

How building users can contribute to greenhouse-gas emission reductions in Finland: comparative study of standard technical measures, user modifications and behavioural measures

M. K. Mattinen · P. Tainio · M. Salo · M. Jalas ·
A. Nissinen · E. Heiskanen

Received: 21 October 2014 / Accepted: 2 June 2015 / Published online: 13 June 2015
© Springer Science+Business Media Dordrecht 2015

Abstract The residential sector is responsible for a considerable share of global greenhouse-gas emissions. In cold climates, space heating and energy-efficiency improvements are critical. Solutions can be off-the-shelf technologies, user modifications to adapt such technologies to local needs or behavioural measures. This paper conducts carbon footprint and profitability analyses of 20 such measures, including conventional technical measures, user modifications and behavioural changes in Finland. The study focuses on detached houses that have the most common heating system in the Finnish context—direct electricity, which is particularly problematic because it limits the options for improvement. The results show that the largest energy and emission savings resulted from heat pump installations and adding insulation to the roof. The most profitable measures were related to heat pumps. Some of the user modifications appeared promising in both respects.

Keywords Greenhouse-gas emission · Cost · Energy efficiency · Measure · Residential house · User modification

Introduction

The search for energy-efficient and low-emission space heating solutions is relevant in many parts of the world. The residential sector uses a large amount of energy worldwide (Saidur et al. 2007), and furthermore, residential heating is responsible for a considerable part of household greenhouse-gas emissions (Huppel et al. 2006). The most striking need for new solutions is in countries with a cold climate. For example, in Finland, energy use in residential buildings for space heating and electric devices was 64 TWh in 2009 (Nissinen et al. 2012). This use was responsible for 11.6 million metric tons (Mt) of greenhouse-gas emissions (GHGE), which accounts for roughly 18 % of Finland's total GHGE of 66 Mt in 2009 (Statistics Finland 2014a).

Energy efficiency and conservation options in the buildings sector have been widely studied (for a review, see Harvey 2009). Because of the cold climate, the Nordic and Baltic countries have relatively long heating periods; hence, we focus on previous research in these particular contexts, which are comparable to the Finnish one. Previous studies have discussed the implications of typical energy conservation measures. There is literature focusing on economic assessment (e.g. Nikolaidis et al. 2009; Tommerup and Svendsen 2006), but some studies also include environmental aspects, typically carbon

M. K. Mattinen (✉) · P. Tainio · M. Salo · A. Nissinen
Finnish Environment Institute, SYKE, P.O. Box 140,
FI-00251 Helsinki, Finland
e-mail: maija.mattinen@ymparisto.fi

M. Jalas
School of Economics, Aalto University, P.O. Box 21210,
FI-00076 Aalto, Finland

E. Heiskanen
National Consumer Research Centre, University of Helsinki,
P.O. Box 24, FI-00014 Helsinki, Finland

dioxide (CO₂) emissions (e.g. Rolfsman 2002; Chan and Yeung 2005; Balaras et al. 2007; Nemry et al. 2010; Ristimäki et al. 2013; Paiho et al. 2014; Droutsas et al. 2014). Kuusk et al. (2014) studied the implications of renovation measures in apartment buildings in a cold climate; they concluded that as a single measure, the insulation of external walls has the greatest effect on energy consumption. These studies focus mostly on technical improvements in the property, and the life cycle approach has not been fully employed in the environmental impact assessment of the measures. In other words, the upstream processes and related emissions have been excluded from the calculation: for instance, the full life cycle of the insulation materials is not considered. A more general analysis of several consumption categories, including housing, by Girod et al. (2014) found that good insulation and the use of renewable power in the home were significant options for climate change mitigation.

When looking at commonly proposed measures for decreasing residential energy use and the related GHGEs, three main approaches can be distinguished as follows: (1) change of habits, for instance, reducing indoor temperatures and using electrical appliances less and more efficiently, (2) replacement of old appliances with new energy-efficient appliances, and (3) investments in energy renovation of the property (thermal insulation). The monetary and emission savings of these types measures have been widely studied (Kopsakangas-Savolainen and Juutinen 2013; de Almeida et al. 2008; Abrahamse et al. 2005). Recently, two additional approaches have risen to decrease the GHGEs of households: (4) shifting electricity use to such hours when the emissions of electricity production are the lowest and (5) installation of new types of (preferably innovative) heating systems that use renewable energy in the property. All of these approaches evidently have relevance in a country like Finland with a cold climate and relatively high GHGEs from electricity production, but it is not clear which approaches have the largest potential for decreasing residential energy use and the related GHGEs.

Following the introduction of smart metering, there are increasing opportunities to reduce greenhouse-gas emissions by shifting the time of use of electricity in households to avoid peak loads (Darby et al. 2013; Moura et al. 2013). Hourly based electricity pricing is already available for households in Finland, and the emission-based steering of electricity consumption is

being studied (Kopsakangas-Savolainen et al. 2014). However, there is still limited research on the concrete implications of hourly based pricing on a household level, in particular in comparison to other options for greenhouse gas and cost reductions.

We add to the discussion a novel category of solutions—user modifications of standard technologies. Such modifications can serve to adapt standard technical assemblies (like heat pumps or other innovative heating systems) to local conditions and needs, or they can reduce the cost and improve the accessibility of solutions that are also available commercially. Such modifications have gained increasing attention in research on the role of users in the development of energy technology (Arnold and Barth 2012). In Austria, end users have led the market development for solar heat collectors and pellet burners (Ornetzeder and Rohrer 2006), and community energy projects have gathered momentum more generally (Seyfang et al. 2013). Users have made next to 200 modifications to heat pump and wood pellet burning systems in Finland, and user engagement has been shown to speed up the diffusion of renewable energy technologies (Hyysalo et al. 2013a, b; Jalas et al. 2014).

The GHGEs of the building stock can be reduced with a number of different, already existing solutions. The purpose of this paper is to study the significance of a few prominent existing solutions (e.g. better insulation), behavioural changes (e.g. lowering the indoor temperature), and a few emerging user modifications, for instance, modified air-to-air heat pumps and do-it-yourself solar heat collectors. The paper aims to quantify the costs and savings of the measures for the residents in a hypothetical ‘average’ detached house in Finnish conditions (cold climate). We limit our analysis to measures applied in houses heated with electric resistance heating (radiators) because the lack of hydronic heat distribution system (i.e. central heating hereafter) presents particular problems for deploying renewable energy. In addition to comparing the economic and GHGE savings, the other costs are briefly discussed in terms of impacts on time use and convenience of carrying out the required behavioural changes or modifications and operating them during the course of daily life. Obviously, such other costs and conditions of adoption cannot be expressed in quantitative terms as easily as the financial costs.

For assessing the order of magnitude of the savings, it was found important to analyse both the ‘old measures’ and the new innovative ways to decrease energy use and

the related GHGEs in the same case study context. The existing literature rarely uses a life cycle approach to examine both technical and behavioral changes on a building level, and this is the research gap that we address. The effects of possible combinations of the studied measures, however, are beyond the scope of this article because it would require a deeper analysis of the preferences and financial constraints of the household, among other things. Our scope also excludes possible effects of the changes in energy expenditure or behaviour on energy consumption in other areas (e.g. mobility) or expenditure and behaviour in other consumption categories (e.g. food). While such rebound effects are considered to be relevant in the existing literature (e.g. Nässén and Holmberg 2009; Chitnis et al. 2013; Binswanger 2001; Murray 2013), they are difficult to estimate comprehensively.

Context of the study

The study's focus on Finland is motivated by three facts: First, Finnish households have diverse heating systems (Vihola and Heljo 2012; Statistics Finland 2014b) which, in many cases, can be improved for better energy efficiency and reduced GHGEs. Second, there are interesting user modifications which adapt generic solutions to local conditions (Hyysalo et al. 2013a, b). Thirdly, there are almost 500,000 detached houses in Finland that are heated by electricity, representing 43 % of detached houses (Statistics Finland 2014c).

Electricity consumption for space heating increased in Finnish households in 2006–2011 (Adato Energia 2013). However, both the electricity price and demands for better energy efficiency, e.g. in the building code, are rising. Electricity prices for detached houses in Finland have been rising for the last 10 years by 5.8 % on average per annum (Statistics Finland 2014d). The concern about climate change and GHGEs has increased public interest in electricity savings and less carbon-intensive forms of space heating such as new heating solutions.

Most of the Finnish detached houses that use electricity for heating have electric radiators (electric resistance heating), instead of central heating. Previously, electric radiators were considered convenient and cheap to install. A shift from merely electricity-based systems to other heating forms, such as heat pumps and different forms of wood, including wood pellets/chips and logs is

taking place in detached houses with central heating (Vihola and Heljo 2012). Electric resistance heating poses special challenges to decreasing the energy-related GHGEs because effective renewable-based heating systems are difficult or costly to implement without an existing central heating system. The installation costs for central heating can be about 12,000€ in a detached house (Mattinen et al. 2014a). Typically, the most feasible and cost-effective ways to cut GHGEs remain unclear to homeowners with resistance electric heating.

Adato Energia (2013) conducts regular surveys to produce and update models on household electricity use in Finland. In a typical single-family house of 120 m² with four inhabitants and electric heating, the total electricity consumption is 19,600 kWh per year. A fireplace is used for additional heating, consuming 2000 kWh of energy from wood fuels. Together, space and water heating consume 67 % of the electricity and the remaining 6400 kWh is used for appliances. Lighting and the sauna stove are the two categories with the highest consumption (1120 and 1000 kWh per year, respectively). The third group is electronic appliances (700 kWh per year) followed by cooking (680 kWh per year), cold appliances (600 kWh per year), laundry (600 kWh per year), mechanical ventilation (600 kWh), car engine heating (400 kWh) and miscellaneous (700 kWh).

