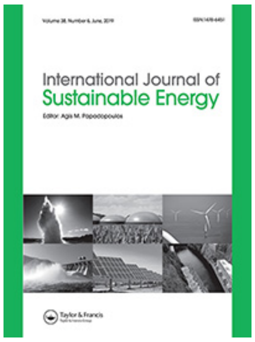

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Occupants' acceptability of zero energy housing in Finland

Jukka V. Paatero [a], Munjur E. Moula [a,b] and Kari Alanne [a]

[a]Department of Mechanical Engineering, Aalto University, Espoo, Finland; [b]Helsinki Institute of Sustainability Science, University of Helsinki, Helsinki, Finland

ABSTRACT

Based on an extensive Finnish data covering 1350 interviews the authors surveyed the end users' perceptions concerning improved energy efficiency, renewable energy integration and zero energy housing. The data has wide social coverage and it matches well with both age and gender distribution in Finland. The survey indicates that solar photovoltaic panels and heat pumps are among most familiar renewable energy technologies to the interviewed occupants while the panels also enjoy the most positive image among the interviewees. However, the interviewees' willingness to pay extra for energy efficient improvements was more munificent than that for the renewable energy installations. Zero energy buildings were only known to roughly half of the interviewees while 48.9% of the respondents did not even know whether there is an energy performance certificate for their house or not.

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KEYWORDS
Zero energy housing; acceptability ; renewable energy

Introduction

The 20-20-20 targets of the European Council include increasing the use of renewable energy to 20% of the end use and reducing gas emissions at least by 20% by 2020, in comparison with the level of 1990 (European Council 2018). The EU target for 2030 (agreed in October 2014) stipulates the share of at least 27% of renewable energy consumption and improving energy efficiency by 27% in comparison to projections of future energy consumption based on the current criteria (European Council 2014). In 2010, households accounted for 26.6% of the total final energy consumption in the EU27 countries (EEA 2013). The design of future buildings in Europe is outlined by the European Building Performance Directive (EPBD), where the building energy sector is committed to reducing annual primary energy consumption and equivalent CO2 emissions according to the EU targets. In the Directive 2010/31/EU (EPBD recast 2010), the Member States agreed that by the end of 2020 all new buildings are to be nearly zero-energy buildings, i.e. buildings with a high energy performance, where significant proportion of energy demand will be covered by locally installed (on-site) renewable energy sources. Further discussions on the definition of zero-energy buildings have been given by several authors (BPIE 2011; Kurnitski et al. 2014; Szalay and Zöld 2014).

The importance of public awareness and attitudes for the widespread implementation and commercialisation of Renewable Energy Technologies (RETs) and the achievement of energy policy targets has been recognised by several scientists (e.g. Moula et al. (2013, 2014); Heiskanen, Matschoss, and Kuusi (2014); Devine-Wright (2008); Assefa and Frostell (2007); Tomc and Vasallo (2015); and Dowd (2011)). In recent studies worldwide, the public acceptance of renewable energy implementation has been commonly investigated from the viewpoint of a whole community. In many studies related to buildings, the approach is often limited to separately examining the occupant's experience of energy efficiency or renewable energy issues in existing low-energy buildings, whereas their

CONTACT Jukka V. Paatero jukka.paatero@aalto.fi https://www.linkedin.com/in/jukkapaatero/

perception of the future net-zero energy buildings and their benefits and costs remains somewhat unclear. Table 1 summarises the public acceptance of renewable energy implementation from the viewpoint of a whole community. The key contents of various research papers are stated and specifying remarks provided to point out the research gaps the present study intends to address.

In Finland, the public attitudes to renewable energy have been systematically investigated since 1983 by the Finnish Energy Industries (Finnish Energy Industries 2014). Occasionally, companies and NGOs survey the customers' perspectives in terms of marketing products or in terms of projects or campaigns supporting energy efficiency or the integration of renewable energy in buildings (e.g. the 'Energy-efficient home' project by the Finnish Energy Agency in 2014). In the communal context, the social acceptability of renewable technology in Finland has been recently examined by Moula et al. (2013, 2017). Experts' attitudes towards energy efficiency have been investigated by Virkki-Hatakka, Luoranen, and Ikävalko (2013) and the homeowners' perspective on the residential heating systems by Rouvinen and Matero (2013). The occupants' preferences have been examined in the Finnish Dream Home survey, which was conducted as a part of the Aalto University Townhouse Habitat Components project in 2014 (Kuittinen 2014). However, the survey did not include energy-efficiency measures and renewable energy issues. Particularly, the impact of the factors such as building type, ownership, income level, education and area of residence on the occupants' perceptions remains unclear.

In general, the correlation between the occupants' attitude and some key discomfort factors (e.g. noise, indoor air quality) has remained with a little attention in the recent studies. Many of the studies focus on the factors affecting the willingness of various stakeholders to the adoption of single technologies, such as heat pumps and solar PV. However, some key RETs (such as micro-wind, micro-CHP and hydrogen technology) have not been included in these studies. As well, there is a lack of knowledge on how local renewable energy implementations impact on the occupants' perception of the reliability of the whole energy system (Käkönen and Kaisti 2012; Hai, Moula, and Seppälä 2017).

The purpose of this paper is to present the results of a survey on of the occupants' preferences on the RET and energy efficiency measures in residential buildings. The survey was conducted within the 'Energy Efficient Townhouse' project funded by the Aalto Energy Efficiency Research Programme. It was carried out in Finland in November and December 2014 and it covered over 1350 interviews that were collected through a probability based Internet panel survey. Further, a commercial survey system was employed.

The results are analysed to find out the impact of the Finnish end users' background on their awareness, information sources, image, willingness to pay and readiness to accept discomfort due to improved energy efficiency, renewable energy integration and net-zero energy housing. The findings are expected to be useful in the commercialisation of new energy technologies and services related to net-zero energy housing and for outlining the future building codes and public incentives. Further, the findings can be utilised to identify barriers in the implementation of these technologies and how to develop them, to improve the supply chain, to increase the knowledge concerning housing occupiers, and how to develop building codes. In addition, in the discussion below, the term Building connected Renewable Energy Technology (BRET) has been applied to represent the variety of RET solutions that can be integrated to buildings (e.g. solar panels) or otherwise directly connected to their energy systems (e.g. heat pumps).

