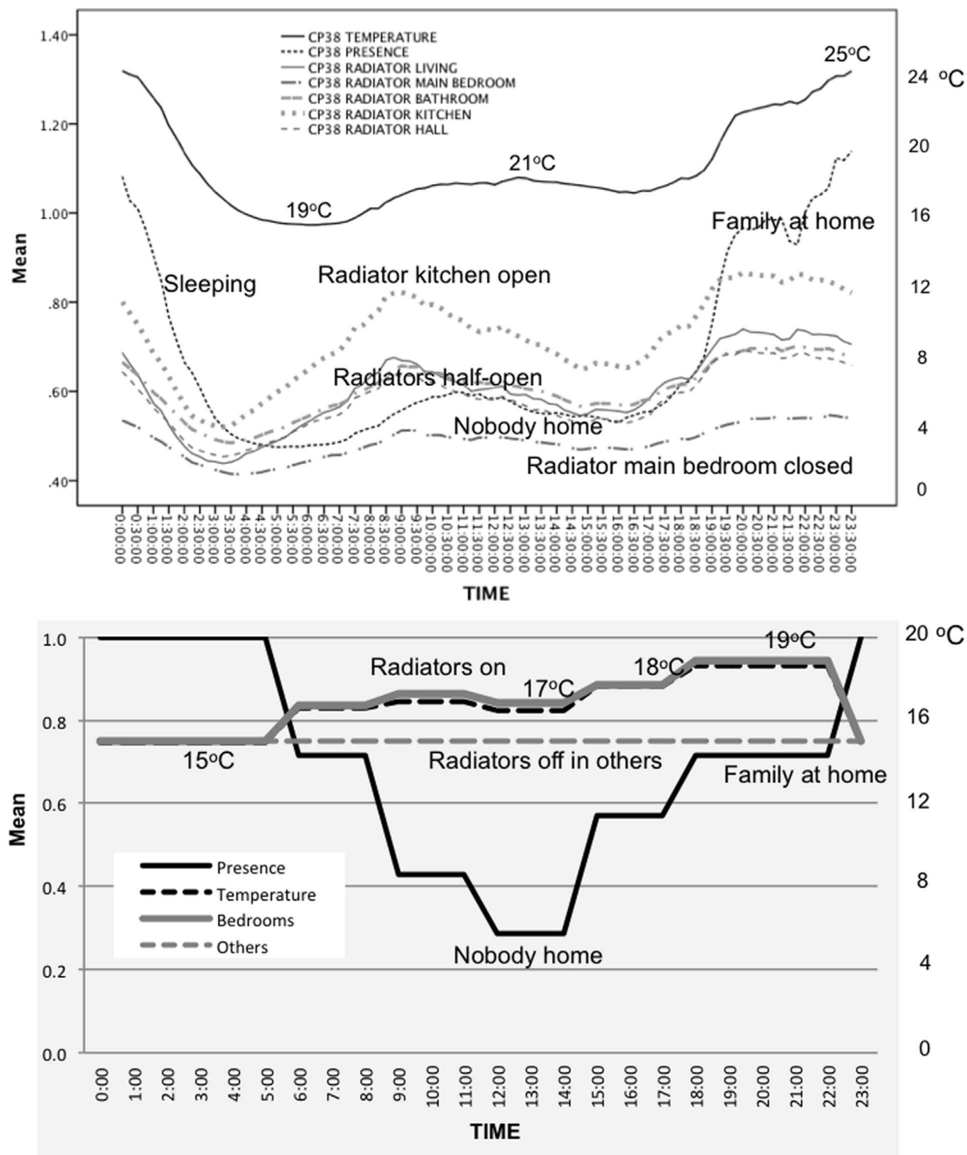

Fig. 6. Occupancy profile for Dwelling 38 and statistical profile for single-parent household.

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 Dwelling 37 and Dwelling 38 could be partially attributed to the activity and clothing of the occupants. In Dwelling 37 the residents reported using extra clothing and sofa throws to keep warm.

