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Abstract

Air-to-air heat pumps are increasingly promoted as a means for energy saving and a future component in a more flexible electricity demand (load management). At the same time, heat pumps potentially contribute to long-term changes in comfort behaviour and practices, which may undermine the energy saving potential. This paper sums up the findings from a Danish research project on air-to-air heat pumps, electricity use and comfort.

If used properly, heat pumps can provide high efficient heating of houses. However, a Danish spot test indicates that air-to-air heat pumps not always result in energy savings. The use of heat pumps might involve changes in the residents' thermal comfort practices like higher indoor temperatures in the winter or air-conditioning (cooling) in the summer. The reasons for this might be both technical and behavioural.

The paper examines the comfort practices that influence the electricity consumption related to air-to-air heat pumps: How do residents use heat pumps? And what are the consequences for the comfort practices and the electricity use? The analysis is based on results from a survey and qualitative interviews among Danish owners of dwellings and summerhouses with focus on their comfort practices. The study also includes results from metering data on the households' actual electricity consumption and technical inspections of heat pumps. The paper draws on a practice theoretical approach, which understands energy consumption as an integral part of everyday practices that integrate different elements, including habits and technologies.

Introduction

In Denmark, air-to-air heat pumps are promoted by energy authorities and in energy saving campaigns as an energy-efficient alternative to direct electric heating (usually convection heaters) in dwellings and summerhouses. Thus, visitors to the website of the Danish Energy Saving Trust (an independent, public sector authority that promotes energy savings) can read that "air-to-air heat pumps are a good and cost-efficient alternative to direct electric heating, especially if you also use your summerhouse outside the summer season" (Danish Energy Saving Trust 2011). There are about 215,000 summerhouses in Denmark (Statistics Denmark 2010), and the majority of these (app. 84 %) have direct electric heating installed while only about one out of ten has an air-to-air heat pump (Kofoed et al. 2010). Furthermore, app. 119,000 dwellings, or 8 % of all single-detached, semi-detached, terraced and farm houses, are heated by direct electric heating, while only 7,700 have a heat pump as their primary heating form (Dansk Energi 2010). Thus, the total potential for substituting electric heating with air-to-air heat pumps is considerable. The Danish Energy Agency estimates that the number of installed air-to-air heat pumps is about 75,000 (Wittrup 2010). Many of these probably supplement other forms of heat supply (e.g. direct electric heating).

Typical air-source heat pumps deliver an amount of energy for space heating that is 3 to 4 times the electricity consumed. Thus, replacing direct electric heating with an air-to-air heat pump should ideally reduce the electricity consumption for heating by about two-third. However, as documented by studies of the so-called rebound effect (see review in Sorrell et al. 2009), theoretical energy savings from energy efficiency improvements are in general only partly realized due to increased quantities of consumption or a general increase in consump-

tion standards (Shove 2003). Furthermore, an unpublished spot test carried out by one of the energy companies participating in this study and including metering data of 81 customers indicated that the replacement of direct electric heating with air-to-air heat pumps resulted in an average reduction of only 11 %. The aim of this paper is therefore to examine the technical and behavioural aspects that influence the electricity consumption related to air-to-air heat pumps by assessing to what extent the installation of heat pumps is followed by changes in comfort practices and how this influence the actual electricity consumption and energy savings.

Heat pumps are in Denmark sold by private firms as well as energy companies. The energy companies have been actively involved in consultancy, sale, financing, promotion and service of heat pumps since the energy crises in the 1970s. Heat pumps (especially ground-source heat pumps) were at that time promoted as an alternative to oil-fired central heating. The energy companies have especially succeeded in selling heat pumps to electric heated dwellings and summerhouses; energy prizes are relatively high in Denmark and private customers pay about 0.24 Euro/kWh, which makes it economically attractive for this group to invest in heat pumps.

This study combines a questionnaire-based survey with qualitative interviews, analysis of electricity metering data and technical inspections of heat pumps. The study includes both dwellings as well as summerhouses with air-to-air heat pumps. The user context for dwellings and summerhouses are quite different and the results are therefore presented and discussed in separate sections in the following.

The paper starts by presenting the theoretical approach and the methods employed in this study. Then, in order to contextualise the empirical findings, follows a general description of the Danish (Scandinavian) comfort practices compared with other countries. Then, the results are presented in the following two sections (for dwellings and summerhouses). The findings are analyzed and summarised in a more general discussion before the paper ends with conclusions. The study has been funded by the Danish research programme "Elforsk" and is based on collaboration between two regional energy companies (Lokalenergi A/S and SEAS-NVE), IT-Energy and the Danish Building Research Institute at Aalborg University.

Theoretical approach

Except for studies within the socio-technical tradition, studies of residential energy consumption in general tend to focus on either the *technical* aspects, e.g. related to heating systems or the level of building insulation, or the *behavioural and attitudinal* aspects like the residents' environmental awareness and motivation for adopting more environmental friendly behaviours. Both approaches illuminate important aspects that determine the actual energy consumption in households. However, due to their focus on either the technical or the behavioural/attitudinal aspects, these studies often fail to take into account how the social and the technical are co-determined.

In order to transcend this classical dualism between the material and the social, it is relevant to shift focus from either the technical or the social to the *practices* that the residents carry out on a daily basis and that determine the level of energy consumption. This is done in the so-called *practice theory approach* that has gained ground in e.g. consumer studies within recent years (Warde 2005; Shove and Pantzar 2005). Practice theorists argue that the social practices, people's doings and sayings, should be at the centre of the analysis (Schatzki et al. 2001). For instance, the way people make their homes comfortable with regard to the indoor climate can be regarded as an everyday practice that determines the household's energy consumption for heating. The practice of comfort is made up of many different sayings and doings that relate to understandings of what a comfortable home is and how to achieve this. For instance, routines of adjusting thermostat settings or airing are part of the overall comfort practices.

The emphasis on bringing practice theory into consumer and environment studies mainly draws on practice theory as formulated by Schatzki (1996) and further elaborated by Reckwitz (2002). The approach resembles early Giddens (1984) and Bourdieu (1976) in its efforts to overcome the structure-actor dualism and that it emphasises how practices rather than e.g. signs or abstract structures are the basis for both the constitution and understanding of the social. Furthermore, both Schatzki and Reckwitz accentuate the collective aspect of practices. Reckwitz states that the single individual acts as a carrier of practices, while Schatzki says that practices are coordinated entities, i.e. a temporally unfolded and spatially dispersed nexus of doings and sayings. Saying that a practice forms a nexus also means that there are certain elements holding it together; however, in the work of Schatzki, Warde and Shove/Pantzar there are slightly different descriptions of the elements holding a practice together.