Methodology

Calculations of greenhouse-gas emissions

To assess the complete GHGEs (i.e. carbon footprint) of technical systems and behavioural changes, the principles of life cycle thinking and life cycle assessment (LCA) were employed. This study compares and describes the relevant physical flows of systems for space heating, domestic hot water and electricity use using an attributional LCA approach. The impacts of systemic changes, which could be assessed with consequential LCA approach, are beyond the scope of this article. This paper aims to quantify emissions and cost savings in an exemplar household within 1 year (year 2011). The potential savings are calculated by comparing a base case with a household that has undertaken technical or behavioral changes. The functional unit is the comfortable living of a family of four in a detached house for one year. More

specifically, the following set of functions are to be performed within the house during 1 year: 160 m² of heated and lighted space, 920 kg of clean clothing and average cooking, showering, bathing and other energy-consuming activities of the family. The reference flows necessary to deliver the performance are described in more detail in ‘Cases and measures analysed’.

The average emission factor for Finnish electricity (SYKE 2013) was used in the electricity-related calculations. This emission factor describes the life-cycle emissions of purchased electricity in Finland, and thus includes the emissions of upstream processes related to both electricity production and raw material extraction.

Methods for profitability calculations

Economic calculations for investments were made using the simple payback method (SPP) and the internal rate of return (IRR). The simple payback period is calculated by dividing investment costs by annual savings (no interest rates were used). The IRR of an investment tells an economically minded investor whether the investment is feasible to carry out with a loan, whether the money should be invested in something else or even be deposited in a bank account at the current interest rate. The current interest rates are approximately 0–2 %, which is even lower than the present inflation. For example, the 3-month Euribor has been on average 2.4 % for the last 15 years (values on first of January), and it has been less than 1.5 % for the last 5 years (Bank of Finland 2014).

The costs of measures to reduce energy use were calculated by combining the investment cost and monetary savings in purchased energy for the lifetime of the measure (calculated according to the restricting component). The sum was then divided by the saved kilowatt-hours of the measure over its total lifetime. This renders a figure which is smaller the better the measure is in economic terms, and negative for measures that save not only energy but also money. The same calculation method was also applied to the cost of decreasing GHGE. No monetary values were calculated for the resident’s own work and effort in implementing the measures.

The average electricity price in 2011 was 11.97 c/kWh for an electrically heated detached house (Statistics Finland 2014d). The price is for an electrically heated house (consumption 20,000 kWh per annum), and it includes both variable and fixed charges. The fixed charges with

taxes add up to 216€ per annum, as fixed charges are roughly 15€ and 3€ per month for transmission and energy, respectively. Thus, the variable cost of electricity comes down to 10.89 c/kWh. The variable cost includes energy, transmission charges per kWh and related taxes. Other electricity using buildings considered in this article are a summer house and a garage. The garage is usually attached to same subscriber line as the household, so the same electricity price was used for the garage. Because the energy savings do not reduce the fixed charges and the variable expenses can be the same in detached houses as in the summer houses, it was justified to use the same electricity price (10.89 c/kWh) also for the summer house.

Cases and measures analysed

Overview of cases and measures

The climate impacts of households are considerable, as has been shown in the previous literature (Nissinen et al. 2014; Hertwich and Peters 2009). The main contributors to the impacts within the housing sector are space heating, domestic hot water and the electricity consumption of the various appliances. Nissinen et al. (2014) have estimated that a policy instrument package targeted at housing would result in about 20 % (2-Mt reduction) in the housing-related GHGEs by 2020 in Finland. This reduction consists of replacing or improving the heating system (0.92-Mt reduction), more energy efficient user behaviour (0.36-Mt reduction), more energy efficient household appliances (0.34-Mt) and energy renovations of building envelopes and technical systems (0.4-Mt reduction). Because of the supposed reduction potential in emissions and the lack of climate impact assessments of user modifications and other innovative solutions, this study considers 20 measures. The measures focus on the main emission contributors of a household and can be further divided in five groups: measures related to renovation, behavioural changes (habits), replacement of appliances, timing of electricity consumption and innovative measures, including user modifications. An overview of the base case and all measures analysed is presented in Table 1. The expected benefits from the measures are mostly from reduced electricity consumption—only one measure (timing of the appliance use) keeps the consumption equal. All measures, with the exception of one innovative measure

Table 1 Overview of the studied case house and related measures

Cases and measures	Short name	Abbreviation	Remarks	Modelling approach
Case house	Base case house (160 m ² detached house, 4 residents), no measures	B	Represents a typical Finnish household.	Literature-based, see Table 2 for list of sources
Measures	Renovation of the house (new windows, extra insulation in outer walls and roof)	R	Needs investments and construction work for better insulation, but no new technology or control of new devices	Calculations based on Mattinen et al. (2014b)
	Changed habits include decrease in indoor temperature and decreases in the use of a sauna stove, electronic appliances and laundry	H	No need for any investments or construction work. Implementation and permanence of change is uncertain.	Literature-based analysis. See 'Measure: changed habits (H)' for details.
	Energy-efficient new appliances (LED lights, fridge and freezer, water saving taps and shower heads)	A	Needs investments, rather easy to put in practice, permanent change (for the lifetime of the appliances).	Literature-based analysis. See 'Measure: energy-efficient new appliances (A)' for details.
	Innovative cost-based timing of electricity use (washing machines)	T	Timing of equipment operation requires rather new appliances and some planning and monitoring	Optimisation problem solved with MS Excel making use of Kopsakangas-Savolainen et al. 2014.
	Installation of conventional air-to-air heat pump	AHP	Needs investments and some monitoring of the systems. Permanent change (for the life-time of the equipment)	Calculations follow Mattinen et al. (2014a).
	Innovative heating systems (solar heat collectors, heat pump modifications)	I		
	Self-built solar heat collector	I_h		Calculations make use of both literature and measured values.
	Ground-source air heat pump (GSAHP)	I_g		Calculations follow Mattinen et al. (2014a)
	Air-to-air heat pump (ASHP) adjusted to low temperature, installed to a garage	I_a		Calculations make use of both literature and measured values.

are modelled in the exemplar house (one measure focuses on heating non-lived spaces).

The innovative measures include technical solutions for domestic hot water and space heating. Two user-generated heat pump inventions, previously identified and analysed by Hyysalo et al. (2013a, b), are studied: a commercialised user design and a user modification, both applied to a common air-source heat pump. The analysed inventions are culminations of more than 100 modifications and innovations by users of heat pump technologies in Finland (Hyysalo et al. 2013a, b). The commercialised user design is a new type of a ground-source heat pump originally invented by a user and subsequently taken into commercial production on a small scale. This solution caters to buildings that lack a central heating system and cannot thus use conventional (boiler-connected) ground source heat pump designs. It combines a ground-heat exchanger and a refrigerant-to-air-type heat pump. This type of a heat pump can be used for space heating even in low outdoor temperatures (temperatures below $-15\text{ }^{\circ}\text{C}$), when a typical air-to-air heat pump fails to operate efficiently; hence, it is relevant for Finnish conditions.

The other invention, the user modification, allows the user to have a low maintenance temperature in a semi-heated or non-lived space (e.g. a summer house or a garage). This is accomplished by installing a supplementary resistor into a simple air-to-air heat pump. This kind of modified heat pump operation can be useful when the user needs a maintenance temperature above $0\text{ }^{\circ}\text{C}$ in order to avoid freezing problems with water piping in non-lived spaces. Heat pumps can cut this maintenance energy use, and the latest off-the-shelf air-to-air heat pumps support this type of functionality, but at a higher price than modified cheap models.

Base case (case B)

The exemplar house studied in this paper is a 160-m^2 detached house with four residents (Table 2), which corresponds to the average living space per person of 39.4 m^2 in Finnish households in 2011 (Statistics Finland 2014e). The year of construction is set to the 1980s because this is the most typical age for Finnish detached houses (16 % were built in that decade). The property is located in the southern part of Finland (the mildest climate zone I, Ministry of Environment 2012). The electricity consumption for space heating (excluding water heating) was estimated with the aid of a

modelling approach described in Mattinen et al. (2014b). It was assumed that the house has natural ventilation (no mechanical ventilation or other air conditioning device) because mechanical ventilation only started to mainstream later in the 1980s. Domestic hot water is heated in a boiler with a heating coil and a control unit to an estimated temperature of $55\text{ }^{\circ}\text{C}$ from an initial temperature of $5\text{ }^{\circ}\text{C}$, resulting in electricity consumption of 58.3 kWh/m^3 . Electricity consumption for appliances in the exemplar house represents a typical Finnish household of four persons living in a detached house (Adato Energia 2013). For clarity in the energy calculation, it was assumed that the building has a simplified one-room layout, and possible losses in domestic hot water heating were excluded.

Measure: renovations (R)

The renovations considered here are technical changes in the building envelope of the base case property. Two types of changes are considered as follows: changing the windows and supplementary insulation of outer walls and roof. This measure requires some understanding of energy efficiency (of the insulation materials, window types) at the moment of purchase. The renovation itself requires either time and some skills or time for finding a decent contractor for the job. All in all, the renovation takes about 4 weeks (160 h of work), but after that no control or concern is required from the resident. There is, however, a risk of rebound, if the room temperature is increased.

The impacts of the changes on the space heating were calculated by using the modelling approach described by Mattinen et al. (2014b). It was assumed that the renovated house fulfils the Finnish building code (Ministry of the Environment 2012); in other words, the thermal transmittances of windows, walls and roof were set to correspond to the norms in the calculation. For the roof insulation, it was assumed that about 25 cm of wood fibre insulation is added. In the outer walls, it was assumed that 13 cm of rock wool insulation was added. The technical details and life-cycle emissions of insulation materials correspond to the Ecoinvent (2010, 2013) processes available.