These results highlight the importance of taking into account actual household characteristics and behaviours on energy calculations. The analysis showed that the three households have different occupancy, heating patterns and thermal comfort preferences. Nuclear households in Dwelling 37 and Dwelling 39 have similar comfort preferences but their occupancy patterns are different given the differences on daily schedules. The single-parent household Dwelling 38 showed different thermal comfort preferences than the other two households.

4.4. Average household profiles vs. monitoring profiles

The occupancy and heating profiles obtained from the monitoring campaigns were examined next to the household profiles previously defined through statistic analysis of a Dutch national sample. The comparisons are shown in Figs. 5–7.

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 Dwelling 38. Although the presence at home is similar, the temperature preferences are much higher in the monitored household. Small differences were found in the comparison between Dwelling 37 and the *3 Adults* household profile. The monitoring profile shows slightly higher temperatures (1 °C), but the radiators in kitchen and halls were only half open. The comparison between Dwelling 39 and the *Nuclear* household profile showed similarities in presence, thermostat setting (temperature in living room) and use of radiators.

The differences observed in Dwelling 38 could have a significant effect on energy demand. These results highlight the importance of taking into account thermal comfort preferences in the building simulations.

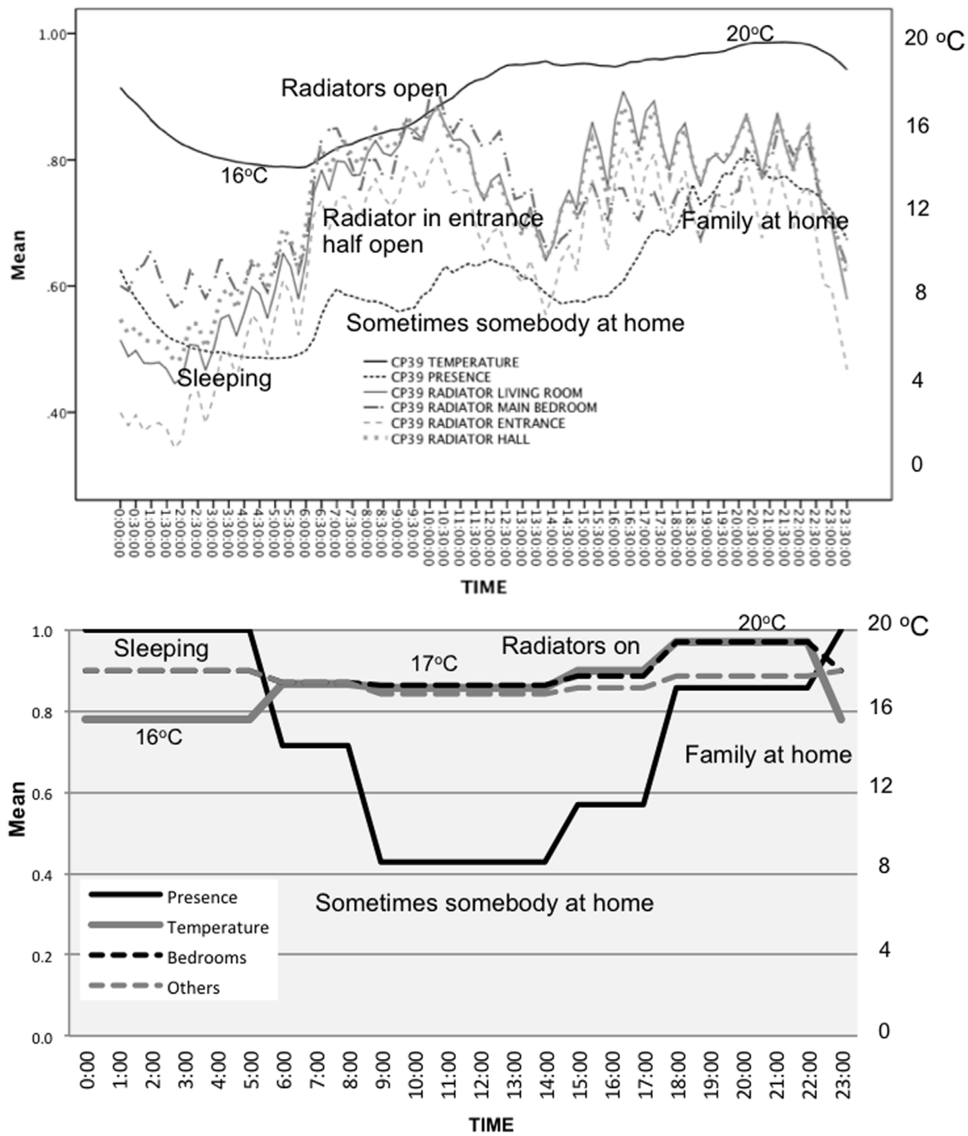

Fig. 7. Occupancy profile for Dwelling 39 and statistical profile for nuclear household.

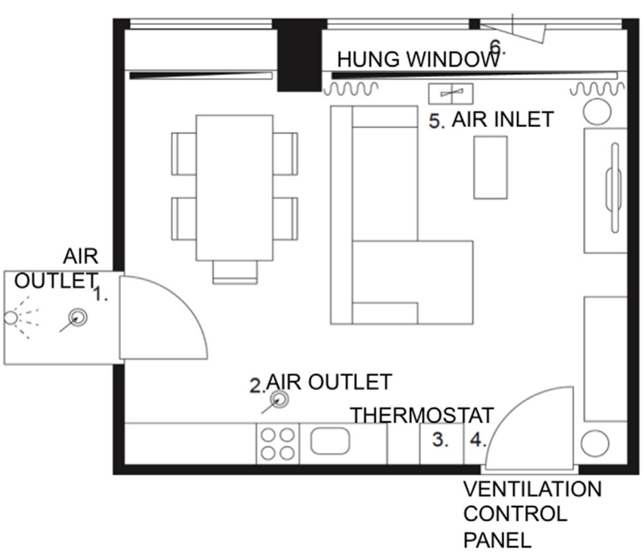

Fig. 8. Mock up of a flat in an experiment space.

5. Co-creation research

Household practices and user interaction with the building and its systems affect energy consumption [14,38]. Balcony and window areas and mechanical ventilation were taken as two examples to explore in adapting the building design to users' needs, based on earlier indications of their importance for the users' wellbeing [19]. For example, windows provide light, social contact, noise protection etc., while mechanical ventilation provides management of air quality, but its interfaces and functioning are sometimes incomprehensible to users [19]. These two building elements are explored via enactment-based user experience research with contextualised elements of the home design in a full-size mock-up. The research investigates tenants' expectation of their home life experience. The research further seeks indications of how tenants define their home experience, which could be formalised and facilitated in a renovation process. The outcomes of this research are intended to support tenants in living pleasantly at home while also saving energy. The life quality notion of 'pleasantly' was adopted as a basic quality. It served to be attentive to the participants' experience and to analyse the data at a deeper level than a functional user-system interaction perspective [16]. The research was a co-creation study, specifically

Fig. 9. Air inlet simulated with a fan hidden in a crate.