Schatzki (1996) writes that *practical understanding*, also described as embodied know-how or routines (the body knowing how to act), is one element in holding a practice together, whereas *explicit rules, principles and instructions* e.g. traffic rules are a second. A third element is the *teleo-affective structure*, which is a compound of something that is goal-oriented and has meaning in a substantial or ethical sense. Teleo-affective structures include purposes, beliefs and emotions. Warde and Shove/Pantzar are obviously inspired by Schatzki; however, they rename the elements and, in the case of Shove and Pantzar, combine practical understandings and explicit rules, principles and instructions into one element called competences. With reference to Reckwitz (2002), they further add *material items* as an element, i.e. things and products. The simplest approach is thus found in Shove and Pantzar (2005), as they operate with just three elements: competences, meanings and products. Shove and Pantzar make an important observation of how material items like products play a significant role in constituting practices. However, for the purpose of understanding energy consuming practices, their conceptualisation of competences as one single category seems too simple as they do not distinguish between on the one hand know-how or non-verbal knowledge and on the other hand explicit, rule-based or theoretical-abstract knowledge.

In an empirical study of comfort practices and energy consumption, the following four elements have been used and proven valuable in empirical investigations of indoor climate (Gram-Hanssen 2010a) and standby consumption practices (Gram-Hanssen 2010b): 1) Know-how and embodied habits; 2) institutionalised knowledge and explicit rules; 3) engagements; 4) technologies. It is the first element (know-how and embod-

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ied habits) that, together with technologies, forms the direct link between practices and energy consumption; it is through our bodily habits ("the way we do things") and our interaction with technology that we activate flows of materials and energy. Thus, differences in comfort practices have important consequences for the level of energy consumption for heating.

Method

The results presented in this paper are based on a survey and qualitative interviews carried out in 2010 among house owners with an air-to-air heat pump. In the survey, 2,793 households were invited by mail to participate in the survey. The sample included both summerhouses and permanently occupied dwellings and was drawn from a customer list from the two Danish regional energy companies that participated in this study. Thus, the study only includes dwellings and summerhouses from two Danish regions (eastern Jutland and the western and southern part of Zealand). 681 completed the online-questionnaire, resulting in a response-rate of 24 %. However, these also included customers with other types of heat pumps than air-to-air, and therefore only heat pumps from manufactures from which the energy companies had been selling air-to-air heat pumps were included in the analysis. The final sample included 481 respondents (405 with a heat pump installed in their dwelling and 76 in their summerhouse).

The questionnaire included 35 questions organized in seven thematic sections that ranged from introducing questions about the installation of the heat pump (e.g. year of installation) and general questions about the household and the house (e.g. year of construction) to questions about the use of the heat pump and changes in comfort practices. With a few exceptions, the questions in the two questionnaires (for dwellings and summerhouses) were identical.

The questionnaires were later combined with metering data delivered by the two energy companies that participated in the study. These data cover the annual, billed electricity consumption for the houses and were used for statistical analyses of the impact of air-to-air heat pumps on the houses annual electricity consumption. However, the sample for this part of the study was narrowed down from the original 481 respondents to 180 respondents (houses); only houses with metering data for at least one year prior to as well as subsequent to the year of heat pump installation were included. Only the main results from the analysis of the electricity consumption are presented in this paper (see Gram-Hanssen et al., forthcoming for a more detailed presentation).

Twelve respondents were selected for face-to-face qualitative interviews and technical inspections of their heat pump on the basis of the questionnaires and the metering data. The aim of these interviews was to provide detailed descriptions of the use of the heat pumps and how they had been integrated into the comfort practices of the household (including changes in heating and/or air-conditioning practices). Only respondents with an air-to-air heat pump installed within the latest five years (2005 or later) were included in the interviews. Furthermore, respondents were chosen in order to ensure variety in the sample with regard to heating system (both houses with a heat pump as the only heating source as well as heat pumps in combination with other heating sources), development in electricity consumption (both increase and decrease), household composition (families with children as well as couples/singles without children living at home), an approximate even distribution between dwellings and summerhouses, and at least three respondents who stated in the questionnaire that they use air-conditioning 5 days or more during an ordinary summer. The respondents, who participated in the interviews, are named "informants" in the following.

The interviews lasted about one hour each and were carried out as semi-structured interviews (Kvale 1996) covering a number of overall themes: General information about the dwelling/summerhouse, daily comfort practices and changes in these, the purchase and use of the heat pump, other changes in energy consumption (in order to identify other possible explanations for changes in the households electricity consumption), interest in environment and energy consumption, and general information about the household. Informants with a heat pump installed in their summerhouse were furthermore asked about how they frost-proof their summerhouse in the winter. In six interviews, also the spouse participated. Therefore, 18 informants were interviewed in total.

Comfort practices in Denmark and other countries

Comfort practices vary considerably between countries and between different regions of the world due to differences in tradition, cultural norms as well as different building traditions and socio-technical systems. For instance, a cross-cultural study by Wilhite et al. (1996) shows great differences between Japan and Norway in end-use patterns for space heating (as well as lighting and hot water use). Norwegians tend to heat all rooms in their homes except for the bedroom: "The entire house is made into a heated envelope which allows the occupants to move freely from one room to another without experiencing discomfort" (ibid.: 797). Also, high indoor temperatures are in Norway closely related to a cultural idea of "cosiness". Different from this practice of "full-house heating", the Japanese tend to heat just one room or even to restrict the heat to the part of the room they occupy. The latter is done by using either an "electrical carpet" or a traditional "person heater" called a "kotatsu", which is a heating unit placed under the dining table which, in combination with a comforter, warms the lower torsos of those sitting around the table. These practice differences between Norway and Japan are obviously due to a complex of reasons including cultural differences as well as differences in buildings traditions and socio-technical systems (e.g. inexpensive electricity in Norway).

In an international perspective, the Norwegian (and Scandinavian) practice of "full-house heating" seems to differ from many other countries with a tradition for heating only few rooms, typically the living room. Thus, a New Zealand study based on detailed monitoring of 400 houses (Isaacs et al. 2010) shows that the New Zealand houses in general are subject to what is named "zone heating" with only the living room being heated during winter evenings. Other rooms, like bedrooms, are seldom heated.