For the windows, the thermal transmittance is assumed to be reduced by replacing the current windows by three-glass-selective ones with a gas fill. It was assumed that the windows have metal-wood frames. Because the windows have to be replaced in any case and the emissions related to the final disposal of a

Table 2 Technical details of the studied exemplar household using direct electricity for space heating. The house is built in the 1980s and has four residents

		Value	Unit of measurement	Source/basis for calculation
General characteristics of the property	Floor area	160	Floor-m ²	Statistics Finland (2014e)
Thermal transmittances of the building structures (<i>U</i> values)	Outer walls	0.28	W/m ² K	Model presented in Mattinen et al. (2014b)
	Roof	0.21	W/m ² K	
	Floor	0.3	W/m ² K	
	Frames, doors	1.0	W/m ² K	
	Windows	1.7	W/m ² K	
Water consumption of the household	Total ^a	226	m ³ /year	Motiva (2014)
	Hot water ^b	66	m ³ /year	
Electricity consumption of the household	Electricity for space heating (excl. water heating)	13,654	kWh/year	Calculations based on Mattinen et al. (2014b)
	Electricity for heating domestic hot water	3850	kWh/year	Temperature of cold water (5 °C) raised to 55 °C
	Lighting	1150	kWh/year	Adato Energia (2013)
	Electronic appliances	770	kWh/year	
	Cooking and dishwashing	680	kWh/year	
	Fridge and freezer	600	kWh/year	
	Laundry (washing and drying)	600	kWh/year	
	Electric sauna stove	1000	kWh/year	
	Car engine heating	300	kWh/year	
	Other appliances	700	kWh/year	
	Total	23,304	kWh/year	

floor-m² floor square metre, *m³* cubic metre, *W/m²K* watt per square metre Kelvin, *kWh* kilowatt hour.

^a Corresponds to daily consumption of 155 l per person

^b Corresponds to daily consumption of 45 l per person

double or triple glazing were assumed to be equal, only the difference in the production-related emissions of the new and old windows was taken into account in the calculation. The GHGEs of the production of the windows are based on the Ecoinvent database (2010, 2013).

The expected lifetime of the insulation materials and windows was assumed to be 30 years. After the lifetime of the insulation material, it was assumed that the rock wool and cellulose fibre will be used in the future refurbishments of the property, and thus, end-of-life emissions were assumed to be non-existent. The effect on the energy demand in each renovation measure was calculated one by one, and the total effect was simply aggregated because the cumulative effect was assumed to be additive.

Measure: changed habits (H)

Changes in habits do not require any replacement of existing devices or investments. In the European

context, households could cut 48 % of their electricity consumption for appliances and lighting by using best available technology and best practice behaviour (de Almeida et al. 2008). Realisation of the saving potential, however, is affected by human, contextual and economic factors and constraints (see e.g. Abrahamse et al. 2005; Barr et al. 2005; Lillemo 2014). Residents need to be aware of their own routines and the need for change and capable of changing their behaviour on a permanent basis (Fischer 2008). In the beginning, the change requires some explicit attention, but over time, the new routine becomes part of the everyday practices.

Measures considered here include lowering the indoor temperature during the heating season and taking electricity saving measures in three appliance categories, based on changes in use patterns in the base case household. The heating electricity consumption is assumed to decrease by 4.7 % compared to the base case (exemplar household) when the indoor temperature is

lowered by 1 °C (Mattinen et al. 2014b). The electricity consumption for the three appliance categories (a sauna stove, electronic appliances and laundry) is presented in Table 2. Together, these categories account for 50 % of the household electricity consumption for appliances. The categories were chosen because of their high or increasing share in the electricity consumption in Finnish households (Adato Energia 2013).

The lighting and the electric sauna stove consume the most electricity in the base case (Table 2). Heating a sauna stove (output 6 kW) to provide required temperatures for bathing (70...80 °C) consumes 4.5 kWh. Maintaining the temperature during use requires an additional 4 kWh of electricity per hour (Work Efficiency Institute 2014). In the base case, the sauna was assumed to be used 125 times per year—this is roughly in line with the assumption that Finns bathe in the sauna twice a week on average. Furthermore, it was assumed that every fourth time, the stove is used only for half an hour and in other times for 1 h. After the changed behaviour, the sauna was assumed to be used 65 times per year, 40 times for 1 h and 25 times for half an hour.

Electronic appliances were chosen as a second consumption category, because the number of appliances is increasing, and the electricity consumption of appliances has more than doubled since 1993 in Finnish households (Adato Energia 2013). The base case consumption of the electronic appliances (770 kWh) was allocated to the following set of devices and their typical use times: two liquid crystal display (LCD) televisions and digital converters, one laptop computer, one desktop computer, one set of stereos, a router for wireless fidelity (wifi) and a video game console (Playstation, Wii or similar). The assumed use times per device ranged between 1 and 8 h per day on average. Altogether, 30 W of standby power for 20 h per day was also included in the appliances' electricity use. Calculated savings are based on reductions of use times and the elimination of the standby power. Conveniently located switches reduce the required effort to cut standby power. Yet standby power cannot always be eliminated, e.g. if a digital receiver is recording during the night. There are differences between households in the types of devices used and the user requirements. This affects the potential to cut down standby power. To simplify the case, an assumption of zero standby power was made.

Laundry is the third category included. A family of four washes 920 kg of laundry per year, the size of an

average washing load being 2.9 kg (Aalto 2003). On average, Finnish families with children do the laundry six times per week (Aalto 2003). Therefore, savings can be gained by washing full loads, but fewer times. In addition, decreasing the number of loads dried in a tumble drier (drying outside on a clothes line instead) reduces the electricity consumption for laundry.

The base case electricity consumption of laundry (600 kWh) was estimated to encompass 210 loads washed at 40 °C, and 107 loads at 60 °C cycle. The electricity consumptions of these cycles were 0.6 kWh and 0.95 kWh, respectively (Work Efficiency Institute 2014). In addition, 178 tumble drying cycles (2.1 kWh per cycle) are included in the base line consumption. If the same amount of laundry is washed in full 5 kg loads, and the number of drying cycles is reduced to 80, the electricity consumption for laundry can be halved.

Measure: energy-efficient new appliances (A)

Appliance and heating electricity consumption can be reduced by replacing existing devices with more energy-efficient ones. Here, savings for the fridge and freezer, lighting and water saving taps and showers are presented. Considering the effort required to implement this measure, the acquisition of the appliances requires some understanding of energy efficiency, but the actual installation is easy and quick.

The calculated savings are based on the direct energy consumption during the use phase. The GHGE of other lifecycle phases (materials, manufacturing, distribution and the end of life) are excluded due to missing data on differences between new (energy efficient) and old appliances. However, the relevance of other phases compared to the use phase is estimated for each device category. The appliances and light bulbs need to be replaced in any case over a certain period of time. In the literature, 14 or 15 years has been the life time of a refrigerator (Faber 2007; Monfared et al. 2014). The operating lifetimes of an incandescent life bulb, compact fluorescent light bulbs (CFL) and light emitting diode (LED)-lighting are 1000, 8500 and 25,000 h, respectively (Scholand and Dillon 2012). In domestic use, the life time of a tap is 16, and of a shower 10 years (Kaps and Wolf 2013).

The base case consumption for one fridge and one freezer is calculated according to Adato Energia (2013). The old devices are replaced with the most energy-efficient fridge (volume 300 l) and freezer (volume

220 l) available in the Finnish market (Topten Suomi 2013), with consumption levels as reported by the manufacturers. The use phase of refrigerators accounts for more than 80 % of the life cycle wide GHGE (Faber 2007). One should note that the GHGEs of the use phase depend heavily on the energy mix used in the electricity production (Monfared et al. 2014).

The lighting in the base case is a combination of incandescent light bulbs, lighting tubes and CFLs, altogether 23 lamps (power consumption 450 W), and savings are a result of replacing them with LED lighting (power consumption 181 W altogether). On average, all lights are used daily for 7 h. The total electricity consumption for lighting is according to Adato Energia (2013). When the old lights are replaced by LEDs and the use time is kept constant, the electricity consumption is reduced by 60 %. The use phase causes 90 % of the GHGEs of LED lighting (Scholand and Dillon 2012).

Domestic hot water savings and the related reductions in the heating energy are based on a case study (Tenhunen et al. 2012). When the old taps and showerheads are replaced with new water saving models, hot water consumption is assumed to be cut by 14 % compared to the base line. The manufacturing phase of taps and showers is excluded because the use phase accounts for more than 99 % of the total GHGEs (Kaps and Wolf 2013). Water savings can be also achieved without installation of new taps and shower heads by installing aerators instead.

In the profitability calculation, the LED light investments amount to 345€, and the savings are 688 kWh/a, resulting in 75€/a. The lifetime of LED lightbulbs and tubes is estimated to be 10 years, so lifetime savings in energy are 6880 kWh and monetary savings are 750€.

Measure: cost-based timing of electricity use (T)

The effects of timing the use of common household appliances (a washing machine and a dishwasher) were considered. The mix of electricity production technologies (and the related emissions) can vary hour by hour, depending on the demand and supply conditions (Kopsakangas-Savolainen et al. 2014). The aim of this analysis of timing was to identify whether households can reduce GHGEs and save money by avoiding appliance use during peak load periods, when electricity is more expensive. This measure presumes that the residents use some time (5 min) to check the prices and plan their actions accordingly. Of course, this practice somewhat restricts the freedom of choice of the residents and

can potentially decrease the quality of life, especially if the timing results in more complicated planning and timing of everyday chores.