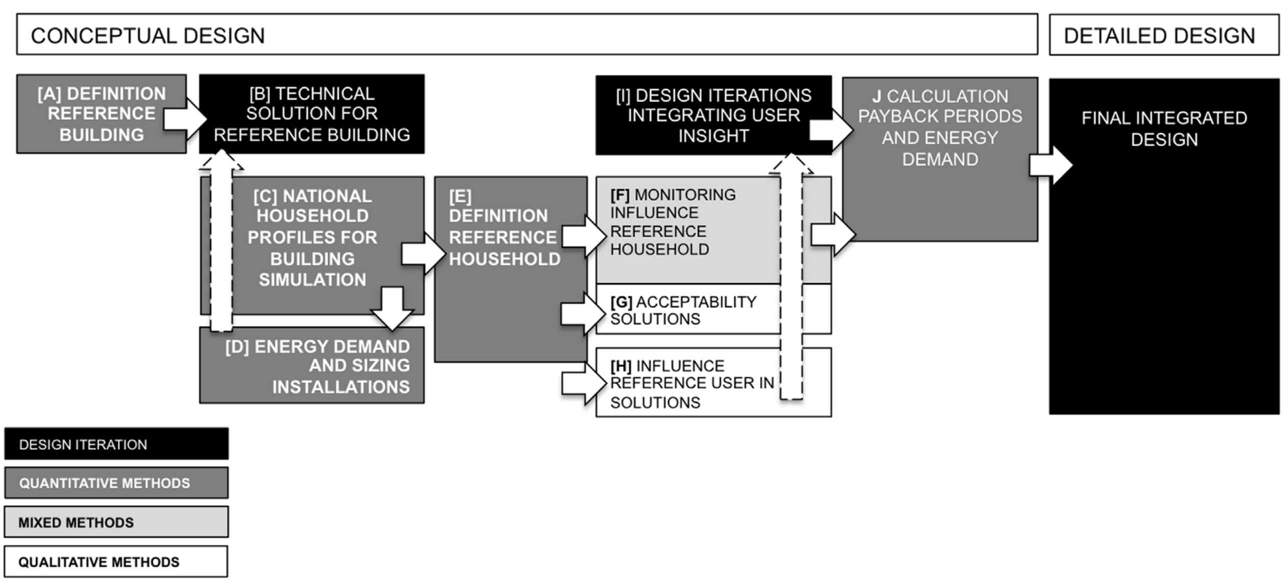

Fig. 10. Approach to integrate user research results to design process.

a co-design study, which in this context means 'the creativity of designers and people, not trained in design, working together in the design development process' [39]. To enable participants to take part from their own experience and perspective, the study took the form of a role play enactments study [37,40–42]. In this method, participants are asked to enact and explore their existing and possible practices in scenarios while being asked to 'think out loud' for communication with the researchers. This technique enables researchers to observe and react to participants' actions and reasoning while supporting participants in immersing in scenarios that are realistic for them. Life experiences should be studied in as realistic a context as possible because product use is situated: it unfolds in ways that people cannot fully analyse or re-tell outside of context [43].

5.1. Mock-up and enactments

A mock-up flat was created at Delft University of Technology, consisting of an interior space furnished as a flat and in which parts of a new window situation and ventilation system were simulated

(Fig. 8). Among the elements used to simulate the situation were: a kitchen simulated with objects and paper print-outs representing appliances, a living room setting with furniture and curtains, a shower simulated with panels and paper print-outs, a custom-made window to be opened like a normal side hung window, a wide windowsill, a ventilation control panel simulated on a tablet, air inlets indicated with print-outs on the side walls and under and behind the radiator, with air flow simulated using a fan hidden inside a crate (Fig. 9), air outlet indicated with prints in bathroom and kitchen, and a thermostat indicated with paper print-outs on the wall.

The participants (Table 7) were recruited from a neighbourhood close to Delft University of Technology. The buildings in this neighbourhood correspond to the reference building type (porch apartment building, mostly social rental). The participants volunteered to take part by responding to a leaflet distributed in this neighbourhood. The eight participants shared socio-economic characteristics with those most likely to inhabit the reference building in terms of age, family status, background, religion, likelihood to work out of home and health condition (Table 7, see also Section 4.1, above). All participants lived in the reference building type (porch apartment building), except for one participant who lived in a gallery building, all in the Netherlands. All of their homes were in non-renovated to only moderately renovated such as with double glazing and central heating. The participants reflected the variation of residents of the reference building.

In each study session the participant(s) was/were invited to experience the simulated home. Each study session consisted roughly of three parts taking 1.5–2 h per participant: introduction, acting out scenarios and in-depth interview. In the introduction the participant was welcomed and after the course of the study was explained, agreements were signed. Basic information on their current home situation was obtained. They received an introduction to the renovated building design, the systems and the renovation process, and a small interview conducted to elicit the participant's initial reaction. The consequences of the renovation were also outlined, for example the energy payment system and the deeper windowsill. The researcher then explained the ventilation system in the role of 'ventilation system contractor'.