Materials and methods

Questionnaire

For the interviews, a questionnaire consisting of 21 background questions and 21 survey questions (in Finnish) was developed. The key criteria for designing the questions were unambiguity, easiness to interpret (by laymen) and a sufficiently extensive collection of background questions. The

Table 1. Acceptability studies on domestic energy savings and Renewable Energy Technologies (RETs).

Reference(s)	Key contents	Remark(s)
Holmgren et al. (2017)	How physical properties of the indoor environment (high vs. low temperature) and labelling ('green' vs. 'conventional') interact and effect the perception on indoor environment	'Green' label positively influences the perception of the indoor environment for occupants, but only within acceptable temperature range
Zalejska-Jonsson (2014)	Willingness to pay for green apartments in Sweden based on database of responses from 477 occupants living in green and conventional multi-family buildings	People are willing to pay more for very low-energy buildings but less so for a buildings with an environmental certificate
Kostakis and Sardianou (2012)	Tourist's perception towards renewable energy supply	–
Sardianou and Genoudi (2013)	Reflection on the adoption of renewable energy in residential sector in Greece	No discomfort factors and the impact of educational background in engineering were investigated
Sütterlin and Siegrist (2017)	Difference in results when assessing the acceptance of renewables on a concrete level (i.e. by addressing drawbacks) or on an abstract level, as done in opinion polls	Evaluating renewables on a concrete rather than abstract level decreases acceptance and provides a more valid base for policy decisions
Zyadin et al. (2014)	Teachers' perception towards renewable energy in Jordan	–
Karlstrøm and Ryghaug (2014)	Public attitudes towards RETs in Norway	The role of party preferences was investigated
Jung et al. (2016)	Current status of public perceptions of RETs that are available in the Finnish market and associated influencing factors	Solar technologies and ground source heat pumps were the most preferred options and evaluated as very reliable. Respondents indicated a strong willingness to invest in RETs
Mills and Schleich (2012)	Adoption of energy saving technologies in buildings – Case Europe	Finland was not among the countries involved, discomfort not included
Rijnsoever (2014)	Identification of selected key factors affecting the adoption of new technology in buildings in Holland	A limited number of respondents (451) within one province
Mahapatra, Nair, and Gustavsson (2011)	Energy advisers' perception in Sweden	–
Du et al. (2014)	Adoption of energy saving technologies in buildings in China	–
Ma et al. (2011 and 2013)	Attitudes towards energy saving appliances in China	–
Hast, Alimohammadisagvand, and Syri (2015)	Consumers' attitudes towards green energy in China and their willingness to buy green electricity or renewable energy systems	Income, building type and view on renewable energy affect willingness to pay for green electricity
Li et al. (2014)	Identification of social and humanistic needs in the context of green buildings in China	The public has certain acceptance of the green building incremental cost
Stieß and Dunkelberg (2013)	Homeowners' barriers for energy-efficient refurbishments	1000 interviews were performed
Nair, Gustavsson, and Mahapatra (2010b)	Factors influencing energy-efficient investments in existing buildings	Discomfort was present only in terms of thermal comfort
Hope & Booth (2014)	Landlords' attitudes towards energy efficiency (tenanted houses)	–
Hayles and Dean (2015)	Tenant's willingness to reduce energy and water consumption in Northern Ireland	Tenants willing to further reduce resource consumption
Berardi (2013)	The perception of construction project stakeholders to energy saving in Italy	–
Zalejska-Jonsson (2012), Baird (2015), Day and Gunderson (2015), Berry et al. (2014), Zhao et al. (2016)	Occupant satisfaction in existing low-energy houses	Users' perceptions on the NZEBs examined by Berry et al. (2014)
Nair, Gustavsson, and Mahapatra (2010a), Liu, Shukla, and Zhang (2014), Nižetić (2017), Hassan et al. (2016), Karytsas and Theodoropoulou (2014), Mahapatra and Gustavsson (2009), Korcaj, Hahnel, and Spada (2015), Schelly (2014), Michelsen and Madlener (2013), García-Maroto et al. (2015)	Acceptance of a various energy saving and RETs in buildings	The acceptance of single technologies and systems is investigated

questions and their optional answers are grouped in Appendix according to their designed aims. The original question Q39 was omitted from the final analysis, because it did not add value to the survey of housing preferences. In addition, all transportation related questions (Q20–21 and Q41–42) have been omitted, as they were left outside the scope of the final analysis.

The background questions covered the demographic details of the interviewees (Q1–Q8 and Q10), the description of the current housing (Q11–Q15), the current energy characteristics of the building (Q16–Q17 and Q19), and the current satisfaction level (Q18). The survey questions first mapped the respondents' awareness of RETs and their preferred sources of information (Q22–Q23). Secondly, the preference information about various energy technologies was asked as well as the justification and the barriers to adopt the new technology (Q24–Q28). Thirdly, the end users' willingness to pay extra and/or to tolerate discomfort or disturbances in energy delivery due to renewable energy implementations was asked (Q29–Q33).

The section covering energy-efficiency improvements was conducted in questions Q34–Q37. The respondents' attitude to the renewable energy and energy efficiency among the interviewees was surveyed in questions Q38 and Q40. In the questionnaire, single options ('radio buttons') and multiple options ('check boxes') were preferred, but numerical answers were also provided according to discretion. A room for an open answer and the 'not known' option was available for the questions Q7, Q11–Q13, Q15–Q16, Q18, Q23, Q26–Q28, and Q33–Q34.

Data collection

The questionnaire was published using an online survey system, pre-tested by seven (7) test users 5 males, 2 females, then working at the Aalto University Dept. of Energy Technology, born 1950–1984 and edited according to their feedback. The public version of the survey was launched on 26 November 2014 and closed on 10 December 2014. The questionnaire was linked to an Internet panel management and survey distribution platform, which was applied to collect the required amount of responses through several Internet panels. Using the platform, the target group was constrained to cover the panelists living in Finland, representing the age groups of 18–80 year-olds. The panelists were approached through a random selection, resulting in probability based survey participation.