For clarity, the use and timing of other appliances than the dishwasher and washing machine were excluded from the analysis. In the base case, the household was assumed to do the laundry and wash dishes at fixed times during the week (17:00–19:00 for the washing machine and 19:00–20:30 for the dishwasher), while in the ‘cost-based timing case’ the household uses the information of the spot price for electricity (Nord Pool Spot 2014) and times the washing to minimise the costs. At present, the hourly prices for the following day are typically announced at 12:42 CET via Nord Pool Spot web-page. Thus, households can use the day-ahead price information to plan their energy-intensive actions for the next day. One should also note that most of the new appliances allow the user to set the start time of a washing programme.

In the cost-based timing case, the total electricity consumption does not change vis-a-vis the base case. The assumed hourly electricity consumptions (kWh/h) for the washing machine and dishwasher were 0.475 and 1.12, respectively (Work Efficiency Institute 2014; Helen 2013). The minimisation was run one day at a time—this corresponds to the assumption that the hourly prices are known 1 day ahead. In other words, the total electricity consumption, as well as the durations of each action, was matched to equal the user’s behaviour in the base case. The actual start time of each action, however, was allowed to vary in the optimisation. The optimised use of the appliances was constrained so that each day, the consumption equals the consumption of the regular user. The minimisation problem was solved by using the generalised reduced gradient code of solver add-in in MS Excel. The corresponding hourly emissions of electricity consumption were calculated by making use of the determined technology and fuel combination on which the hourly production is based, following the approach presented in Kopsakangas-Savolainen et al. (2014). In order to seek the maximum theoretical saving potential, the optimisation was run with the week price and emission data of January 17–23, 2011, which expected to be the peak consumption week.

Measure: installation of an air-to-air heat pump (AHP)

Here, the installation of a standard air-to-air heat pump (abbreviated as ASHP hereafter) as a retrofit in the exemplar house was studied. The life-cycle impacts of

the studied ASHP and the performance of the heat pump were taken into account in a similar manner as in Mattinen et al. (2014a). It was assumed that the refrigerants are handled in a proper way because a qualified person does the installation work. For the resident, it takes about 8 h of work to have an ASHP system in operation.

In the profitability calculations, the cost of a common ASHP as a turnkey solution was assumed to be 1400€.

Measure: self-made solar heat collector (I_n)

The first user innovation considered here is a do-it-yourself (DIY) solar thermal collector. A solar thermal collector uses the sun's radiation energy to heat water, which can be either used for domestic hot water or space heating, or both. Here, only domestic hot water was considered because the exemplar property lacks a central heating system. The necessary know-how for building the collector can be acquired in a self-build course, which also provides the materials. All in all, the resident needs about 40 h of work to gain a functioning system. Jalas et al. (2014) have shown that people engage in self-building in Finland because it offers an opportunity to learn about solar heating and its use while engaging in enjoyable collective work, while obtaining a solar heater at reasonable cost.

The thermal collector consists of an absorbing collector, a water tank, a pump unit, piping, a heat exchanger and a control unit. The sun's radiation is converted to heat in the absorbing collector that includes an absorbing plate and a frame. The absorbing plate consists of tempered glass that allows the sun's radiation to light on to an insulating polyurethane plate, which is coated with a thin aluminium sheet. The heat is then transferred to a heat carrier liquid (mixture of water and antifreeze) circulating in the piping. After this, the collected heat is transferred to the water by a liquid-to-water heat exchanger, and the hot water is distributed further to be used for heating or for domestic hot water. The cooled heat carrier liquid is then circulated back to the collector unit with the aid of an electric pump. The electric pump works automatically within the given temperature rates: It starts circulating the heat carrier liquid when the collector reaches 60 °C and shuts down when temperature lowers to 55 °C.

In this study, an absorbing collector with a net surface of 8 m² was considered. The annual thermal energy output of the collector system was estimated to be

300 kWh/m² because it was assumed to be well-built (i.e. properly insulated and including a commercial absorber) and correspond almost to a commercial collector. A typical commercial collector can reach up to providing 500 kWh/m² per annum in Finland when installed at a 20–60° horizontal angle and pointing towards South East–South West. Also, piping from the collector to accumulator was assumed to be well insulated, so possible losses of the heat transfer from collector to accumulator were excluded. The monthly distribution of the annual production is based on the Finnish guidebook (Heimonen 2011) and expert knowledge of the authors.

It was assumed that the hot water boiler itself and the related heating coil and control unit were existing in the property and the solar collector is installed as a retrofit. In the analysis, only the manufacturing, transport and waste handling of the absorbing collector and electric motor were included. The piping was excluded, because it was assumed to be a minor contributor in the system's life cycle. The impacts of two types of collector frames were studied as follows: an aluminium and a wooden frame. The detailed bill-of-materials (BOM) of the systems is presented in Table 3, and it corresponds to the materials used in DIY solar thermal collector building course (Eurajoki 2014) as well as an estimate of wood as the alternative frame material. The assumed lifetime of an aluminium system was 30 years, and of a wooden one, 15 years. The electric motor responsible for pumping the water was assumed to have a lifetime of 15 years, whereas the other components have longer lifetimes.

Table 3 Bill of materials of the solar thermal collectors: of an aluminium and of a wooden

Material/part	Aluminium collector, mass [kg]	Wooden collector, mass [kg]
Aluminium	71.2	34.4
Copper	25.8	25.8
Wood	0	59.3
Polyurethane	5.0	5.0
Tempered glass	80.0	80.0
Flexible aluminium duct	1.0	1.0
Steel	5.0	5.0
Electric motor	2.0	2
Total mass	190.1	212.6

The inventory results of Ecoinvent (2010) were used for materials and electric motor. The motor (power of 10 W) was assumed to be used, on average, for 8 h during 6 months. For aluminium, the production mix including primary and secondary aluminium was used. The components were assumed to be shipped and transported by truck from Europe to Finland. In the end-of-life phase, it was assumed that the metal, wood and glass parts of the collector are sorted and handled/recycled separately, and the other parts and materials are landfilled. The end-of-life emissions for materials calculated from values by Dahlbo et al. (2011a, 2011b), using the overall sum of the emissions (i.e. produced emissions minus avoided emissions). The carbon storage calculation of the wooden frame is not reported separately here, because the assumed life time of the collector is less than 100 years. The assumed hot water consumption of the household with four residents was 180 l per day, and thus, the annual energy demand for hot water was about 3800 kWh.

In the profitability calculations, the costs correspond to those of a real, representative self-building course (Eurajoki 2014): The course itself costs 255€, and the materials for an 8 m² collector, 1775€.

Measure: ground-source air heat pump (I_g)

The first heat pump invention considered is a commercialised user design: A ground-source air heat pump (GSAHP) comprises a vertical heat collector (also termed a ground heat exchanger, GHE) placed in the ground, a heat pump unit and a fan. The heat pump unit consists of an evaporator, a compressor and a condenser. The operational principle is analogous to a conventional air-source heat pump; further details and the life-cycle-greenhouse-gas emissions of the system have been described and determined previously (Mattinen et al. 2014a). Information for purchasing a GSAHP is readily available in the market and in the public sphere; hence, no expert services are needed. However, for the installation, a qualified person is needed. Furthermore, the system requires a borehole that makes the installation a little more complex than of a conventional air-to-air heat pump, resulting in about 36 h of work to have GSAHP system in operation.

The approach described by Mattinen et al. (2014b) was used to calculate the related life-cycle GHGE during 1 year use in the exemplar house. The heat pump was assumed to be installed as retrofit, and no

refrigerant leakage happens in the end-of-life of the heat pump. The emissions of a GSAHP are compared to baseline situation that uses solely direct electricity for space heating. The system needs a 120-m deep borehole because every kilowatt of generated heat from a heat pump needs 20 m of borehole in bedrock (Finnish Borehole 2014) and 10–20 m extra (Juvonen and Lapinlampi 2013). The cost of drilling was assumed to be 30€/m (Finnish ground-source-heat-pump forum 2014), and the heat pump itself costs 3500€ (Salmela 2012). The installation work was assumed to consist the work of two professionals for 1 day (salary of 50€/h). Altogether, a GSAHP costs as a turnkey solution around 7900€.

Measure: modified air-to-air heat pump (I_a)

The second type of user innovation considered here is a simple modification for a conventional ASHP identified by Hyysalo et al. (2013b). The simple idea of the modification is to fool the indoor temperature sensors of the ASHP in order to achieve lower indoor temperatures than those provided by standard models. The modification involves the installation of a supplementary resistor that allows the user to achieve a lowered preheat maintenance temperature for a space. The implementation of the modification requires acquaintance with the available online documentation and skills and competence to use specific tools for installing the resistor. The time needed for the modification depends on the residents' skills, but about 12 h of work is needed to buy a simple air-to-air heat pump and make the modification.

Typically, the lowest temperature a cheap air-to-air heat pump maintains in a space is about +16 °C, but with the resistor modification, the maintained temperature can be lowered to +8 °C, for instance. For the modification, a negative temperature coefficient (NTC) thermistor is connected in parallel in the temperature probe of the heat pump's indoor unit. An NTC thermistor is a resistor that lowers its resistance with increasing temperature, and it is easy to install afterwards by an ordinary user. This do-it-yourself user modification has been successfully implemented and documented in the main user-run heat-pump Internet forum in Finland (www.lampopumppufoorumi.net).