Wilhite et al.'s study also shows interesting differences with regard to the practice of night temperature set-back; less than half of the interviewed Norwegian households set back temper-

atures at night and about one-third do not lower their thermostat settings while away for a weekend trip or a holiday, whereas every household in the Japanese sample turn the heat down or off in the night and when they leave the house. Similarly, only about one-third of the New Zealand households heat their living room or other rooms during night, morning or daytime (Isaacs et al. 2010), and the use of timer-controlled central heating systems are widespread in UK (Shipworth et al. 2010).

Like in Norway, "full-house heating" is also a dominant practice in Danish homes. Furthermore, it is widespread to heat most of the house to a comfortable temperature; a recent survey-based study finds that the mean self-reported temperature of Danish home-owners' living room is 21.1 degrees Celsius (Adjei et al. 2011). However, the temperature in bedrooms is often somewhat lower than in the living-room. Also, temperature set-back during night and daytime is less widespread in Danish households compared to for instance New Zealand and UK; only about one-fourth (24 %) of the Danish dwellings are subject to the practice of temperature set-back (ELMODELbolig 2011).

In Denmark, water-based heating-systems dominate. 62 % of Danish dwellings are heated by district heating and 32 % has central heating based on e.g. oil or natural gas. Wood-burning stoves as primary heating are atypical.

Heat pumps in dwellings

RESULTS FROM SURVEY AND ANALYSIS OF METERING DATA

The majority (76 %) of the 405 respondents with an air-to-air heat pump installed in their dwelling live in a single-detached house, while 14 % live in a farm house and 10 % in a terraced or semi-detached house. The age and income distribution of the respondents differ significantly from the overall distribution of the population and house owners in the two regions. There is an overrepresentation of older people in the survey (table 1), which also influences the rate of employment with 44 % of the respondents being retired persons receiving pension (cf. 26 % of the Danish population) and only 51 % in employment (cf. 65 % of the Danish population older than 15 years in 2008). As a result, households belonging to low-income groups (less than 400,000 DKK/year or app. 53,000 Euro/year) are overrepresented; 45 % of the respondents belong to this group (cf. 34 % of the house owners in the two regions). (Statistics Denmark 2010)

However, it is not possible to conclude whether the overrepresentation of older (retired) persons and low-income households reflects the actual socio-demographic characteristics of air-to-air heat pump owners or a methodological bias. Still, when interpreting the following results it should be kept in mind that the respondents in general are older than the rest of the population and less affluent than the house owners in the regions.

The respondents were asked about the reasons for their decision to purchase a heat pump. As seen in table 2, the majority indicate that they wanted to save money and energy, while considerable less chose "to improve comfort". Thus, the economic rationale has a high priority – at least in the respondents' own post-rationalization of the reasons for the purchase of the heat pump. More than two-third of the respondents indicate that they are very satisfied with their heat pump, and only one percent are very unsatisfied with it (not shown here).

The majority (86 %) used electricity (direct electric heating) as their primary heating source prior to the installation of the heat pump. This probably reflects that most campaigns and commercials for heat pumps are targeted owners of electric heated houses. Of the respondents with prior direct electric heating, many (44 %) indicate that they now use the heat pump as their primary heat source, while almost as many (41 %) indicate that direct electric heating is still their primary heating. Only 11 % of all respondents state that the heat pump is their only heating source. This shows that the majority of respondents combine heat pumps with other heating sources – predominantly direct electric heating (at least 36 % of all respondents) and/or a wood-burning stove (49 % of all respondents).

The heat pump in most cases heats the living room (81 % of all respondents), the kitchen (56 %) and hallway/corridor (50 %). Only 38 % of the respondents report that it heats bedrooms. This indicates that the heat pumps are mostly installed in the central and common rooms of the household.

164 respondents had a wood-burning stove before they got the heat pump, and of these 39 % report that they use less wood after they got the heat pump, 39 % that it has not influenced their firewood consumption, 31 % do not know and only 3 % indicate that they now use more wood. This indicates that heat pumps in some dwellings partly substitute firewood.

Whether people change their comfort practices and norms after the purchase of the heat pump is a main research question in this paper. Table 3 shows that 50 % of the respondents do not believe that they have changed habits in relation to how much time of the year they heat their house, while 23 % believe they heat for a shorter period and 17 % believe they heat for a longer period. Thus, heat pumps do not in general result in an extended heating season. Table 4, however, indicates that about one third of the households have raised the indoor temperature after the installation of the heat pump, while only 5 % think they keep a lower temperature.

51 respondents (13 %) report that the heat pump heats rooms that were not previously heated. More than half of these (29) indicate the size of the previously un-heated floor space to be between 11 and 40 m^2. As the interviews indicate (next section) many of these medium-sized rooms may be (new-built) extensions like garden rooms.

With regard to air-conditioning, a potential new comfort practice and energy consumption driver, we asked the respondents if their heat pump could be used for air-conditioning. As air-to-air heat pumps in general can be used for cooling, the aim of this question was to measure to what extent the heat pump owners were aware of this. Surprisingly, only 76 % indicate this as possible, while 22 % answer "no" and only 3 % "do not know". Among the 306 respondents who know that their heat pump can be used for air-conditioning, only 21 % (64 households) have actually used it. Table 5 shows that the majority of these respondents (55 %) only use the air-conditioning 1-9 days during an ordinary summer, while 17 % use it for 15 days or more. Thus, the use of air-conditioning is not widespread, although 16 % of all respondents do it one or more times during an ordinary summer.

Thus, the results from the survey indicate that only minor changes in comfort practices take place after the installation of heat pumps in dwellings. In most cases, the heat pump (partly)

Table 1. Age distribution in survey and in general in the regions of the survey.

	Survey	Population in regions
0-40 years	5,4%	32,1%
41-60 years	46,0%	38,0%
61- years	47,9%	29,0%
Not answered	0,7%	-

Table 2. Reasons to purchase the heat pump (respondents could indicate more than one alternative).

	Number	Percent
To save money on heat consumption	290	72%
To save energy	257	63%
To improve comfort	152	38%
Contributing to reduced pollution	92	23%
Heating system needed renewing	14	3%
Not applicable, Heat pump installed before we moved in	39	10%
Others	27	7%

Table 3. Changing practices related to heating season after purchase of heat pump.

	Number	Percent
No change	206	51%
Heat is turned on for a shorter period of the year than previous	93	23%
Heat is turned on for a longer period of the year than previous	69	17%
Not applicable, Heat pump installed before we moved in	37	9%
Total	405	100%

Table 4. Changing practices related to temperature after purchase of heat pump.