Data analysis

After closing the survey, the collected data were exported from the online survey system to a spreadsheet for in-depth analysis. The independent (explaining) and dependent variables were selected according to the survey questions as follows:

(1) Independent variables by question: Q1–Q8, Q10–Q15
(2) Dependent variables by question: Q16–Q19, Q22–Q38, Q40

Most of the variables were assigned to a single question, for example, the background variables such as gender (Q1), age group (Q2) or professional status (Q7). However, two independent variables were defined on the basis of more than one question for the sake of straightforwardness. Firstly, 'family size' was created from questions Q3 and Q4 by identifying families with children and households with no children on the basis of given number of family members. Secondly, 'area of residence' was formulated as per postal codes (Q11), by dividing Finland into three separate areas, namely (i) Helsinki metropolitan area, (ii) other Finland and (iii) Northern Finland.

The raw data were re-organised in a spreadsheet application, where there was a separate sheet for each question. Applying suitable functions (e.g. 'lookup') together with conditional and logical operators questions such as 'Which percentage of males among the respondents have district heating in their home?' could be answered. Furthermore, an indicator was assigned to each group of respondents (as per their background) to reveal percentages that deviate more than 20% of the distribution of responses among all the interviewees.

The open questions were analysed through a simple qualitative content analysis, by identifying certain words and calculating their repetition for each question.

Statistical analysis

As the data applied here has been collected through a probability based Internet panel survey, it follows the characteristics of binomial data sample (Hays, Liu, and Kapteyn 2015). The data was analysed using spreadsheet calculations and standard statistical operations to identify the selected statistical characteristics of the data. These characteristics include identifying the frequency f_i of selected opinions i and a possibility to portray the frequency against another variable.

The uncertainty of obtained results has been evaluated using the classic Clopper–Pearson binomial confidence intervals that provide accurate confidence intervals for binomial data with any sample size (Clopper and Pearson 1934). A 95% confidence interval has been applied throughout the paper. For a sample size of 1350 interviews the confidence interval is mostly within 5–20% of the observed frequency f_i or 1-f_i (whichever is smaller). However, when f_i is above 90% or below 10% the confidence interval relative to f_i or 1-f_i begins to widen significantly. For example, when f_i is around 2%, the confidence interval up is 0.9 pp and down 0.7 pp, correspondingly. While the relative accuracy of such low (or high) frequency values worsens, the overall observed trend remains correct.

Background data

Among 1351 interviewees, there were 769 females (57.0%) and 581 males (43.0%). According to Statistics Finland (2017), there were 50.8% females and 49.2% males in the Finnish population in 2014, when the survey was launched. Hence, females are slightly overrepresented in the survey data. The survey data by age group and its statistical conformity with the whole population is shown in Figure. 1.

The data in Figure 1 indicate that age groups 35–54 year-olds are overrepresented and the youngest age groups slightly underrepresented. Instead, the sample is close to the age distribution of the whole population in 55 year-olds and elder 479 of 1350 interviewees (35.5%) represented the households of one adult, 747 (55.3%) were households of two adults and the rest were families with three or more members. Children in the age group of 0–6 years were present in the household of 183 interviewees. The corresponding numbers for the age groups 7–15 and over 15 year-olds are 319 (23.6%) and 257 (19.0%), respectively. In other words, 31% of the respondents represented a family with children and the rest (69%) households with no children. The question regarding the education (Q5) was answered by 1354 interviewees. The mostly represented level of education was high school or vocational education (31.0%), followed by college (21.8%) and academic education (19.4%). 238 of 1351 interviewees (17.6%) mentioned technical education (engineer, technician or mechanic).

In Q7, the respondents were asked to indicate the primary option to describe their professional status. 398 of 1353 interviewees (29.4%) chose ‘retired’. The number is high compared to the number of people (253 interviewees, 18.7%) who mentioned to have achieved the official age of retirement in Finland, i.e. 65 years. The second most represented profession was ‘worker’ (332 interviewees), followed by officer (146 answers). There were 137 (10.1%) unemployed among the respondents, which is slightly higher than the employment rate in Finland in November, 2014 (8.3%).

The gross income (Q8) (i.e. the sum of annual incomes of all the family members before taxes) was mentioned by 1331 households. The majority (51.0%) belonged to the group with less than 40000 € per annum, followed by 32.8% in the group of 40001–70000 €, 10.0% in 70001–90000 € and 6.2% in the group of more than 90000 €.

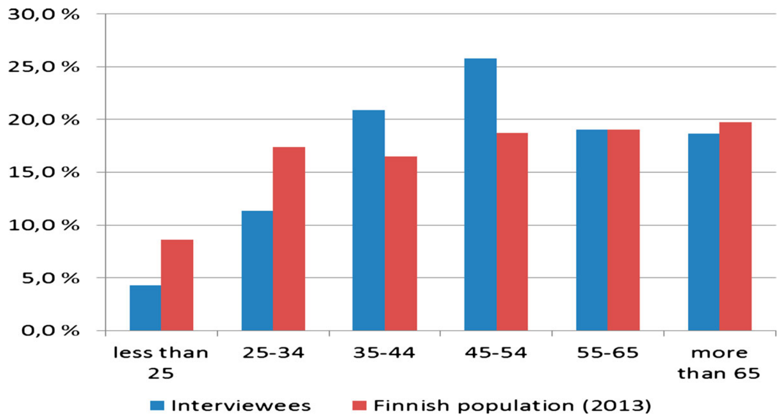

Figure 1. Age distribution of the Finnish population and among the interviewees of the survey (Q2).

The postal code (Q10) was used as the representation of the area of residence of the interviewees in Finland. According to the postal code, Finland was divided into three regions so that the whole country became covered. The postal code was mentioned by 1336 interviewees. Greater Helsinki area had the highest representation (66%), followed by other Finland (24%) and Northern Finland (9%).