A 20-m² garage and a 40-m² summer house that use the heat pump for the maintenance heating were considered. The thermal properties of both buildings correspond to semi-heated spaces in the Finnish building code

(Ministry of the Environment 2010), with the following thermal transmittances: the floor and the roof $0.14 \text{ W/m}^2\text{K}$, the outer walls $0.26 \text{ W/m}^2\text{K}$ and the windows and doors $1.4 \text{ W/m}^2\text{K}$. The GHGEs and costs are calculated and compared for 1 year. As the reference cases, the buildings are heated by using solely electric radiators that are already in place. The other life-cycle phases (i.e. construction or maintenance) of the studied properties are omitted, because they remain the same as in the base case. The life-cycle impacts of the studied ASHP, energy performance and energy demand of the buildings were calculated as in Mattinen et al. (2014a). The energy performance modelling corresponds to the mildest climate zone conditions in Finland (average outdoor temperature approximately $+5 \text{ }^\circ\text{C}$). The indoor temperature, however, was set to be $+8 \text{ }^\circ\text{C}$. In the calculation, the passive gains, such as thermal gains from the sun, people and use of appliances were not taken into account, because the premises are not used for continuous living. Energy for space heating generated by a heat pump and the pump's electricity consumption were calculated with the aid of the technical properties of the heat pump. It was assumed that the heat pump did not have a limiting temperature for operation. The coefficient of performance (COP) and the input power (P_{in}) of the modified heat pump were modelled linearly, by using the values given in the internet thread: $\text{COP}=2.5$, $P_{\text{in}}=0.66$, at the outdoor temperature of $-15.7 \text{ }^\circ\text{C}$, and $\text{COP}=3.2$, $P_{\text{in}}=0.77$, at the outdoor temperature of $-3 \text{ }^\circ\text{C}$ (Lampopumput 2009).

In the profitability calculations, the cost for the ASHP was similar as in the conventional ASHP case, and the modification is practically free (the cost of an NTC thermistor is about 1 °).

Results

Table 4 collates the energy use, emissions and costs for the base case and the renovated house. In Fig. 1, the effects of measures (except the summer house and garage related) are presented relative to the base case. Only

differences in the energy use and emissions are presented because the saving in costs equals the relative saving in energy use. The life cycle approach can be seen in the renovation case, as well as in the innovative cases results, for instance, the relative savings of the heat pumps differ a little compared to the saving in energy. The details of the implications of all studied measures are collated in Table 5.

The cost of decrease in energy use and the cost of decrease in GHG emissions are also presented in Table 5. For example, in the LED light bulb case (B-A, lighting), when the investment cost and monetary savings are combined, the lifetime cost of the investment is -404 ° , so the investment saves money over its lifetime. This sum divided by lifetime energy savings (6880 kWh) gives the cost for decrease in energy use ($-0.05970 \text{ }^\circ/\text{kWh}$); in other words, every saved kilowatt-hour also saves money (0.059 °).

In the innovative measures, both types of the thermal collector systems have about $650 \text{ kg CO}_2\text{eq}$ lower emissions per annum compared to the reference system. The aluminium frame has higher emissions because the manufacturing phase, namely, the production of aluminium is more carbon intensive compared to wood. Simply calculated, the CO_2eq saving per year would 'repay' the emissions occurred during the manufacturing and transport phase after two summers.

The results of the profitability calculations are collated in Table 6. The higher the IRR and, on the other hand, the lower the SPP, the better the investment is. SPP tells how many years of savings are required to match the original investment. On the other hand, IRR tells the highest feasible interest rate that can be paid for a loan to make the investment. The calculated IRR values can be compared also to the investment objects that people usually have in Finland: the 3-month Euribor interest for a deposit (average for the last 15 years) or the annual mean return from Helsinki stock exchange or bonds (Nyberg 2009), given also in Table 6. For example, if a loan is tied to the 3-month Euribor and the borrowed money is used for LED light bulbs (IRR 17.3 ° , see

Table 4 Energy use, GHG emissions and costs for the base case (B) and the renovated house (R)

Case	Electricity use [kWh/a]	GHG emissions [kg $\text{CO}_2\text{eq/a}$]	Energy-related costs [$^\circ/a$]
B	23,304	6991	2752
R	18,501	5616	2230

GHG greenhouse gas, kWh kilowatt hour, kg CO_2eq kilograms carbon dioxide equivalent

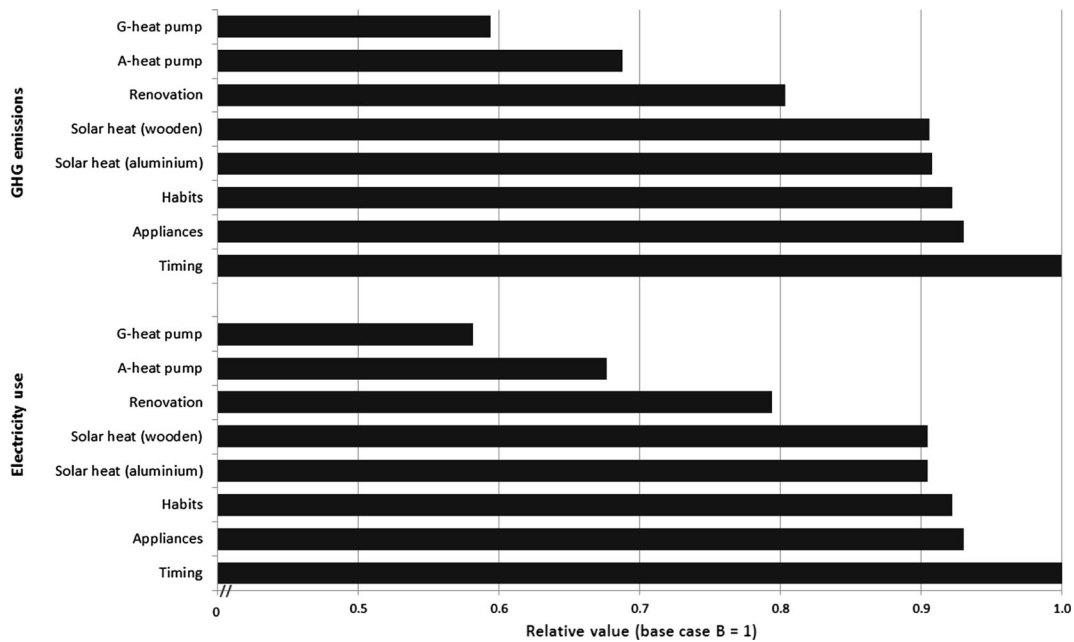


Fig. 1 Differences applicable for the base case in electricity use and greenhouse-gas emissions (GHGE) due to measures. The base case (B) corresponds to value 1, and the effect of the measures are presented relatively to this. Short names of the measures as in Table 1

Table 6), the light bulbs will pay the interest and more. Taps and showerheads (IRR -0.5%), on the other hand, are not profitable investments. Because of the high IRR value of the air heat pump measure (B-AHP), the ASHP seems a better investment than stocks on average. In the renovations category, only adding extra insulation to the roof seems worth doing with a loan because the IRR is higher than the Euribor interest rate. From a greenhouse-gas perspective, almost all of the studied methods are economically justifiable. In the EU emission trading scheme, the price for CO_2 has been lately roughly $5\text{€}/\text{t}$. Only renovating the windows and walls, replacing the fridge and freezer, and taps and showerheads seem to result in a higher price for decreasing GHG emissions than $5\text{€}/\text{t}$. The rest of the studied measures are actually also saving money while decreasing GHG emissions.

One should note that in reality, the borehole required for the GSAHP system is usable with very little maintenance even after the heat pump should be replaced, so the residual value after 15 years is at least 3000€ and would raise the IRR to 12% . Moreover, the high IRR for the conventional ASHP (measure B-AHP) can be explained by simplifications made in the calculations that assume that the property has a simple one-room layout. In real life, the living space is divided with walls and has furniture, and these elements restrict the air flow, and thus reduce the effect of the heat pump.

Discussion

In the example house, the three most effective measures in terms of the calculated energy and greenhouse-gas savings are the following (see Tab. 5): installation of an innovative modified ground-source heat pump, installation of a conventional air-source heat pump and refurbishment of the building envelope (adding extra insulation and changing the windows for high-performance ones). The estimated energy saving potential of changed habits is in the same order of magnitude as the effect of more efficient appliances and the installation of a thermal solar collector. In the terms of GHGE, the savings gained through behavioural changes are comparable with the ones gained with the solar thermal collector. The costs of reducing energy and GHG emissions in Table 5 and the simple payback periods in Table 6 show that most of the measures also save money during the expected lifetime. Only the renovation measures and the replacement of the fridge and freezer and changing taps and showerheads do not save money in their lifetime. Monetary savings of cold appliances could be improved if the assumption of choosing the best available products on the market would be compromised and new appliances from a lower energy class were chosen. In the case of taps and shower heads, aerators installed in existing taps and showerheads could provide water savings with

Table 5 Decreases in energy use, GHG emissions and costs from measures. Abbreviations as in Table 1