	Number	Percent
Same temperature as previously	223	55%
Temperatures are generally kept lower than previously	19	5%
Temperatures are generally kept higher than previously	123	30%
Not applicable, Heat pump installed before we moved in	40	10%
Total	405	100%

Table 5. Number of days the heat pump is used for air-conditioning during ordinary summer. Dwellings.

Number of days	Number	Percent
1-4 days	24	38%
5-9 days	17	27%
10-14 days	12	19%
15 days or more	11	17%
Total	64	100%

replaces existing heating sources in parts of the house (mostly the living room, kitchen and adjacent hallways) without profound effect on overall practices in relation to the length of the heating season and temperature. However, it is important to notice that a substantial minority (23 %) reduces the length of the heating season (possible added energy saving) while 30 % indicates higher temperatures (possible reduced energy saving).

All in all, this indicates that substantial reductions in electricity consumption should be expected with the installation of the heat pump. The analysis of the metering data for 138 of the dwellings shows that the installation of the heat pump results in an average annual electricity saving of app. 2,000 kWh the first year after the installation. This is based on the degree days corrected consumption and corresponds to a reduction in the average total household electricity consumption (including consumption for other purposes than heating) of 14 %. For houses with direct electric heating prior to the installation of the heat pump and the heat pump as the primary heating source now (N = 70), the energy saving is somewhat higher, about 2,500 kWh, which corresponds to a 18 % reduction in the average total household electricity consumption. Besides a degree day correction, these average saving values are also corrected for a general trend among the participating dwellings of a yearly and heat pump independent decrease in consumption of 5 %. (See Gram-Hanssen et al. Forthcoming for further details)

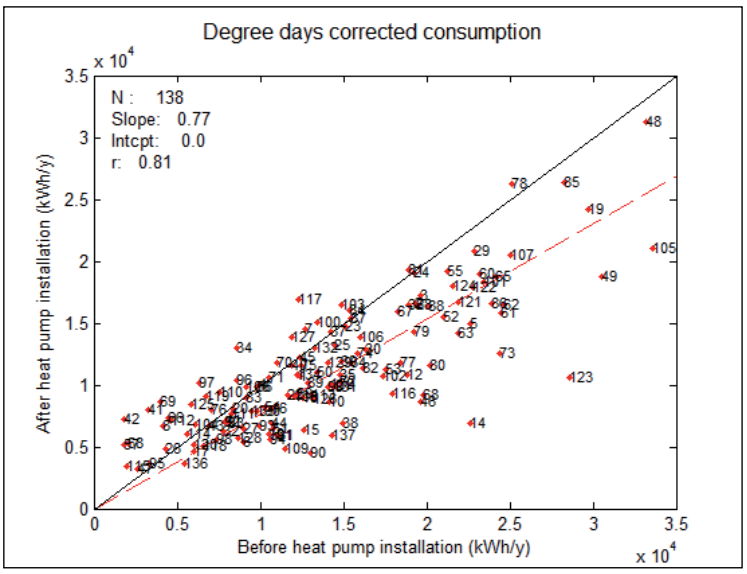

Figure 1. Annual electricity consumption before and after heat pump installation. Degree days corrected.

Figure 1 shows the degree days corrected electricity consumption before and after the installation of the heat pump. The figure shows the general tendency towards lower electricity consumption. A remarkable exception is dwellings with low electricity consumption before the installation of the heat pump, which seem to have a tendency toward *increased* energy consumption. A possible explanation for this is that these households did not have electric heating before they purchased the heat pump.

A multiple linear regression analysis that takes into account different variables other than the installation of the heat pump that might influence the development of the households electricity consumption (e.g. change in household members, preferred temperature, heating period, improved insulation etc.) indicates that the effect of the installation of the heat pump in itself is a reduction of about 35 %, and that the influence of the variables extra TV, income level and change in heating season partly explains why the actual electricity reduction is lower than 35 %. (See Gram-Hanssen Forthcoming for further details on the regression analysis)

RESULTS FROM INTERVIEWS

Informants from eight dwellings were interviewed; two of these were actually summerhouses that had been turned into permanently occupied dwellings (see table 6 at the end of this section for more details on the informants). Only two dwellings had the heat pump as the only heating source. One of these was occupied by Erling Jacobsen (all informant names are pseudonyms) who lives in a 50 m^2 house, actually a summerhouse used as his dwelling. The heat pump replaced direct electric heating and resulted in almost a halving in his annual electricity consumption. Erling explains that he decided to purchase the heat pump because he received "a good bargain" from the local energy company. His main interest was to save money. Except that he believes the heat pump distributes the heat more evenly in the house, he has not experienced any comfort changes. In this respect he differs from most of the other informants, who feel that the heat pump has improved the indoor comfort. Typically, the informants mention benefits like less moisture, better air quality and a better "circulation" of the indoor air. For example, Richard & Irene Rasmussen experience that they do not need to air their living room as often as before; they think that the heat pump clean the air (air-to-air heat pumps are equipped with dust filters). The informants often emphasised these non-economic advantages of the heat pump, while the energy saving was put more in the background. This indicates that even though the economical aspect may play an important role for the decision to purchase a heat pump, other things such as improved indoor air quality play a more central role for the informants' later experience of the heat pump.

In four of the eight dwellings the installation of the heat pump has been followed by an *increase* in the annual electricity consumption, but for various reasons. In two dwellings, the heat pump was installed in connection with a new-built extension to the house: Frank & Grete Henriksen installed their heat pump in a 25 m^2 garden room or conservatory that was built in 2007. Their present dwelling was originally their summerhouse, which they have used as their dwelling since 2008. Building the extension was part of their decision of turning the summerhouse into their dwelling as they needed more space for this. Heating the garden room makes it possible to use it also in the winter (the rest of the house is heated by a wood-pellets stove and electrical under-floor heating). Grete explains that if the garden room had not been heated in the winter "then you would have had to close this off, and that's not what was the idea – that's not why we built this. The idea is that we should be able to use this as an extra room." The heat pump was chosen as an "economically okay" alternative to other forms of heating (e.g. direct electric heating). Their electricity consumption has increased by 30–40 %, although a significant part of this is due to the couple's increased use of the house.

Ellen & Michael Andreasen also built a similar 30 m^2 extension (garden room) to their house. The rest of the house is heated by district heating. They decided to install a heat pump in the garden room because it was cheaper in installation costs compared to central heating (due to costly piping work), it was a more simple solution than a wood-burning stove (no need for a chimney), and it could be used for air-conditioning in the

Table 6: Informants with a heat pump installed in their dwelling. All names are pseudonyms.