The majority of 1354 interviewees (58.3%) characterised their residence as 'suburb' (Q11). The 'countryside' option was selected by 20.1% and the 'city center' option by 18.5% of the respondents. The most popular housing type (Q12) was an apartment building (607/1351 answers, 44.9%), followed by detached houses (35.0%) and row houses (15.9%). The most common ownership (Q13) was 'owner-occupied house' (834/1354 answers, 61.6%). A great majority of the interviewees (911/1327, 68.7%) mentioned to live in a household with less than 100 m^2 (Q14). 916 of 1354 respondents (67.7%) do not have a secondary residence (e.g. a summer cottage) (Q15).

Results

Current heating system, integrated sustainable energy system and building energy performance

The most common primary heating systems among the interviewees (Q16) were district heating (661/1356 answers, 48.7%) and direct electric (or electric baseboard) heating (326 answers, 24.0%). 51 households (3.8%) were equipped by a ground-source heat pump and 92 (6.8%) with oil heating. In general, the respondents knew the heating system of their current home well. However, as many as 66 (4.9%) of the respondents did not know what is the primary heating system of the house they live in. The proportion of 'I don't know'-answers was exceptionally high among less than 25-year-olds (33% of the respondents belonging to this age group answered, 'I don't know') and students (26%). Also 25–34 year-olds (14%), freelancers and unemployed (12%) and tenants (11%) didn't know the heating system. Further, among homeowners only 1% answered, 'I don't know', indicating this mainly being an issue outside homeowners.

The majority of the interviewees (953/1345, 70.8%) did not mention to have a sustainable energy system in their house (Q17). The most common sustainable system proved to be the air-sourced heat pump, which is in 14.9% of the households. 9.3% of the interviewees indicated that they do not know whether there is a renewable energy system in their house from the options listed in Q17. These are mostly less than 25-year-olds (31%), students (27%) and tenants (21%). The 'I don't know' answer was the most common among the tenants (20%) and residents of apartment buildings (15%), whereas residents of detached houses and homeowners were the most knowledgeable with only

1.5% and 3.2% correspondingly who didn't know whether there is a sustainable energy system in their home.

Since 1 June 2013, Energy Performance Certificate has been mandatory in Finland for new, detached houses (built in 1980 or later). On 1 July 2014 the requirement has been extended to row houses and office buildings and by the end of 2020 it will be extended to all buildings (more than 50 m^2) that are not secondary residences (summer cottages etc.) or protected buildings. Among the interviewees, 510/1354 (37.8%) answered 'not rated'. The answer was the most common among homeowners (74%) and among those who live in the countryside (67%). As many as 661 (48.9%) answered, 'I don't know' to the question about the energy performance certificate (Q19). The proportion was the highest among the respondents who live with the right of residence (79% of these respondents), are tenants (72%) or in an apartment house (70%). The proportion of students (70%) and less than 25-year-olds (69%) is also high, as well as that of those who live in the greater Helsinki area (63%) and in a city center (62%). The 'don't know' answer was the most common among the residents of apartment buildings (70%), whereas 18% of the residents of detached houses didn't know whether their home is energy performance certified. The year of construction of the interviewees' house was not asked in the present study.

Current experience of discomfort

The survey data indicate that the majority of the interviewees mentioned thermal discomfort in the form of too high temperatures in summer (70%) or too low temperatures in winter (61%) to appear in the house they live in. Any of the other listed problems occurred in less than 50% of the households. They also indicated that the occupants of detached houses were more satisfied with wintertime temperatures (46% with 'no problem') than those of apartment buildings (33%). The discomfort experienced among the interviewees is shown in Figure 2, sorted according to individual discomfort items (Q18).

Awareness and sources of information

The interviewees' awareness of the key BRETs and the concept of a zero energy house (Q22) is shown in Figure 3. The data reveal that solar PV panels and heat pumps are the most familiar RETs. Correspondingly, micro-wind power, solar thermal systems and net-zero energy buildings are known to roughly half of the interviewees only. Advanced micro-cogeneration technologies suitable for residential buildings, i.e. hydrogen fuel cells and Stirling engines, are unknown to the majority of the respondents.

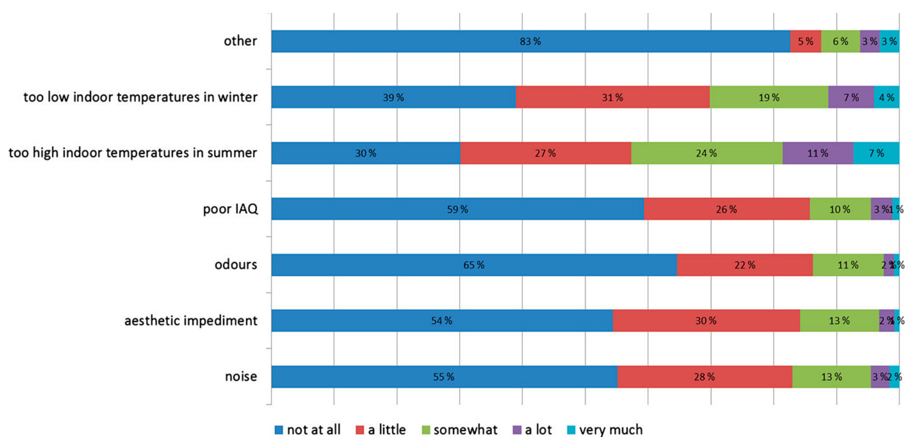

Figure 2. The experienced discomfort among the interviewees sorted according to individual discomfort items (Q18).