Type of measure	Decrease in electricity use		Decrease in GHG emissions ^{a,c}		Decrease in energy-related costs ^{b,d}		Cost of decrease in energy use ^d [€/kWh]	Cost of decrease in GHGE [€/kg CO ₂ eq]
	Absolute decrease [kWh/a]	Per cent decrease (within measure /compared to base case)	Absolute decrease [kg CO ₂ eq/a]	Per cent decrease [%] (within measure /compared to base case)	Absolute decrease [€/a]	Per cent decrease [%] (within measure /compared to base case)		
B-R	1212	9/5	356	9/4	132	9/5	0.084	0.285
Walls (30)	1755	13/8	484	13/7	191	13/7	0.013	0.046
Roof (30)	1835	13/8	536	13/7	200	13/7	-0.065	-0.223
Total (30)	4803	35/21	1376	35/20	523	35/19	0.000	-0.003
B-H	642	5/3	193	5/3	70	5/3	-0.109	-0.363
Space heating (1)	497	50/2	149	50/2	54	50/2	-0.109	-0.363
Sauna (1)	379	49/2	114	49/2	41	49/1	-0.109	-0.363
Electronic appliances (1)	300	50/1	90	50/1	33	50/1	-0.109	-0.363
Laundry (1)	1818	11/8	545	11/8	198	11/7	-0.109	-0.363
Total (1)	688	60/3	206	60/3	75	60/3	-0.059	-0.196
B-A ^e	393	66/2	118	66/2	43	66/2	0.217	0.723
Lighting (10)	552	14/2	166	14/2	60	14/2	0.003	0.010
Fridge and freezer (14)	1632	29/7	490	29/7	178	29/6	0.060	0.200
Taps and showerheads (10)	0	0	2	1/<1	5	6/<1	na	-2.272
Total (10)	7548	55/32	2184	53/31	822	55/30	-0.090	-0.312
B-T	2234	58/10	647	56/9	243	58/9	-0.082	-0.284
Washing machines (1)	2234	58/10	658	57/9	243	58/9	-0.056	-0.190
A-heat pump (10)	9757	71/42	2839	69/41	1062	71/39	-0.055	-0.189
B-AHP	3257	62/na	897	57/na	355	62/na	-0.066	-0.239
I	3510	62/na	973	57/na	382	62/na	-0.069	-0.249
B-I _n (A1 frame) (30)								
B-I _n (Wooden frame) (15)								
B-I _g (15)								
G-I _a (garage) (10)								
SH-I _a ^e (summer house) (10)								

na not applicable, GHGE greenhouse-gas emission

^a Including life cycle-based emissions of the equipment for the innovative heating systems

^b Including investments for installed new appliances and systems

^c Emission factor for Finnish electricity: 0.3 kg CO₂eq/kWh

^d Variable price of electricity 0.1089€/kWh

^e Only the use phase (energy use) included, i.e. other life cycle phases of the appliances (e.g. lamps) are excluded

Table 6 Results of economic assessment. Abbreviations as in Table 1

Type of measure	Details	Investment costs (€)	SPP (years)	IRR (%)
B-R	Windows	7000	53.1	−3.3
	Walls	6402	33.5	−0.7
	Roof	2400	12.0	7.3
	Total	15,802	30.2	0.0
B-H	Space heating	0	0.0	na
	Sauna	0	0.0	na
	Electronic appliances	0	0.0	na
	Laundry	0	0.0	na
	Total	0	0.0	na
B-A*	Lighting	345	4.6	17.3
	Fridge and freezer	1794	41.9	−12.1
	Taps and showerheads	618	10.3	−0.5
	Total	2757	15.5	−5.3
B-T	Washing machines	0	na	na
B-AHP	A-heat pump	1400	1.7	58.1
I	B-I _h (Al frame)	1775	7.3	10.7
	B-I _h (Wooden frame)	1775	7.3	10.2
	B-I _g	7900	7.4	10.4
	G-I _a (garage)	1400	3.9	21.8
	SH-I _a *(summer house)	1400	3.7	24.2
Reference	Euribor	na	na	2.4
	Stocks	na	na	18.7
	Bonds	na	na	7.8

SPP simple payback period, IRR internal rate of return, na not applicable

lower investment costs. In monetary terms, the most attractive investment seems to be investing in LED light bulbs and ASHPs. These investments seem to give an even better return on invested money than stocks in Helsinki (Finland) on average. Most of the studied investments give a higher return on investment than the current margin and interest rate for the 3-month Euribor. All of these investments would be feasible to carry out even with a loan. Unfortunately, every household is not eligible for a bank loan, so they are in a situation where they do not have enough money to save more money. However, the LED lighting measure can be taken even without a loan. Naturally, the extent of the savings achieved via particular measures depends on the study context: our analysis pertains to a particular typical Finnish building and its residents, and more general conclusions are indicative rather than definitive.

There are some simplifications in our calculations; for instance, the layout of the building is assumed to be very simple, and assumptions were made regarding the materials, among other things, in the analysis of the life

cycle phases of the devices. The assumed simple layout of the building may exaggerate the benefits of the air heat pumps somewhat because it allows the heat to spread more evenly than it would in real life, depending on the actual room layout, amount of furniture etc. Other examined measures do not benefit from this assumption. Despite the simplifications, the calculations indicate that there is a clear saving potential in the studied measures, which is in line with previous findings pertaining to energy-efficiency investments (e.g. Kuusk et al. 2014) and behavioural changes (Abrahamse et al. 2005). Compared to previous research, our analysis offers three novel perspectives: Both technical and behavioural changes were considered from a life-cycle perspective; the assessment included the energy, greenhouse-gas emissions and cost impacts of these measures, and the alternative measures analysed in parallel with conventional ones included innovative and rather new energy conserving measures.

The comparison of technical and behavioural measures indicates that both offer potential and that some

behavioural changes are on par in terms of savings potential to technical measures like the replacement of household appliances with more energy-efficient ones. Energy saving through behavioural changes and retrofits are not fully comparable with each other, however. If LED lights are installed, energy saving requires no further action. Changing the existing habits and routines requires attention and effort especially in the beginning. If the new practice turns into a routine, behavioural changes create savings on an ongoing basis. The instruments to support behaviour change (i.e. information campaigns, financial instruments etc.) are outside the scope of this article. Consulting the vast literature on empirical research on behavioural change potential, however, provides an overall understanding of the magnitude of behaviour change potential. Empirical results can be compared with modelled results presented in this paper to assess how realistic the estimated potential is. Previous studies show that behavioural interventions in residential energy use, e.g. tailored feedback, render savings between 2 and 10 % (Abrahamse et al. 2005, 2007; see also Delmas et al. 2013). Although the results presented here are not fully comparable, we find the order of magnitude is about the same. The development of feedback mechanisms and implementation of new pricing models can further support the necessary behaviour change. These mechanisms and models include breakdown of total electricity use to individual appliances (Karjalainen 2011), smart metering, in-house displays (Buchanan et al. 2014) and time-of-use tariffs (Carroll et al. 2014; Paetz et al. 2012). More empirical studies are needed to reveal the potential and the most effective interventions to realise the energy savings presented in this paper.

The life cycle approach also shows that the savings gained from energy-efficient and renewable investments clearly outweigh any additional emissions from the production stage. In this paper, the renovations were assumed to be conducted and appliances replaced at the end of their technical life span. It is possible that earlier replacement and the resulting energy savings could outweigh the additional GHGE from manufacturing. The optimal time for replacement depends on the GHGEs in manufacturing, transport and recycling, as well as on the greenhouse-gas intensity of electricity in the use phase. For instance, the optimal lifespans of cold appliances seems to vary (Bakker et al. 2014; Tasaki et al. 2013; Rüdener and Fischer 2011; Kim et al. 2006). Defining an optimal time for

renovations and appliance replacements in the Finnish context is outside the scope of this article.

Another further point for analysis would be the rebound effects (Nässén and Holmberg 2009), i.e. the question of how the changes in energy expenditure or behavioral change affect energy consumption in other areas or expenditure and behaviour in other consumption categories. For instance, if the energy performance of the house is increased, will the indoor temperature be increased? What is done with the money saved on the electricity bill? Is it saved, invested or consumed for other purposes, and what are the (environmental) impacts of these actions? Yet, if rebound effects are considered, the positive spillover effects should also be analysed (Hertwich 2005). In particular, some of the user innovations studied for this paper are linked to positive spillover effects like environmental activism (Jalas et al. 2014), and it is likely that behaviour changes could also entail such effects. Whether this actually is the case in the study context remains a task for further research.

Our analysis suggests that user innovations or modifications of standard technologies to local context offer potential for energy and cost savings and reductions of greenhouse-gas emissions. The particular innovations analysed for the present study address the specific challenges present in the Finnish context. The number of households using direct electricity for space heating without a central heating system is roughly 400,000. Instead of installing an air-source heat pump (as is increasingly the case today), the households could benefit more from a ground-source air-heat pump that operates in lower temperatures than a conventional air-to-air heat pump. The installation of GSAHP requires digging or drilling (depending on the installation site and type), but otherwise, the use is easy and does not require expertise. In Finland, there are next to half a million summer houses, which most typically use electricity or wood for space heating. Even though the majority of the summer houses are used between May and September, in some houses, there is a need for maintenance heating so that the plumbing does not freeze. Modifying a cheap conventional air-to-air heat pump for this heating purpose can be a feasible and easy way to cut the electricity costs. The modification requires some skills, but the modification is rather simple and well documented (in Finnish) in a popular online user forum. In other countries and types of buildings, the particular challenges are likely to be different. However,

our analysis suggests that further research might benefit from exploring other local user modifications of standard technical solutions.

Conclusions

User innovations and the involvement of residents in energy issues have received increasing interest. The order of magnitude of a set of energy-related measures in a residential building was quantified in this study in the context of an example household in a cold climate, including both standard technical measures, local user innovations and behavioural changes. Both the economic and emission perspective were considered using a life cycle approach. This analysis yielded a first estimate of some novel ways available for the residents of detached houses to pursue emission reductions related to their housing. The solutions studied differ both in the terms of their scope of emission reduction and the feasibility of their adoption. Our results indicate that the three most effective ways to reduce energy use and greenhouse-gas emissions were as follows: introduction of either a conventional air-to-air heat pump or an innovative ground-source air-heat pump, or adding extra insulation to the roof. On the other hand, the three most profitable measures were as follows: installation of an air-to-air heat pump (IRR 58 %), use of a modified heat pump in a summer house or a garage (IRR \approx 22 %) and LED lighting (IRR \approx 17 %). These measures are all rather easy to adopt and maintain in the households. It is worth mentioning the habit changes too because they require no investments, yet render negative costs per kilowatt-hour (−0.109). The extra insulation and air-to-air heat pump installation in the property are effective ways to reduce the greenhouse-gas emissions related to housing, whereas the modified heat pump in the non-inhabited space has only a minor effect on climate impact mitigation. The studied measures are mostly viable for Finns living in detached houses; only the timing of the dish washing and laundry are not likely to be feasible on a large scale, because the practicality and the ease are likely to be more relevant than the marginal cost saving in a household. The feasibility of the timing, however, could change with the aid of a smart control system that would optimise the use of devices and use the price information available online. In general, we conclude that technical improvements should not be analysed merely in their standard format and for their direct effects, but also in

terms of how they influence user behaviour and how they might be modified to address local constraints.