In order to support the participants in the home experience-oriented co-creation, they were provided with 16 everyday scenarios to choose from as relevant to themselves and to enact such as, for example, just being at home, cooking for visitor, going to sleep, painting something in the house or smoking. The participants were free to change and adapt the scenarios – they primarily served to enable participants to step into the frame of mind of focusing on their own life experience. No more information was given but the research assistant supported participants in starting to enact them by demonstrating it. The researcher occasionally prompted elaboration with questions such as: "what would you do in this case? "can you portray it? "can you say out loud what you're thinking? "what do you expect to happen now? "what do you think of this?

Last, a semi-structured in-depth interview was conducted about their opinions on a renovation process that would introduce such new features of their apartment. It used a printed visualisation of six general steps: Initiation, Exploration, Preliminary design, Definitive design, Execution, Evaluation, but these were not discussed in-depth and exhaustively, since most participants only had general and global remarks on the process. Data collection took three days over a period of three weeks, with 8 separate sessions in total (most with one participant due to living alone, some with two). For each session there was one participant (or two), one interviewer, and one observer in the same room and one observer in a separate room that had camera access, which the participants knew.

5.2. Analysis

The analysis took as a starting point Strengers' [44] critique that home systems and interfaces should not be designed for the user who fits the system model, but rather be designed in view of living practices [18] with dynamic mutual shaping of practices among residents and their home environment ([17], based on [45]). The data was analysed using qualitative content analysis [46]. As unit of analysis, the home experience rather than specific practices was adopted. Key concepts of self-determination theory (autonomy, relatedness, competence [47]) and meaning of home (privacy, safety, control, intimacy etc. [48]) served as starting points for a theme analysis of life qualities around a core theme we established: expectation of pleasant living at home (in view of potential change). The data was first condensed by creating a database of salient statements and observations from the video recordings and assigning codes to the statements, in order to prevent inadvertently excluding data. This was followed by an abstraction stage in which three researchers repeatedly engaged with the data, creating various theme categorisations.

5.3. Co-creation enactment research results

A full report of the results is outside the scope of this paper, since the paper presents and discusses the integration of the approaches and results rather than each one in itself. This paper only summarises results, in so far as they aid the paper's aim. The results are presented according to the requirements for renovation process and renovation outcomes. These themes resulted from the analysis:

5.3.1. Grip on the future

Expected experience: Residents want to get an idea of what the renovation will be like. They want to be able to estimate what the consequences are so that they can make a well-considered choice.

Renovation process: The participants did not find it easy to trust such a project and would like to see examples. Recommendations are to create a set of trustworthy stakeholders, invite participation early and differentiate between tenants' situations.

5.3.2. Fairness, free from worries and threats

Expected experience: Regarding fairness, tenants already living frugally felt they should equally benefit, not just currently high energy users. Participants also feared unwelcome surprises after the renovation: participants wanted to be assured of fresh air but also able to close it off to avert danger (block dangerous air, prevent theft). They did not trust new ventilations systems to be able to do this.

Renovation process: The participants of this research were all adamant that a renovation should not cost them money in the form of a rent increase, and wanted assurances on paper about this. However, in a previous case study of a longer term participation process it was found that upon transparent, clear negotiation, a moderate rise in cost was acceptable and is probably most often possible. There should also be minimum disruption during building process, preferably without relocation.

5.3.3. Homes should reflect ideals

Expected experience: The home is a very personal and private environment, as some of the participants emphasised. Privacy indoors should be guaranteed (windows), while being able to seek social contact outside. For some senior participants it was important that no window beams obstruct the view of the street when they sat by the window. They also wanted to not be conspicuously visible. It is key that a renovated home facilitates treasured low involvement habits, which should not conflict with sustainability.

The residents' sense of familiarity with their home should be facilitated and supported, especially when it comes to spatial qualities they now value, like a spot at a window from which to gaze outside. Preserving this lightens the burden of adjusting to a renovated situation.

Renovation process: Several participants view a sustainable renovation as an important chance to realise idealistic goals. Participants want to be able to feel like they can influence their personal environment and life as autonomously as possible.

Because sustainable renovation meshes in various ways with participants' own ideals and values, it should be addressed early in a renovation process, not as ideology but connected to actual living practices. It is also key to design and test a usable, transparent and fair cost structure.

5.3.4. Support of activities & lifestyle

The home supports a great portion of people's everyday life. People have different lifestyles between homes but also within homes.