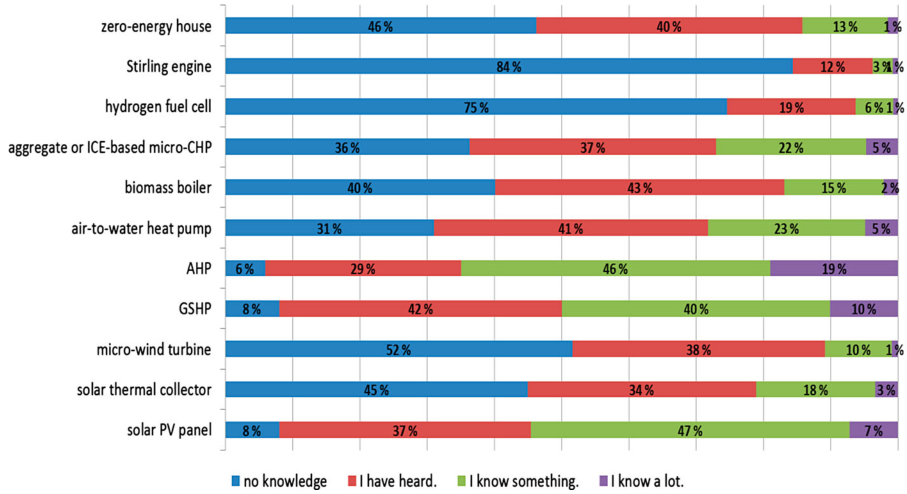

Figure 3. The interviewees' awareness of the key BRETs and the concept of a zero energy house.

Moreover, 621 of 1350 respondents (46%) mentioned to have no knowledge on zero-energy houses. The answer 'no knowledge' was the most common among the groups of respondents with comprehensive school education (72%) less than 25-year-olds (68%) and students (65%). Correspondingly, the smallest number of 'no knowledge' answers occurred among the respondents with high income (more than 90000 € per annum) (24%) and those who have a leading professional role (25%). 59% of tenants did not have the knowledge. The 'no knowledge'- answer was also somewhat common among those who live in apartment buildings (53%). Among 1345 respondents, Internet (39.2%) is the key source of information on renewable energy and the energy efficiency of buildings (Q23). This was followed by radio and TV (22.5%) and books, newspapers and magazines (20.9%). The usage of other information sources appeared in 17.3% of the answers.

Occupants' attitude to building connected renewable energy

The question whether the respondents experienced it important to have an integrated, domestic solar or a micro-wind power plant in their house (Q24) divided the opinions. 396 of 1351 respondents (29.3%) answered 'yes', 33.2% 'no' and 37.5% did not express their opinion. The 'yes' answer was the most common among those who had an academic post-graduate education (55%) and freelancers (41%), who also responded 'I don't know' the most often (47%). Entrepreneurs knew their attitude the best (22% 'don't know' answers), but they also had quite a many 'no' answers (41%). 797 of 1351 (59%) interviewees believe that the building connected generation of renewable energy would improve the reliability of the community energy supply as whole (Q25).

The pre-eminent key justification for a decision to purchase an integrated, renewable energy plant (Q26) would be savings in annual operation and maintenance costs (812/1341 answers, 60.6%). Cutting the consumption of natural resources was mentioned by 22% and curbing climate change by 13%, whereas instructions and regulations were mentioned only by 2.5%. The result may partly be a consequence of the current financial crisis in Europe and therefore the survey should be repeated another year to draw the final conclusions.

The preferred factors that hinder the transition to integrated RET were high investment costs (1270/1329 answers, 96%), high operational costs (1247/1327, 94%) and satisfaction to the present system (1187/1324, 90%). Correspondingly, low operational and maintenance cost was mentioned as at least of a little impact for the decision to invest in a renewable energy system (1303/1321 answers, 99%) among easy maintenance (1298/1316, 99%) and easy use (1298/1316, 99%).

Further, 445 of 1352 interviewees (33%) were ready to pay extra for renewable energy based energy system (Q29). However, 340 of 575 respondents (59%) are ready to pay only 5–10% more, 167 interviewees (29%) 10–20% more and 52 interviewees (9%) 20–30% more. The willingness to pay extra for renewable energy is highlighted among 25–34 year-olds (46%), academically educated (45%), leaders and experts (44%) and freelancers (47%). High annual income (more than 70,000 € per annum, 40%) also encourages to invest in renewable energy based system.

When contrasted, aesthetic impediment because of an integrated renewable energy system was easier for the respondents to adopt than noise. 488 of 1336 interviewees (36.5%) answered 'not at all' to the noise, whereas only 281 of 1334 (21%) said 'no' to the aesthetic impediment (Q31). For the majority of the respondents (880/1346, 65%) the possible disturbances to the supply and distribution of electricity and thermal energy due to the complexity of a distributed, renewable energy system were of no significance (Q32).

Perception of the home's energy-efficiency

The key justifications to improve the homes' energy efficiency (Q34) were similar to those to purchase an integrated renewable energy system. However, the significance of savings in operation and maintenance costs was even more highlighted. It was mentioned in 907 of 1339 answers (67.7%), whereas cutting the consumption of natural resources was mentioned by 17.7% and curbing climate change by 11.2% of the responses.

The interviewees' willingness to pay extra for energy efficient improvements was more munificent than that for the renewable energy installations. Here, 934 of 1335 respondents (70%) were ready to pay extra, though still parsimoniously. 45.5% of the respondents were ready to pay 5–10% more, 18.7% of the interviewees 10–20% more and 4.4% of the interviewees 20–30% more. The willingness to pay 5–10% extra was highlighted among less than 25 year-olds (61%), officers (53%) and respondents earning 40001–70000 €/y (51%). 12% of the freelancers and 14% of the respondents with an academic post-graduate education were willing to pay 20–30% extra. Further conclusions cannot be made, since the sample size of freelancers (17) and post-graduates (22) is presumably too low to be statistically significant.

Further, 367 of 1350 interviewees (27.2%) were unwilling to decrease the room temperature of occupied zones (kitchen, living room) because of improved energy efficiency (Q36). This result was emphasised among 65 year-olds and more (34.7%), entrepreneurs (36.5%), those who have comprehensive school education (34%) and those who live in a semi-detached house (33%). The results also imply that the interviewees who had answered 'very much' to 'too low indoor temperatures in winter' in Q18 are more likely to be unwilling to decrease room temperatures.