Acknowledgments The funding from Academy of Finland grants Local Adaptation and Innovation in Practice in Achieving Carbon Neutrality (AKA 140933) is gratefully acknowledged.

References

- Aalto, K. (2003). Who washes the laundry in Finland? Textile care in households and use of textile care services. English summary for National Consumer Research Centre Publication 11: 2003. http://www.ncrc.fi/files/4495/summary_laundry_.pdf. Accessed 29 Aug 2014.
- Abrahamse, W., Steg, L., Vlek, C., & Rothengatter, T. (2005). A review of intervention studies aimed at household energy conservation. *Journal of Environmental Psychology*, 25, 273–291.
- Abrahamse, W., Steg, L., Vlek, C., & Rothengatter, T. (2007). The effect of tailored information, goal setting, and tailored feedback on household energy use, energy-related behaviors, and behavioral antecedents. *Journal of Environmental Psychology*, 27, 265–276.
- Adato Energia. (2013). Kotitalouksien sähkönkäyttö 2011 (Household electricity consumption in 2011, in Finnish). http://www.adato.fi/portals/2/attachments/Energiatehokkuus/Kotitalouksien_sahkonkaytto_2011_raportti.pdf. Accessed 13 Aug 2014.
- Arnold, M., & Barth, V. (2012). Open innovation in urban energy systems. *Energy Efficiency*, 5(3), 351–364.
- Bakker, C., Wang, F., Huisman, J., & Den Hollander, M. (2014). Products that go round: exploring product life extension through design. *Journal of Cleaner Production*, 69, 10–16.
- Balaras, C. A., Gaglia, A. G., Georgopoulou, E., Mirasgedis, S., Sarafidis, Y., & Lalas, D. P. (2007). European residential buildings and empirical assessment of the Hellenic building stock, energy consumption, emissions and potential energy savings. *Building and Environment*, 2007(42), 1298–1314.
- Bank of Finland. (2014). Euribor rates. http://www.suomenpankki.fi/fi/tilastot/korot/pages/tilastot_markkina_ja_hallinnolliset_korot_euriborkorot_pv_chrt_fi.aspx. Accessed 1 Oct 2014.
- Barr, S., Gilg, A. W., & Ford, N. (2005). The household energy gap: examining the divide between habitual- and purchase-related conservation behaviours. *Energy Policy*, 33, 1425–1444.
- Binswanger, M. (2001). Technological progress and sustainable development: what about the rebound effect? *Ecological Economics*, 36, 119–132.
- Buchanan, K., Russo, R., & Anderson, B. (2014). Feeding back about eco-feedback: how do consumers use and respond to energy monitors? *Energy Policy*, 73, 138–146.
- Carroll, J., Lyons, S., & Denny, E. (2014). Reducing household electricity demand through smart metering: the role of improved information about energy saving. *Energy Economics*, 45, 234–243.

- Chan, A. T., & Yeung, V. C. H. (2005). Implementing building energy codes in Hong Kong: energy savings, environmental impacts and cost. *Energy and Building*, 37, 631–642.
- Chitnis, M., Sorrel, S., Druckman, A., Firth, S. K., & Jackson, T. (2013). Turning lights into flights: estimating direct and indirect rebound effects for the UK households. *Energy Policy*, 55, 234–250.
- Dahlbo, H., Myllymaa, T., Manninen, K. & Korhonen, M.-R. (2011a). GHG emission factors for waste components produced, treated and recovered in the HSY area - Background document for the calculations. www.hsy.fi/julia2030/Documents/Waste_GHG_factors_background_doc_2011_v2_logot.pdf. Accessed 9 Apr 2014.
- Dahlbo, H., Myllymaa, T., Manninen, K. & Korhonen, M.-R. (2011b). GHG emission factors for waste components produced, treated and recovered in the HSY area - Annex 1. http://www.hsy.fi/julia2030/Documents/Waste_GHG_factors_background_doc_tables_2011_logot.pdf. Accessed 9 Apr 2014.
- Darby, S., Strömbäck, J., & Wilks, M. (2013). Potential carbon impacts of smart grid development in six European countries. *Energy Efficiency*, 6(4), 725–739.
- de Almeida, A., Fonseca, P., Banderinha, R., Fernandes, T., Araújo, R., Nunes, U. (2008). Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe. Project report for REMODECE. http://remodece.isr.uc.pt/downloads/REMODECE_PublishableReport_Nov2008_FINAL.pdf. Accessed 26 Aug 2014.
- Delmas, M. A., Fischlein, M., & Asensio, O. I. (2013). Information strategies and energy conservation behavior: a meta-analysis of experimental studies from 1975 to 2012. *Energy Policy*, 61, 729–739.
- Droutsas, K. G., Kontoyiannidis, S., Dascalaki, E. G., & Balaras, C. A. (2014). Ranking cost effective energy conservation measures for heating in Hellenic residential buildings. *Energy and Buildings*, 70, 318–332.
- Ecoinvent. (2010) Life cycle database, v. 2.2. www.ecoinvent.ch. Accessed 9 Apr 2014.
- Ecoinvent. (2013). Life cycle database, v. 3.1. www.ecoinvent.ch. Accessed 23 Sept 2014.
- Eurajoki Christian Folk High School. (2014). Solar thermal collector building course (in Finnish). <https://www.eko.fi/sivu.aspx?taso=2&id=172>. Accessed 15 July 2014.
- Faberi, S. (2007). Preparatory Studies for Eco-design Requirements of EuPs. LOT13: Domestic Refrigerator & Freezers.
- Finnish borehole Inc. (2014). <http://www.suomenporakaivo.fi/maalampokaivot/>. Accessed 22 July 2014.
- Finnish ground-source-heat-pump forum. (2014) <http://www.maalampofoorumi.fi/index.php>. Accessed 22 July 2014.
- Fischer, C. (2008). Feedback on household electricity consumption: a tool for saving energy? *Energy Efficiency*, 1(1), 79–104.
- Girod, B., van Vuuren, D. P., & Hertwich, E. G. (2014). Climate policy through changing consumption choices: options and obstacles for reducing greenhouse gas emissions. *Global Environmental Change*, 25, 5–15.
- Harvey, L. D. D. (2009). Reducing energy use in the buildings sector: measures, costs, and examples. *Energy Efficiency*, 2, 139–163.
- Heimonen, J. (2011). Solar guidebook 2012, Calculation guidebook for energy production of solar heat and electricity (in Finnish). <http://www.ym.fi/download/noname/%7BF4F73E83-56AF-4112-AD7B-0E1F1804D38B%7D/30750>. Accessed 29 Apr 2015.
- Helen (Helsingin Energia). (2013). Electricity consumptions of electric appliances (in Finnish). http://www.helen.fi/Documents/Energiatori/Kulutustuvut/kulutustuvut_suomi.pdf. Accessed 6 Feb 2014.
- Hertwich, E. G. (2005). Consumption and the rebound effect an industrial ecology perspective. *Journal of Industrial Ecology*, 9, 85–98.
- Hertwich, E. G., & Peters, G. P. (2009). Carbon footprint of nations: a global, trade-linked analysis. *Environmental Science and Technology*, 43(18), 6414–6420.
- Huppes, H., de Koning, A., Suh, S., Heijungs, R., van Oers, L., Nielsen, P., & Guinée, J. B. (2006). Environmental impacts of consumption in the European Union. *Journal of Industrial Ecology*, 10(3), 129–146.
- Hyysalo, S., Juntunen, J. K., & Freeman, S. (2013a). User innovation in sustainable home energy technologies. *Energy Policy*, 55, 490–500.
- Hyysalo, S., Juntunen, J. K., & Freeman, S. (2013b). Internet forums and the rise of the inventive energy user. *Science & Technology Studies*, 26(1), 25–51.
- Jalas, M., Kuusi, H., & Heiskanen, E. (2014). Self-building courses of solar heat collectors as sources of consumer empowerment and local embedding of sustainable energy technology. *Science and Technology Studies*, 27(1), 76–96.
- Juvonen J. & Lapinlampi T. (2013). Energiakaivo (Energy well), Ympäristöopas (Environmental guidebook, in Finnish). Edita Prima Oy. https://helda.helsinki.fi/bitstream/handle/10138/40953/YO_2013.pdf?sequence=4. Accessed 22 July 2014.
- Kaps, R. & Wolf, O. (2013). Green Public Procurement for Sanitary Tapware – Technical Background Report. JRC Scientific and policy reports. http://susproc.jrc.ec.europa.eu/ecotapware/docs/GPP_Technical_background_Report_Tapware_final.pdf. Accessed 1 Sept 2014.
- Karjalainen, S. (2011). Consumer preferences for feedback on household electricity consumption. *Energy and Buildings*, 43, 458–467.
- Kim, H. C., Keoleian, G. A., & Horie, Y. A. (2006). Optimal household refrigerator replacement policy for life cycle energy, greenhouse gas emissions, and cost. *Energy Policy*, 34, 2310–2323.
- Kopsakangas-Savolainen, M., & Juutinen, A. (2013). Energy consumption and savings: a survey-based study of Finnish households. *Journal of Environmental Economics and Policy*, 2(1), 71–92.
- Kopsakangas-Savolainen, M., Mattinen, M., Manninen, M. & Nissinen, A. (2014). Hourly-based greenhouse gas emissions of electricity—possibilities for households and companies to decrease their emissions, SSRN Working paper series, doi: 10.2139/ssrn.2411425. Accessed 25 Aug 2014.
- Kuusk, K., Kalamees, T., & Maivel, M. (2014). Cost effectiveness of energy performance improvements in Estonian brick apartment buildings. *Energy and Building*, 77, 313–322.
- Lampopumpu. (2009). Lampopumpu.info internet forum, discussion topic related to air-to-air heat pump modification (in Finnish). <http://lampopumpu.info/foorumi/index.php?topic=6986.0>. Accessed 3 Sept 2014.
- Lillemo, S. C. (2014). Measuring the effect of procrastination and environmental awareness on households' energy-saving behaviours: an empirical approach. *Energy Policy*, 66, 249–256.