Name (age of informants)	Household size (adults and children living at home)	Replace direct electric heating?	Development in electricity consumption (approximate electricity consumption before)	Technical inspection (comments, e.g. risk of unintended cooling)
Heidi Hemmingsen (49)	2 adults, 3 child.	No	App. 25% reduction (12,000 kWh/year)	No unintended cooling
Frank & Grete Henriksen (62 & 60)	2 adults	No	App. 30% increase (6,000 kWh/year)	Lower efficiency due to physical obstruction of indoor component + risk of unintended cooling
Jacob & Ruth Adamsen (55 & 58)	2 adults	Yes	App. 10% reduction (10,000 kWh/year)	No unintended cooling
Erling Jacobsen (61)	1 adult	Yes	App. 50% reduction (7,200 kWh/year)	No unintended cooling
Helene & Kenneth Hansen (49 & 55)	2 adults, 2 child.	Yes	App. 10% reduction (14,000 kWh/year)	No unintended cooling
Ellen & Michael Andreasen (50 & 53)	2 adults, 3 child.	No	App. 60% increase (4,200 kWh/year)	No unintended cooling
Jesper Holm (68)	2 adults	Yes	App. 90% increase (3,500 kWh/year)	No unintended cooling
Richard & Irene Rasmussen (72 & 70)	2 adults	No	App. 20% increase (3,700 kWh/year)	No unintended cooling

summer. Their annual electricity consumption has increased about 60 % since the heat pump installation. The technical inspection and calculations of the theoretical energy need for heating the garden room indicate that heating only explains about half of this increase. The rest (about 1,000 kWh/year) may partly be due the residents' frequent use of the heat pump for air-conditioning in the summer. Ellen and Michael switch on the air-conditioning if it is hot in the garden room and/or in the house, and in the questionnaire they state that they use the air-conditioning more than 15 days pr. year.

The third example of increased electricity consumption is Richard & Irene Rasmussen. In their case, the heat pump replaced oil-based central heating in their living room and kitchen. They installed the heat pump in order to reduce their expenditures on fuel oil. This resulted in a moderate increase (app. 20 %) in their electricity consumption and a significant reduction in the fuel oil consumption from app. 2,000 litres/year to 1,000 litres/year.

Finally, the fourth example of increased electricity consumption is Jesper Holm. He and his wife live in their former summerhouse, and they installed two heat pumps in relation with a thorough renovation that was carried out before they moved into the summerhouse. Like in the case of Frank & Grete Henriksen, the increased electricity consumption seems to be close related to the change in the use of the house.

The above examples illustrate the complexity of reasons behind changes in electricity consumption. Besides this general observation, they also illustrate two different ways in which the potential energy saving effect of heat pumps in some cases is outbalanced by changed practices and general increases in standards and norms: By an extension of the heated floor area or by using the heat pump for air-conditioning in the summer. However, the latter seems not to be an important driver of increased electricity consumption in general. Besides the Andreasen family, only Helene & Kenneth Hansen used air-conditioning, and in their case only occasionally on warm summer days (if they have guests and it is too hot to be outside). Several of the informants are even quite sceptical about air-conditioning. For instance, Jacob Adamsen thinks it is unnecessary to use air-conditioning as the summers are not too hot in Denmark. On the other hand, some of the informants who do not use air-conditioning are less reserved to the idea of using air-conditioning sometime in the future. Thus, Richard & Irene Rasmussen think that as they get older they might benefit from using air-conditioning in order to avoid draught from open windows and doors. Similarly, Heidi Hemmingsen imagines that she and her husband would have used air-conditioning in warm summer nights, if the heat pump had been installed in the bedroom (and not in their living room).

A third example of increasing standards is Helene & Kenneth Hansen, whose heat pump replaced direct electric heating in their kitchen and living room, but with only about 10 % reduction in the household's electricity consumption. The moderate decrease might partly be explained with higher temperatures:

> Kenneth: We have probably got a higher temperature in here [in the living room and kitchen].
>
> Helene: Yeah, previously we were satisfied with 20 degrees (…)
>
> Kenneth: (…) now it's 21.5, so we have actually raised the indoor climate – the temperature, right, since we have got the heat pump. In a way, we have allowed ourselves a bit of luxury.

Previously, the Hansen family kept the indoor temperature at 20 degrees in order to save money, but now they have increased the temperature as they think of the heat pump as less expensive than direct electric heating. The metering data indicates that this change in comfort practice has resulted in a smaller energy saving that would have been expected. Increased temperatures, and the previous example of air-conditioning, are both examples of "rebound effect".

Heat pumps in summerhouses

RESULTS FROM SURVEY AND ANALYSIS OF METERING DATA

The survey includes only 76 respondents with an air-to-air heat pump in their summerhouses, and the statistical results are therefore associated with higher uncertainties. With regard to age, there is an over representation of old respondents. 91 %

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Table 7. Reasons to purchase the heat pump (respondents could indicate more than one alternative).

	Number	Percent
To save energy	46	61%
To improve comfort	40	53%
In order to frost-proof the house in the winter	39	51%
To save money on heat consumption	38	50%
Contributing to reduced pollution	16	21%
Not applicable, Heat pump installed before we moved in	2	3%
Heating system needed renewing	0	0%
Other	6	8%

Table 8. Changing practices related to heating season after purchase of heat pump.

	Number	Percent
No change	25	33%
Heat is turned on for a shorter period of the year than previous	5	7%
Heat is turned on for a longer period of the year than previous	42	55%
Not applicable, Heat pump installed before we moved in	4	5%
	76	100%

Table 9. Changing practices related to temperature after purchase of heat pump.

	Number	Percent
Same temperature as previously	32	42%
Temperatures are generally kept lower than previously	1	1%
Temperatures are generally kept higher than previously	40	53%
Not applicable, Heat pump installed before we moved in	3	4%
Total	76	100%

are older than 50 years; the national figure for summer house owners is 78 % (Andersen and Vacher 2009). More than 75 % of the respondents are older than 60 years, which means that the majority (62 %) of the respondents are pensioners.