On the other hand, 666 of 1342 interviewees (50%) were willing to accept a slight structural change in their home with an aim at improving energy efficiency. 32% of the respondents were willing to change the building inside the definition 'somewhat' and 12% accepted no change at all. The rest were ready to make significant changes. Different groups of respondents were quite unanimous in their opinions regarding structural changes. However, the result suggests that the interviewees who had responded 'not at all' to 'aesthetic impediment' in Q18 were commonly not willing to accept structural changes, either.

Further, 585 of 1349 respondents (43.4%) considered improving the buildings' energy efficiency more important than increasing the local generation of renewable energy (Q38). Correspondingly, 43% of the interviewees prefer the local renewable energy generation.14% of the respondents could not give their preference. The preference of improving the buildings' energy efficiency is slightly emphasised among 65-year-olds and older (55%), retired (51%) those, who earn more than 90,000 € per annum (52%) and those who live in semi-detached houses (52%). The local renewable energy generation is preferred especially among 25–34 year-olds (51%) and interviewees living in in countryside (51%).

Occupants' attitude to BRETs and zero energy houses

The data on the attitudes of interviewees towards selected BRETs and zero energy houses (Q40) are indicated in Figure 4. The data show that integrated solar PV has clearly the most positive image among the interviewees. Even 74% of the respondents consider their image on solar PV very positive or at least somewhat positive. On the other hand, the greatest number of 'neutral' image is attached to fuel cells and hydrogen technology. The comparison with the data in Figure 2 implies that the better the awareness regarding the given technology, the better the image of that technology.

The 'very positive' image of zero energy buildings was highlighted among post-graduate-educated respondents (24%) and the interviewees who indicated their professional status as freelancer (24%). However, this result cannot be considered statistically significant due to the small total number of these respondents in the survey data. The 'somewhat positive' attitude is slightly emphasised among experts or leaders (43%).

Summary of open questions

The Finnish words 'maaseutu' (countryside), 'kirkonkylä' (village) or 'taajama' (locality) were mentioned repeatedly in the 39 open answers to Q11, which implies that the words 'lähiö- tai esikaupunkialue' (suburb) and 'haja-asutusalue' (countryside) are unfamiliar to a fraction of respondents.

In the answers to Q13 ($N = 15$), the shared ownership (with a family member etc.) was understood as an individual form of ownership. Then, the Q15 received 41 open answers, the majority of which referred to investment housing on another locality. Two respondents mentioned to have an apartment outside of Finland (Turkey, Goa).

Air heat pump repeated six (6) times among the 41 open responses to Q16, while a wood-fueled hydronic heating system has been mentioned repeatedly. Thich indicates that there could have been a separate option for them in the original survey.

Further, Q18 received a versatile selection of open answers ($N = 67$), which implies that the word 'problem' has been understood in several ways and may have been too general for the survey. A conclusion can be drawn, however, that draught and negligence of the neighbours and authorities have been experienced a problem reducing the living comfort.

The open answers to Q23 ($N = 21$) were mostly alternative approaches to the answers by options. Here, for example, the word 'education' was replaced by the word 'profession'. Two respondents mentioned energy utility as the primary source of information.

The reliability of energy supply and a possibility to be independent of the energy utility were visible in the open answers to Q26 ($N = 22$). The answers to Q27 ($N = 34$) revealed the respondents'

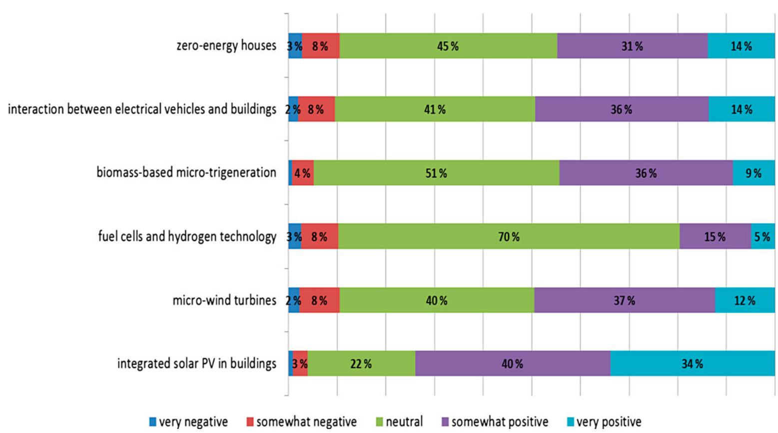

Figure 4. Attitudes of interviewees towards selected BRETs and zero energy houses (Q40).

frustration to either bureaucracy (e.g. 'The society penalizes small-scale generation.') or the lack of possibility to make a decision to invest in renewable energy ('law, regulations and building codes' or 'the resistance of the housing association'). Similar reasons occurred (inversely) in the open answers to Q28.

Q33 received 87 open answers in total. Regarding the readiness to accept faults because of renewable energy implementation, the general message was that the new, potentially more complicated energy systems should be well-tested and the service should be taken care of in a way that electrical blackouts can be avoided.

Summary of results and discussion

Extensive data covering 1350 interviews was collected in Finland. In this paper the data concerning the end users' knowledge, information sources, image, willingness to pay and readiness to tolerate discomfort concerning improved energy efficiency, renewable energy integration and zero energy housing has been evaluated. While the age distribution of interviewees matches rather well with that of Finnish population, females and 35–54 year-olds were overrepresented and less than 25 year-olds underrepresented in the survey data. Likewise, the number of retired respondents (29.4%) was high compared to the number of people (18.7%) who mentioned to have achieved the official age of retirement in Finland, i.e. 65 years. The majority of 1354 interviewees (58%) characterised their residence as 'suburb', and the most common ownership was 'owner-occupied house' (62%), which indicates a good presence of potential occupants for the future townhouses.

When the energy issues were considered, 4.9% of the respondents did not know what the primary heating system of their house was. These respondents were commonly young tenants, unemployed and freelancers. The most common RET in the interviewees' current residence was an air heat pump. However, 9.3% of the interviewees did not know whether there was a renewable energy system in their house. These were mostly less than 25-year-olds (31%), students (27%) and tenants (21%). The 'don't know' answer was the most common among the residents of apartment buildings (16%), whereas only 3% of the residents of detached houses didn't know whether there is an RET in their home.