- Mattinen, M. K., Nissinen, A., Hyysalo, S., & Juntunen, J. K. (2014a). Energy use and greenhouse gas emissions of air-source heat pump and innovative ground-source air heat pump in cold climate. *Journal of Industrial Ecology*. doi:10.1111/jiec.1266.
- Mattinen, M. K., Heljo, H., Vihola, J., Kurvinen, A., Lehtoranta, S., & Nissinen, A. (2014b). Modeling and visualization of residential sector energy consumption and greenhouse gas emissions. *Journal of Cleaner Production*, 81, 70–80.
- Ministry of the Environment. (2010). Finnish Building code part C3, Thermal insulation of buildings (in Finnish). www.finlex.fi/data/normit/34163-C3-2010_suomi_221208.pdf. Accessed 29 Apr 2014.
- Ministry of the Environment. (2012). Finnish Building code part D3, Energy efficiency of buildings (in Finnish). http://www.finlex.fi/data/normit/37188-D3-2012_Suomi.pdf. Accessed on 3 Sept 2014.
- Monfared, B., Furberg, R., & Palm, B. (2014). Magnetic vs. vapor-compression household refrigerators: a preliminary comparative life cycle assessment. *International Journal of Refrigeration*, 42, 69–76.
- Motiva. (2014). Water consumption (Veden kulutus, in Finnish). http://www.motiva.fi/koti_ja_asuminen/mihin_energiaa_kuluu/vedenkulutus. Accessed 26 Sept 2014.
- Moura, P. S., López, G. L., Moreno, J. I., & De Almeida, A. T. (2013). The role of Smart Grids to foster energy efficiency. *Energy Efficiency*, 6(4), 621–639.
- Murray, C. K. (2013). What if consumers decided to all ‘go green’? Environmental rebound effects from consumption decisions. *Energy Policy*, 54, 240–256.
- Nässén, J., & Holmberg, J. (2009). Quantifying the rebound effects of energy efficiency improvements and energy conserving behaviour in Sweden. *Energy Efficiency*, 2(3), 221–231.
- Nemry, F., Uihlein, A., Colodel, C. M., Wetzels, C., Braune, A., Wittstock, B., Hasan, I., Keißig, J., Gallon, N., Niemeier, S., & Frech, Y. (2010). Options to reduce the environmental impacts of residential buildings in the European Union – Potential and costs. *Energy and Buildings*, 42, 976–984.
- Nikolaïdis, Y., Pilavachi, P. A., & Chletsis, A. (2009). Economic evaluation of energy saving measures in a common type of Greek building. *Applied Energy*, 86, 2550–2559.
- Nissinen, A., Heiskanen, E., Perrels, A., Berghall, E., Liesimaa, V., & Mattinen, M. (2012). Combinations of Policy Instruments to Decrease the Climate Impacts of Housing, Personal Transport and Food, Final report of the KUILU-project (in Finnish, abstract in English). The Finnish Environment 11/2012. https://helda.helsinki.fi/bitstream/handle/10138/38758/SY11_2012.pdf?sequence=1. Accessed 17 May 2014.
- Nissinen, A., Heiskanen, E., Perrels, A., Berghäll, E., Liesimaa, V., & Mattinen, M. K. (2014). Combinations of policy instruments to decrease the climate impacts of housing, passenger transport and food in Finland. *Journal of Cleaner Production*. doi:10.1016/j.jclepro.2014.08.095.
- Nord Pool Spot. (2014). www.nordpoolspot.com. Accessed 3 Jan 2014.
- Nyberg P. (2009). Essays on Risk and Return. Edita Prima Ltd, Helsinki 2009. p 19. <https://helda.helsinki.fi/bitstream/handle/10227/368/198-978-952-232-035-3.pdf?sequence=2>. Accessed 15 July 2014.
- Ornetzeder, M., & Rohrer, H. (2006). User-led innovations and participation processes: lessons from sustainable energy technologies. *Energy Policy*, 34(2), 138–150.
- Paetz, A.-G., Dütschke, E., & Fichtner, W. (2012). Smart homes as a means to sustainable energy consumption: a study of consumer perceptions. *Journal of Consumer Policy*, 35, 23–41.
- Paiho, S., Hoang, H., Hedman, Å., Abdurafikov, R., Sepponen, M., & Meinander, M. (2014). Energy and emission analyses of renovation scenarios of a Moscow residential district. *Energy and Buildings*, 2014(76), 402–413.
- Ristimäki, M., Säynäjoki, A., Heinonen, J., & Junnila, S. (2013). Combining life cycle costing and life cycle assessment for an analysis of a new residential district energy system design. *Energy*, 63, 168–179.
- Rolfsman, B. (2002). CO₂ emission consequences of energy measures in buildings. *Building and Environment*, 37, 1421–1430.
- Rüdenauer, I., & Fischer, C. (2011). ComeOn Labels Common appliance policy—all for one, one for all—energy labels. Instruments for the Replacement of Old Appliances. Version 2: 13.12.2011. <http://www.come-on-labels.eu/download/replacement-old-appliances>. Accessed 7 Apr 2015.
- Saidur, R., Masjuki, H.H., Jamaluddin, M.Y. (2007). An application of energy and exergy analysis in residential sector of Malaysia. *Energy Policy*, 35(2), 1050–1063.
- Salmela, H. (2012). Personal communication with CEO H. Salmela, Jääsähkö Inc., Kallunki, Finland, September 2012.
- Scholander, M.J. & Dillon H.E. (2012). Life-cycle assessment of energy and environmental impacts of LED lighting products, Part 2: Led manufacturing and performance, solid-state lighting program. http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2012_led_lca-pt2.pdf. Accessed 28 Aug 2014.
- Seyfang, G., Park, J. J., & Smith, A. (2013). A thousand flowers blooming? An examination of community energy in the UK. *Energy Policy*, 61, 977–989.
- Statistics Finland. (2014a). Finland’s greenhouse gas emissions without LULUCF sector 1990–2010. http://www.stat.fi/til/khki/2010/khki_2010_2012-04-26_tau_001_en.html. Accessed 2 Oct 2014.
- Statistics Finland. (2014b). Number of buildings by intended use and heating fuel. http://193.166.171.75/Dialog/varval.asp?ma=020_rakke_tau_102&ti=Number+of+buildings+by+intended+use+and+heating+fuel+on+31+Dec.+2013&path=../Database/StatFin/asu/rakke/&lang=1&multilang=en. Accessed 2 Oct 2014.
- Statistics Finland. (2014c). Number of buildings by intended use and heating fuel, Available: http://193.166.171.75/Database/StatFin/Asu/rakke/rakke_en.asp. Accessed 2 Oct 2014.
- Statistics Finland. (2014d). Energy Prices. http://www.stat.fi/til/ehi/2014/01/ehi_2014_01_2014-06-19_tie_001_en.html. Accessed 15 July 2014.
- Statistics Finland. (2014e) Floor area per dwelling by type of building 1970–2011. http://www.tilastokeskus.fi/til/asas/2011/asas_2011_2012-05-22_tau_002_en.html. Accessed 2 Oct 2014.
- SYKE (Finnish Environment Institute). (2013). Emissions of electricity purchasing in life cycle calculations in Finland (in

- Finnish). www.ymparisto.fi/fi-FI/Kulutus_ja_tuotanto/Resurssitehokkuus/Elinkaariajattelu/Sahkonhankinnan_paastot. Accessed on 11 Mar 2014.
- Tasaki, T., Motoshita, M., Uchida, H., & Suzuki, Y. (2013). Assessing the replacement of electrical home appliances for the environment an aid to consumer decision making. *Journal of Industrial Ecology*, 17, 290–298.
- Tenhunen, J., Jäpölä, J., Lahti, L., Laine, R., Mikkola, T. & Seppälä, S. (2012). Seurantatutkimus vesikalusteiden vaikutuksesta vedenkulutukseen ja kasvihuonekaasupäästöihin rivitalokohteessa (Case study of tapware changes and effects on water consumption and related greenhousegas emissions in one rowhouse in Finnish) (in Finnish). <https://www.ymparisto.fi/hinku/Kohteet/Tiedot.aspx?Id=178>. Accessed 1 Sept 2014.
- Tommerup, H., & Svendsen, S. (2006). Energy savings in Danish residential building stock. *Energy and Buildings*, 38, 618–626.
- Topten Suomi. (2013). Listing of the most energy efficient household electrical appliances (in Finnish). <http://www.topten-suomi.fi/>. Accessed 12 Nov 2013.
- Vihola, J. & Heljo, J. (2012). Heating Systems Development 2000–2012. Report 2012:10 of Tampere University of Technology, Department of Civil Engineering, Construction Management and Economics (in Finnish, abstract in English). https://dspace.cc.tut.fi/dpub/bitstream/handle/123456789/21114/vihola_heljo_lammitystapojen_kehitys_2000_2012.pdf?sequence=1. Accessed 26 Sept 2014.
- Work Efficiency Institute. (2014). Home's energy guidebook (Kodin energiaopas, in Finnish). <http://www.tts.fi/kodinenergiaopas/>. Accessed 29 Aug 2014.