Most of the Danish summerhouses were built during the welfare boom in the 1960s and 70s and often in coastal areas or close to lakes and forests. Danish summerhouses, which typically have a floor space of 60–70 m^2, are mainly used by their owners in holidays and weekends during the summer and less often in the winter. About 15 % of the summerhouses are used (legally or illegally) as permanently occupied dwellings, mainly by old-age pensioners (Andersen & Vacher 2009; Hjalager 2009). It therefore seems likely that some of the respondents in this survey live in their summerhouse throughout the year. Unfortunately, the questionnaire did not include a question on this. A "follow-up" survey was therefore carried out by calling the respondents by telephone in order to ask about this (and a few other follow-up questions, see later). We only succeeded in getting in contact with 35 respondents. Of these, 8 respondents (app. 23 %) use their summerhouse as their dwelling. Even though the number of respondents is very low (and the uncertainty very high), this indicates that roughly estimated 15–30 % of the respondents in the original survey use their summerhouse as their dwelling.

Similar to dwellings, most respondents indicate the possibility of saving energy and money as a reason for purchasing the heat pump (table 7). However, the interest in getting a better comfort is more pronounced among the summerhouse owners (53 %) than was the case for dwellings (38 %). Also, 51 % states that they intended to use the heat pump to keep the summerhouse frost-proof in the winter. Thus, these results show a more complex picture of reasons for purchasing a heat pump compared to dwelling owners, who primarily focused on saving money and energy. As we will show later, this seems to reflect that heat pumps in the case of summerhouses form part of a more thorough change of the comfort standards than is the case for dwellings.

In more than two-third (72 %) of the summerhouses the heat pump is the primary heat supply, and about three-quarter (78 %) report that they used direct electric heating as their primary heat supply prior to the heat pump. Thus, more than half of the respondents (59 %) have changed from direct electric heating to heat pump. Furthermore, 80 % indicate that they also use firewood for heating, and half of those (47 %) who had a wood-burning stove also before the installation of the heat pump indicate that they use less firewood now, while 35 % states that it is unchanged. This shows that the heat pump in many cases (32 % of all respondents) partly substitutes firewood consumption.

With regard to comfort practices (table 8 and 9), more than half of the respondents indicate that the heat is turned on for a longer period of the year (55 %) and that they have increased the temperature (53 %) since they got the heat pump. This indicates that the installation of heat pumps is followed by more extensive changes in comfort practices in summerhouses than was the case for dwellings. Thus, some of the potential energy saving might be offset by increased energy use due to higher comfort standards.

It is likely that some of the increase in the length of the heating season is related to changes in the winter heating practice. The answers to the question "In which way is the heat pump used for heating in the winter months?" show that 24 respondents (32 %) primarily use the heat pump to frost-proof their house during the winter, while 38 respondents (50 %) states that they use the heat pump as their primary heating. As it was only possible for the respondents to give one answer, the share of respondents that uses their heat pump to frost-proof the house is probably higher. In order to clarify this, a few questions on the winter heating practices were included in the follow-up survey. This showed that among the 27 respondents who did not use their summerhouse as their dwelling 23 respondents (85 %) state that they heat their summerhouse to 10-16 degrees Celsius the entire winter. Only 2 respondents "shut down" their summerhouse for the winter (i.e. turn off all heat and frost-proof water installations), while 2 respondents heat their summerhouse to about 5 degrees Celsius. Interestingly, only 13 respondents (48 %) heated their summerhouse before the heat pump, and all of these (except one) report that they have increased the temperature. Despite high uncertainties, the follow-up survey seems to support the finding that it is common to use the heat pump to keep the summerhouse heated up to 10-16 degrees during the winter, and that most of the summerhouses previously either were "shut down" for the winter or heated to lower temperatures. This indicates a significant increase in heating standards that might partly outweigh the potential energy saving of the heat pump.

With regard to air-conditioning, only 39 respondents (51 %) are aware that their heat pump can be used to this. Of these, only two respondents use air-conditioning 10–14 days during an ordinary summer and no respondents use it for more than 14 days. This indicates that the use of air-conditioning is moderate and probably not (yet) a driver behind increased electricity consumption.

To sum up, the survey indicates a number of changes in comfort practices (increased temperature, longer heating seasons, less firewood consumption and a widespread use of heat pumps to keep the house heated in the winter) that potentially can outweigh the energy saving potentials. This observation is supported by the analysis of the metering data for 42 summerhouses (figure 2), which shows no significant reduction in the average electricity consumption. A more detailed study of the metering data shows that summerhouses with low electricity consumption before the heat pump installation actually tend to increase their consumption (probably because they are now heated during the winter), while houses with previous high consumption tend to achieve a reduction. See Gram-Hanssen et al. Forthcoming for further details.

RESULTS FROM INTERVIEWS

Four interviews concerning summerhouses were carried out (see table 10). In all four cases, the summerhouse owners used their heat pump to keep their summerhouse heated during the winter (this had not been a criterion for selection of informants). Actually, this played an important role for the informants' original decision about purchasing a heat pump. One example is the 72 year-old Nora Poulsen, who has her own summerhouse (her husband died a few years earlier), which she uses 2–3 months per year in total – although, only a few days per month during the winter. Nora explains that before the installation of the heat pump, the summerhouse would only be heated in the winter if she used it. However, there had been some problems with moisture and mould in the house, and this played an important role for her decision on getting a heat pump. Now, these problems have disappeared, and: "… that was why I got it [the heat pump]. Because I thought 'I won't take the risk of spoiling the house because it is not used [in the winter]' (…). And I thought 'but then I must spend the money it costs'. In any case, it has been good for the house." The summerhouse previously had direct electric heating, and when asked if it would have been an alternative to use this for heating the house during the winter, Nora answers: "But that I wouldn't have done (…) it is simply too expensive."

It was a widespread assumption among the informants that it was good for the house (the building materials) to be heated during the winter. For instance, John Nørgaard had been told by the heat pump salesperson that it would be the best for the walls

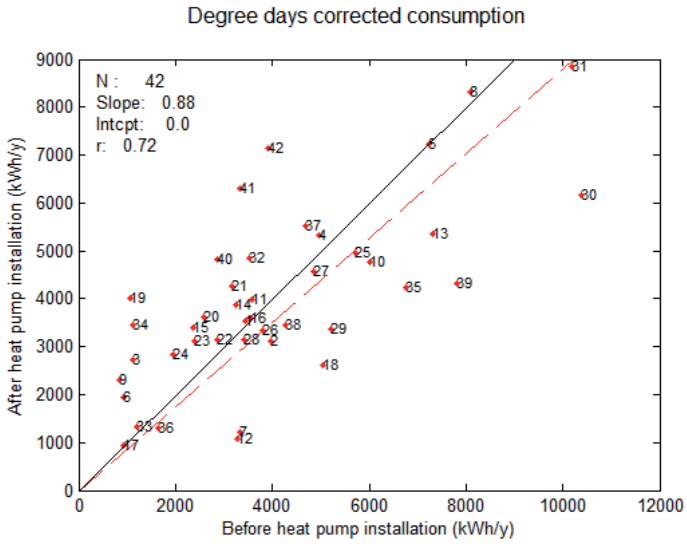

Figure 2. Annual electricity consumption before and after heat pump installation. Degree days corrected.