Concerning energy technology solutions, solar PV panels and heat pumps were the most familiar RETs. Zero energy buildings were known to roughly half of the interviewees. Advanced microcogeneration technologies suitable for residential buildings, i.e. hydrogen fuel cells and Stirling engines, were unknown to the majority of the respondents. Further, integrated solar PV had clearly the most positive image among the interviewees. The greatest number of 'neutral' image was attached to fuel cells and hydrogen technology. A correlation between the image and the awareness regarding the given technology exists.

Among the interviewees, there was no consensus whether it is important to have an integrated, domestic solar or a micro-wind power plant in their house. However, the majority of the interviewees believed that the building connected generation of renewable energy would improve the reliability of the community energy supply as whole. The key justification for both a decision to purchase an integrated, renewable energy plant and to invest in energy efficiency improvements was savings in annual operation and maintenance costs. Correspondingly, the key barrier is high investment costs. However, the interviewees' willingness to pay extra for energy efficient improvements was more munificent than that for the renewable energy installations. Most of the respondents willing to pay were ready to pay only 5–10% extra.

Further, 48.9% of the respondents did not know whether there is an energy performance certificate for their house. They lived with the right of residence (79% of these respondents), were tenants (72%) or in an apartment house (70%). The proportion of students (70%) and less than 25-year-olds (69%) was also high, as well as that of those who lived in the greater Helsinki area (63%) and in a city center (62%). The 'don't know' answer was the most common among the residents of apartment buildings (70%), whereas 18% of the residents of detached houses didn't know whether their home is energy performance certified.

Curiously, the majority of the interviewees mentioned thermal discomfort due to too high or too low room temperatures as the key problem in their residence. The occupants of detached houses were more satisfied with winter-time temperatures (46% with 'no problem') than those of apartment buildings (33%). However, only 27.2% of the respondents were unwilling to decrease the room temperature of occupied zones (kitchen, living room) because of improved energy efficiency (Q36). The result was slightly emphasised among the interviewees who had experienced a lot of 'too low indoor temperatures in winter'. The respondent's age, housing type and ownership did not affect the answers, but the younger the respondent was, the more often he/she answered 'can't control' to this question.

Overall, the impact of economic factors was clear in the survey data, but it may be partly explained by the vicinity of the dept crisis in Europe (see e.g. Ruffert (2011)). Therefore, the survey should be repeated another year to draw further conclusions.

Concerning the open questions included to the survey (see Appendix for details), it became apparent that to a fraction of respondents the employed terminology was party unclear. On the other hand, the portfolio of options in the survey and the related instructions were insufficient for some questions, while also some too general words (e.g. 'problem') were used. Additionally some specific issues were identified through the open questions. For example, it seems that the expression 'primary heating system' was not understood correctly by all the interviewees.

Some additional observations from the open questions was that the reliability of energy supply and a possibility to be independent of the energy utility were visible as desired trends of development. Further, the respondents' frustration to either bureaucracy or the lack of possibility to make a decision to invest in RET was revealed. Some additional concern about blackouts due to the integration of RET was also expressed.

As a further note, the authors wish to underline that their survey results match well with some of the results presented by Mills and Schleich (2012). While our data did not include material about if households with young children are more likely to adopt energy-efficient technologies or not, it did confirm two other of their key findings. It showed that households with a high share of elderly members placed more importance on financial savings and had lower levels of technology adoption Holmgren et al. (2017). In addition, the data also shows that higher education levels are associated with energy-efficient technology adoption, as does the data by Mills and Schleich (2012) and Moula, Lahdelma, and Hai (2015).

Conclusions

The ongoing improvement of the energy efficiency of built environment increasingly includes the local integration of RET. To support the related commercial activities and development of future building codes and policies it is crucial to gain added insights about occupants' perceptions and the impact of underlying factors. Although the public perception of RET implementations at the communal level has been investigated in earlier studies worldwide, the comprehensive understanding on the perspectives of homeowners and occupants is yet somewhat limited. To fill the research gap, the authors collected and analysed an extensive Finnish survey data covering 1350 interviews mapping the end users' knowledge, information sources, image, willingness to pay and readiness to tolerate discomfort concerning improved energy efficiency, renewable energy integration and zero energy housing.

The results indicate that solar PV panels and heat pumps are the most familiar RETs to the interviewed occupants while the panels also enjoy the most positive image among the interviewees. On the other hand, the interviewees' willingness to pay extra for energy efficient improvements was more munificent than that for the renewable energy installations. In addition, most of the respondents willing to pay were to pay only 5–10% extra for the improvements. While the familiarity and positive image of photovoltaics could be utilised in any public campaigns concerning the introduction of RETs to the occupants, the low willingness to pay extra should also be considered in designing public initiatives. Further, any campaigners of advanced energy solutions should absolutely also recognise the low awareness on advanced micro-cogeneration technologies suitable for residential buildings, i.e. hydrogen fuel cells and Stirling engines.

Concerning the housing, the awareness about zero energy buildings (roughly half of the interviewees) has still major room for improvement. In similar manner, the occupants are not very well aware about the energy performance of their residences, as 48.9% of the respondents did not even know whether there is an energy performance certificate for their house or not. Improving awareness on these matters would be valuable to the advancement of energy efficiency of buildings and any related public campaigns. In addition, the indicated limited awareness also makes performance on these areas less valuable in the marketing of buildings with high energy performance.

In addition, the survey results underlined the preference of occupants to use Internet as their main source for information concerning renewable energy and the energy efficiency of buildings. It suggests that any related campaigns would likely benefit from the use of topical Internet publishing as well as established online information portals.

Overall, increased communication is required to improve the awareness of occupants concerning the energy performance and energy technology at their home. This might take place in traditional locations like, for example, the bulletin boards at the entrance of an apartment house or local newspapers, or modern platforms like online information portals, social media, etc.

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ORCID

Jukka V. Paatero http://orcid.org/0000-0002-6661-2777
Munjur E. Moula http://orcid.org/0000-0001-8710-4985
Kari Alanne http://orcid.org/0000-0002-5461-6201

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Appendix

Table A1. The list of background (Q1–Q21) and survey (Q22–Q42) questions.