Expected experience: The home should support activities for the specific household. It should cater for differences in climate needs within the home, and also within different rooms and time of the day and night. Participants also do not distinguish clearly between ventilation and heating system and expect them to work together.

There should be sufficient air extraction from kitchen and bathroom, with low noise emission. Participants express the need to experience and be able to regulate daylight. Participants are adamant that rooms should not get smaller, except if an activity can be fulfilled in another way. Especially for older people, exterior or semi-exterior space is important.

Renovation process: It requires negotiation and a good process of matching personal preferences to spaces. Added spaces, e.g. a new deeper windowsill, could make up for other changes. As seen in the previous theme, provisions for lifestyle preferences are key, such as the possibility of hanging up curtains.

5.3.5. Support control over health and comfort

Expected experience: Perceived temperature is an important indicator for comfort for participants. A constant, determinable temperature is an important plus in a renovation, warm in winter and cool in summer. In addition, participants make a connection between ventilation and temperature control and expect them to work together. Seniors need higher temperatures, and handle large temperature differences less well.

Renovation process: Participants prefer minimized influence from neighbours (smell, noise, temperature), and no sharing of systems if possible. This will not always be possible in a renovation, so expectations should be managed carefully and transparently. Achievable effects should be emphasized, for example that new systems present no added effort and support existing habits. Habits and possible changes should be addressed non-prescriptively but through design and co-creation in relation to comfort and health. A desirable effect to emphasize (and guarantee) is that the renovation contributes to an optimally healthy indoor climate and can even reduce health issues, which is what some participants hoped. Some (e.g. some older participants) thought ahead to potential future health issues more than others.

5.3.6. Support control over and ease with home systems

Participants want to be in control and have influence on the indoor climate.

Expected experience: In the light of previous literature (see start of Section 5), an obvious recommendation is: integrate system design with household practices. For example, support use of own senses to assess ventilation. Participants also had routines and reasons for opening of windows, for example when cleaning with strong detergents. Apart from this, they trusted vents to be sufficient.

Renovation process: Current ventilation interfaces, including the one investigated, are not as direct and easy to use as the ones the reference residents know. This is because the new systems tend to hide functionalities from users and confine operation into boxes with buttons or screens.

6. From user research to design process

The objective of the user research is to increase the acceptability of renovation projects and reduce uncertainties related to occupants' behaviour. In this section, we focus on the feedback of the results of the investigations to the design process. The main question was: how to translate the user research into information valuable for the design team?

During the design process of the renovation solution presented in this paper, a number of questions raised by the design team. These were:

1) What is the effect of different household typologies on the sizing of PV panels?
2) What could be the effect of the occupants on the payback periods of the renovation and building technology?
3) What is the uncertainty created by the type of occupancy?
4) How to test the design decisions that could potentially affect the acceptability of the renovation (for example the solutions for the balcony and windows)?
5) How to test the design decisions that could potentially affect the energy performance of the building (systems' control, ventilation system)?

Fig. 10 shows the approach used to integrate the results from the user research presented in this paper into the conceptual design process (e.g. before the detailed design). As a first step, the reference building was defined [A] based on the intentions of the renovation, the market needs (housing associations portfolio) and relevant policies and regulations such as the zero-on-the-meter concept (NOM) and the Energy Performance Compensation (EPV) [49].

As a second step of the design process, technologies and design solutions were selected based on technical constrains of the reference building and costs that could be covered by the investment of housing associations in their portfolio [B]. In addition, in order to size the installations (heating system, energy generating technologies) and determine the financial feasibility of the solutions, the design team needed to know the energy demand of the renovated solution, as well as the effect that different household typologies could have on the energy performance. Therefore, energy demand was calculated based on energy simulations for the seven different Dutch household profiles statistically defined [C]. The results from the simulations were used to roughly calculate the number of PVs panels required to meet the demand, and to calculate the payback periods of the renovation costs [D].