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if they were not exposed to high temperature fluctuations. Similarly, the couple Edith and Tonny Karlsen had been told the same by the carpenter who built the extension to their summerhouse.

All informants explain that it is nice to arrive to a heated summerhouse. Several told about how they (prior to the heat pump) had developed special routines for heating up the cold house. For instance, John Nørgaard and his wife would turn up the direct electric heating and light a fire in the wood-burning stove as the very first thing upon their arrival to the house. When they would drive to their daughter's place (she lives close to the summerhouse) and stay there for a few hours until the summerhouse had got a comfortable temperature. Now, with a heat pump heating the house to about 16 degrees Celsius, it has become much easier and faster for them to heat the house to a comfortable temperature. Edith and Tonny Karlsen also tell about how it previously had been uncomfortable and inconvenient to arrive to a cold house. They experienced problems with moisture and the wooden floor and the walls almost "sweat" when they turned on the heat:

> Tonny: And we had to drive down here [to the summerhouse] the day before [they intended to stay in the house] and take all our bedclothes and everything – take it back home [to their dwelling] and put it in the tumble dryer. Because otherwise she [Edith] would get nettle rash.
>
> Edith: I'm allergic to house dust mites …

Thus, heating up the house to about 15 degrees Celsius during the winter is generally experienced as both more comfortable and convenient by the informants. As a consequence, all informants (except for John Nørgaard and his wife) use the house more often during the winter. This actually played an important role for Jens Panduro and his wife's decision on purchasing a heat pump. They saw the heat pump as a possibility for heating the house during the entire winter without spending too much money on electricity, and thus avoid the troubles of shutting down the house for the winter and also make it more attractive to use the house more often for short stays during the winter. However, Jens and his family only use their summerhouse for 6-8 days in total during the winter. Only John Nørgaard and his wife stay in their summerhouse frequently during the winter (about tree out of four weekends).

Prior to the heat pump, John Nørgaard and Edith and Tonny Karlsen kept their summerhouses heated up to 5 degrees Celsius by use of direct electric heating, while Nora Poulsen and Jens Panduro "shut down" their houses for the winter (frost-proofing water installations etc.). In the case of John Nørgaard, the electricity consumption almost halved with the installation of the heat pump, while the Karlsen couple experienced a reduction of about a quarter. Contrary to this, Jens Panduro experienced a trebling in the annual electricity consumption, which is most likely due to changed winter heating practices (however, a minor part of this – about 10 % of the electricity consumption – can be due to technical problems with the installation of the heat pump; in order to prevent theft, John had built a box of wooden bars around the outer part of the heat pump, which may reduce the heat pumps efficiency). Finally, Nora Poulsen experienced almost a halving of the electricity consumption, but this is most likely due to a change in her use of the summerhouse, as she used it as her dwelling the years before the installation of the heat pump.

All informants keep their summerhouse heated up to 16 degrees Celsius during the winter because the air-to-air heat pumps cannot be set at a lower setpoint temperature. This is a remarkable example of how the characteristics of technologies co-determine the development of (new) practices. Besides John Nørgaard, the informants explain that they would have preferred 10-12 degrees Celsius as setpoint instead; they think it is an unnecessary energy consumption to keep the house heated at 16 degrees. On the other hand, all informants appreciate that the house is well-heated and it only takes little time to raise the temperature to a comfortable level. Thus, there is some ambiguity between wanting to save (or: not wasting) energy and money while, at the same time, taking pleasure in the comfort and convenience of a well-heated house. Nora Poulsen explains: "… if it [the temperature] was four degrees lower, it would save some electricity, wouldn't it. Even though, I don't think it's unreasonable that I have to pay about forty hundred [Danish kroner] to keep the house heated all year around – you can say – (…) everything is running on electricity."

Two of the informants (John Nørgaard and Nora Poulsen) also mention another type of comfort improvement. In the evenings they often light a fire in the wood-burning stove, but a few hours after they have gone to bed, the fire goes out and without other heating the house would be cold in the morning. Before the heat pump, they generally refrained from using the expensive direct electric heating to keep the house heated in the night, but now they use the heat pump for this. As Jens explains, it is an unpleasant "way to start your day" with a low temperature in the house.

John Nørgaard and Edith and Tonny Karlsen are the only informants who have used their heat pump for air-conditioning. Edith and Tonny explain that their summerhouse can reach temperatures of about 30 degrees Celsius on hot summer days. They therefore turn on the air-conditioning in the evening in order to make it comfortably cool when they go to sleep. The air-conditioning did not play a role in their original decision of purchasing the heat pump, but they appreciate this possibility. They estimate that they used the air-conditioning 7–8 days in 2010 (not a warm summer in Denmark). John Nørgaard and his wife only use the heat pump for air-conditioning 3–4 times in the summer. However, as they use the automatic control feature of the heat pump (at which the heat pump either heats or cools if the indoor temperature gets lower or higher than a specific temperature range) the heat pump sometimes turns on the air-conditioning if the temperature in the living room gets high due to the heat from the wood-burning stove. When asked if they do something to avoid this, John explains that the air-conditioning is only running for a short time and he compares it with other types of consumption that could potentially be avoided if people cared about it: "you could also turn of the light [every time you do not use it] – but you don't".

Nora Poulsen and Jens Panduro never use air-conditioning. Like the majority of the informants in general, Jens rejects the idea and expresses an understanding of air-conditioning as an unnecessary and superfluous consumption: "It is also a kind of principle that I have. That is, you should not use energy on cooling – I think that is luxury (…). If you sweat [on hot summer days], you just have a swim or you can take something to drink and sit down in the shadow."

Table 10. Informants with a heat pump installed in their summerhouse. All names are pseudonyms.