	Question	Optional answers
Q1	Are you?	Female male
Q2	How old are you?	less than 25 25–34 35–44 45–54 55–65 more than 65 years old
Q3	How many adults are there living in your household?	1 2 3 or more
Q4	How many children are there living in your household?	0–6 year-olds (integer) 7–15 year-olds over 15 year-olds (integer)
Q5	What is your highest education?	comprehensive school high school or vocational school college university of applied sciences academic education (M.Sc) post-graduate education (PhD)
Q6	Do you have a technical education?	yes/no
Q7	What is your professional status?	worker officer leader entrepreneur freelancer retired unemployed student housewife/homemaker other, what? (open text)
Q8	What is the annual gross income of all the family members before taxes?	less than 40000 €/y 40001–70000 €/y 70001–90000 €/y more than 90000 €/y
Q10	ZIP/postal code	number
Q11	How would you describe your current area of residence?	city center suburb countryside other, what? (open text)
Q12	What type of building do you live in currently?	apartment building row house semidetached house detached house other, what? (open text)
Q13	What kind of ownership do you have?	owner-occupied house tenantship the right of residence other, what? (open text)
Q14	What is the size of your current residence?	number of rooms (number) area of house (number)
Q15	Do you have other residences?	no other residences summer cottage time-share other holiday home other, what? (open text)
Q16	What kind of a heating system is there in your current house?	direct electric heating electric storage heating district heating ground-source heat pump oil heating

(*Continued*)

Table A1. Continued.

Question	Optional answers
	gas heating wooden pellet heating fireplace other, what? (open text) I don't know.
Q17 Is there any of the following in your current house?	solar photovoltaic panel solar thermal collector micro-wind turbine ground-source heat pump air source heat pump air-to-water heat pump biomass boiler (excl. fireplaces and pellet boilers) aggregate or micro-chp power unit none of the above technologies I don't know.
Q18 Do you have some of the following problems in the house?	noise aesthetic impediment odours poor indoor air quality too high indoor temperature in summer too low indoor temperatures in winter other, what? (open text)
Q19 The Energy Performance Rating of my house is:	A B C D E F G not rated I don't know.
Q22 On the scale (no knowledge/I have heard/I know something/I know a lot) estimate your knowledge on the following energy technologies.	solar photovoltaic panel solar thermal collector micro-wind turbine ground-source heat pump air heat pump air-to-water heat pump biomass boiler (excl. fireplaces and pellet boilers) aggregate or micro-chp plant (internal combustion engine) hydrogen fuel cell Stirling engine zero-energy house (ZEH)
Q23 What is your primary source of information on renewable energy and the energy efficiency of buildings?	education books, newspapers and magazines radio and TV Internet housing association, janitor etc. family members, relatives and friends other, what? (open text)
Q24 Do you experience important that there is solar power and/or micro-wind power plant integrated in your home?	yes no I don't know.
Q25 In your opinion, is the following statement true? 'The local generation of renewable energy within a building would improve the reliability of the community energy supply?'	yes no I don't know
Q26 Assume you are about to make a decision to purchase a solar power plant, micro-wind turbine or a	savings in annual operation and maintenance costs

(*Continued*)

Table A1. Continued.

	Question	Optional answers
	biomass boiler for your house. What is your most important justification for the decision?	curbing climate change cutting the consumption of natural resources instructions and regulations other, what?
Q27	On the scale (not at all/a little/somewhat/a lot/very much/I don't know) estimate how much the following issues hinder the transition to renewable energy (solar PVT, micro-wind, biofuels) in your house?	lack of knowledge on the available options lack of knowledge on the options suitable for my house high investment costs high operational costs satisfaction to the present system no possibility to make this decision other, what?
Q28	When I make a decision to invest in renewable energy, how important I consider the following issues? (Give your answer on the scale: no importance/a little important/somewhat important/important/very important)	low investment costs low operational costs easy to use easy to maintain the system operates automatically status, imago or visibility other, what?
Q29	Are you ready to pay extra for the system based on renewable energy?	yes no
Q30	If your answer to the previous question was 'yes', how much extra you would be ready to pay for a renewable energy solution (in comparison with the conventional solution)?	5–10% more 10–20% more 20–30% more 30–40% more 40–50% more over 50% more
Q31	How much extra impediment (in comparison with the current situation) you would be ready to accept? (Give your answer on the scale: not at all/a little /somewhat /significantly)	extra noise aesthetic impediment
Q32	Would it be easier for you to accept possible faults or blackouts in the supply and distribution of electricity or thermal energy presuming that you know the complexity of a renewable energy system to be the reason for these faults?	easier does not matter more difficult
Q33	You can complement your previous answer to this text box.	(open text)
Q34	What is the most important justification for you to improve the energy efficiency of your house?	savings in operational and maintenance costs curbing climate change reducing the use of natural resources instructions and regulations other, what? (open text)
Q35	How much extra (if any) you would be ready to pay for the enhanced solutions with improved energy efficiency?	not at all 5–10% more 10–20% more 20–30% more 30–40% more 40–50% more over 50% more
Q36	How much would you be ready to cut the room temperature (in the kitchen and/or the living room) to improve the energy efficiency?	not at all by 1 degree by 2 degrees by 3 degrees or more I can't control the room temperature in my home.
Q37	How great a change (in comparison with the building without extra structures) would you be ready to accept?	not at all a little somewhat significantly
Q38	In your opinion, which one is more important in the future?	improving the energy efficiency of buildings increasing the local generation of solar PV and micro-wind electricity I don't know.

(*Continued*)

Table A1. Continued.

	Question	Optional answers
Q40	What kind of opinion/conception do you have about the following energy solutions and/or systems? (Give your answer on the scale: very negative/somewhat negative/neutral/somewhat positive/very positive)	integrated solar PV in buildings micro-wind turbines fuel cells and hydrogen technology biomass-based micro-trigeneration (electricity, heating, cooling) systems interaction between electrical vehicles and buildings zero-energy houses (ZEH)