In the third step of the design process, a number of questions were raised by the design team regarding the users' acceptability of the design solutions from the previous phase. In order to answer these questions, the reference households were defined [E]. The characteristics of the reference households served to define the socio-economical characteristics of the prospective residents. These socio-economical characteristics were used to select the case studies. Two types of studies were carried out in parallel during this phase: 1) monitoring of three households living in rental-social dwellings, and 2) mock-up ventilation and window study with young, elderly and minority households. The monitoring study was carried out to investigate the influence of the socio-economical characteristics and thermal comfort preferences of the household in the performance of the building [F]. The mock-up balcony study was carried out to test a specific design solution estimated to be a sensitive issue for user acceptance of the renovation process [G]. The mock-up ventilation study was carried out to test a specific solution deemed important because of its influence on energy consumption and due to the high impact that the user has on it [H]. The mock-up ventilation and window study was carried out to elicit occupants' expected home experience in relation to solutions deemed important because of their influence on energy consumption and due to the high impact that the user has on it and vice versa, to test this solution and to co-create design choices [G, H]. User requirements and user-specific energy demand were defined based on the user investigations. A number of design iterations was carried out taking into account the feedback provided by these investigations [I].

As a final step of the process, a final solution was selected, and new energy demand calculations and payback periods specific for a renovation case study were carried out [J].

7. Discussion and conclusions

The investigations reported in this paper highlight the effect of different household types on energy consumption and occupants' requirements. Three types of investigations were presented in this paper: statistical analysis of a national Dutch household survey, monitoring data of three case studies in the Netherlands, and enactment research with mock-ups of parts of the renovation 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 household typology and occupants' behaviour, as well as user requirements. These results, especially the results of the monitoring campaign (e.g. thermal comfort preferences) are tied to the specific monitored cases and should not be generalised to the population. However, the approach developed in this study can be applied to renovation processes in any other country. Furthermore, the results provide insight into reasons that a set of users have for their response to systems and changes, and these reasons can inform the reasoning and understanding in this and other design projects.

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 during the life-time of the buildings;
- 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 their specific situation, attitudes and thermal comfort preferences;
- the differences in lifestyle, attitudes and preferences depend not only on household typology but also on socio-economic characteristics;
- the acceptability research led to recommendations for the renovation process;
- the four elements of the renovation strategy (technological design, business model, monitoring and acceptability) lead to a final design concept for the building, and
- trust and variation in preferences are likely to affect resident willingness to agree to renovation and to engage in low energy consumption, which is an idealistic goal for many of them.

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 (i.e. the prospect tenant of the building to be renovated). 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. Thus, in some instances, the use of statistically defined heating patterns might be more appropriate. The enactment study did not result in profiles corresponding to the occupancy profiles, even though two groups were specifically investigated: seniors and households with foreign background. 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 in occupancy research, and their integration can help to determine the occupant preferences and requirements in building renovation projects.

An important objective of the research was to establish how to preserve the possibility for participation and openness within a streamlined financial and technical process, which is necessary for the manufacturing and installation of the pre-fabricated façade elements. The research show that all participants, regardless of their characteristics (household profiles) had concerns and needs – although these varied in themselves – in relation to fairness, freedom from worries and threats, support of activities and lifestyle, support of control over health and comfort, and support of control over home systems. On the other hand, differences on requirements were seen between the senior participants and the younger participants regarding the balcony, type of windows and windowsill solutions. These results indicate the type of building elements that could be up for discussion with the residents in a renovation process. The full range of possibilities for the tenants within technical and financial constrains within each project should be further investigated.

The co-creation enactment research added insights into phenomena established through the monitoring campaign that shape further steps. Rather than being blamed when energy savings are not achieved, the residents will be disappointed about the process and results, which would be a long-term risk for the acceptability of this type of projects. The co-creation enactment research also showed that people hate to be forced into habit change if they feel it is being pushed onto them. This implies that a participation process should present the implications for habits transparently and openly for co-shaping by participants. This insight provides ways forward for renovation process concepts [15].

The user research presented in this paper unites the possibilities of integrating qualitative and quantitative data collection and analysis around building renovation projects. The participation of the tenants could enable residents to find their own motivation for the renovation and to be open to the new experiences it brings, in a way that also provides design teams and investors with realistic expectations for energy use post-renovation.

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