Name (age of informants)	Household size (adults and children living at home)	Replace direct electric heating?	Development in electricity consumption (approximate electricity consumption before)	Technical inspection (comments, e.g. risk of unintended cooling)
Nora Poulsen (72)	1 adult	Yes	App. 50% reduction (4,400 kWh/year)	No risk of unintended cooling
John Nørgaard (63)	2 adults	Yes	App. 50% reduction (5,500 kWh/year)	Risk of unintended cooling
Jens Panduro (56)	2 adults, 2 child.	Yes	App. 300% increase (1,000 kWh/year)	Lower efficiency due to physical obstruction of outdoor component + no unintended cooling
Edith & Tonny Karlsen (63 & 68)	2 adults	Yes	App. 10% reduction (7,700 kWh/year)	No unintended cooling

Changing practices and consequences for electricity consumption

The survey and interviews indicate that the installation of air-to-air heat pumps in *dwellings* is followed by only moderate changes in the residents' comfort practices. Thus, the installation of heat pumps generally results in electricity savings as showed by the metering data. However, the actual savings are smaller than the "potential". As the metering data analysis indicates, only about the half of the potential saving from changing to heat pumps is realised. The survey and the qualitative interviews indicate at least three reasons for this: First, in about 10 % of the dwellings the heat pump is used to heat rooms that have not previously been heated, such as new-built extensions like conservatories or garden rooms. As the interviews suggest, dwelling owners might choose heat pumps to heat extensions because of the image of heat pumps as a cost-efficient heating form. Secondly, this image also seems to motivate a subgroup of heat pump owners to increase the indoor temperature in their dwelling. Thirdly, about 15 % of the respondents use air-conditioning in the summer, although frequent use is rare. However, the use of air-conditioning is not widespread, which might be closely related to an understanding of this as an expensive, unnecessary and superfluous luxury. Rather than due to economic constraints, the informants seem to limit their use of air-condition because of a more general normative rejection of the necessity of cooling in Denmark. Similar non-economic limits to the use of air-conditioning have also been found in other studies, e.g. an older study from US (Kempton et al. 1992). This is an example of how engagements, as an element of practices, co-construct comfort practices.

Compared to dwellings, the changes in comfort practices are much more significant in relation to *summerhouses*. Actually, the metering data analysis indicates that the potential energy savings is outbalanced by increased convenience and comfort standards. The interviews show that the purchase of heat pumps is an integrated element of a general improvement of the comfort in summerhouses. This finding is supported by the survey; compared to the dwelling owners, the summerhouse owners indicate a much more diverse range of reasons for their purchase of a heat pump, including saving money and energy as just two among other reasons (table 7). Improving the comfort and frost-proofing the house were also important reasons. In the case of the summerhouse owners, the heat pump (with its image as inexpensive heating) forms part of a general project aimed at making the summerhouse more comfortable by heating it during the winter and improving the air quality (reduce problems with moisture). Similarly, informants with a wood-burning stove appreciate that the heat pump can be used to keep the house heated during the night so they avoid to wake up to a cold house.

These examples of increased comfort standards show that the purchase and use of heat pumps form part of a general change of comfort practices in summerhouses that make these almost identical to the comfort practices in dwellings, i.e. characterised by "full-house heating" and by minimal temperature variations during day and night. This "normalisation" of the summerhouse comfort practices parallels the general increase in the building standards of summerhouses that have taken place within the last 20–30 years. Investments in summerhouse renovations have been extensive and more and more houses are equipped with facilities like internet, television, fully equipped bathrooms and white goods. Also, the gardens are more well-kept (in many cases similar to the gardens to single-detached family houses) than were the case a few decades ago (Andersen & Vacher 2009; Hjalager 2009). The adoption of "full-house heating" comfort practices in summerhouses increase the energy needed for space heating, which outweigh the electricity saving potentials of replacing direct electric heating with heat pumps. As a result, heat pumps seem to be a questionable solution to achieve higher energy efficiency in summerhouses.

Interestingly, the understanding of heat pumps as cost-effective and good for the indoor air quality, and the very idea of heating the summerhouse the entire winter, closely reflects the images communicated in the regional energy companies' heat pump campaigns targeted summerhouse owners with direct electric heating. In these campaigns, the companies typically emphasizes the possibility of saving money with heat pumps as well as the benefits of heating the summerhouse during the winter such as smaller risk of frost injuries, a better indoor climate and that it is more attractive to use the house. For instance, a 2006 advertisement in the customer magazine from one energy company had the title: "Save cold cash on the heating bill – and enjoy a nicely warm summerhouse all the year round". Several of the informants actually still remembered these campaigns, and the interviews indicate that these campaigns succeeded in influencing the summerhouse owners' understanding of how the heat pumps can be used (and in forming new comfort practices). The "side-effect", however, is that the potential energy savings is outbalanced by increased comfort standards.

With regard to the elements that hold the studied comfort practices together, it is interesting to notice how decisive the institutionalised knowledge of the heat pump as an energy-efficient and cost-effective alternative to direct electric heating is; this knowledge is disseminated in campaigns etc. and acts

as a mediator or "midwife" for thorough practice changes in summerhouses, which in the end level the differences between comfort practices and standards in summerhouses and dwellings. This also shows how important it is to include also other elements than just the technical aspects in a coherent and comprehensive energy policy.

Also the technical characteristics – the design and operation modes – of the heat pumps play a particular important role as a constituting element of the practices studied here. Again, this is seen most strongly in relation to the practices in summerhouses. As described, most of the summerhouse owners would have liked to heat their house up to only 10-12 degrees Celsius, but due to technical limitations of the heat pumps, this was not possible.

Conclusion

Heat pumps are increasingly assigned a central role in energy planning and energy policy. Not only as a means to save energy and reduce the environmental impact related to space heating, but also as part of the realization of the "smart grid" through load management. However, this study points out a number of pitfalls that might, if not taken into account, undermine the potential advantages of replacing direct electric heating with heat pumps. For summerhouses, the analysis of metering data shows no significant reduction in the average electricity consumption. As the interviews and the survey show, this can be explained by a general increase in the comfort standards in summerhouses subsequent to the installation of the heat pump (e.g. higher temperatures or keeping the house heated during the winter in order to prevent moisture problems and making it more comfortable to use for short periods during the winter). The higher comfort standards imply an increase in the need for space heating that outweighs the potential electricity saving of replacing direct electric heating with heat pumps. The most important practice change is related to the widespread use of the heat pump for heating the summerhouse during the entire winter. The purchase of the heat pump is followed by changes in comfort practices that make these similar to the comfort practices in dwellings.

With regard to dwellings, the analysis of metering data shows that the installation of heat pumps is followed by a significant reduction in the actual electricity consumption (app. 35 %). Thus, heat pumps in this case contribute to higher energy efficiency. However, the actual energy saving is significant lower than the potential energy saving. Also in this case increasing comfort standards seem to explain at least some of this (e.g. increased indoor temperature).

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