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Heat pumps and user practices – energy reductions or increased comfort?

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ABSTRACT

This paper deals with individual air-to-air heat pumps in dwellings and summerhouses and the question of to what extent they deliver actual savings in energy consumption[*†]. Results show that 40% of the expected reduction in electricity consumption is transferred into increased comfort in the homes, including increased heating areas, keeping a higher temperature and a longer heating season and using the heat pump for air-conditioning. Data include electricity consumption in 185 households before and after installation of heat pumps together with survey results of 480 households. Furthermore 12 households are selected for in-depth analysis including technical inspection and qualitative interviewing. Especially for summerhouses results indicate that there on average is no reduction in electricity consumption, as energy efficiency is outbalanced by increased comfort. These results have to be taken into account when making long term energy planning for a sustainable energy system.

INTRODUCTION

The sale of air-to air heat pumps has been quite high, notably in Norway where there are sold some hundred thousand [1] but also in Sweden and France expanding sales figures of heat pumps are reported. In Sweden domestic heat pump sale rose from approximately 20000 to 80000 per year between 2006 and 2007 and in France from approximately 50000 to 70000 per year [2]. Studies from several different European countries has pointed out that there is good economical reason for the consumers to install air-to-air heat pumps [3, 4, 5]. The question of what role air-to-air heat pumps play in a future sustainable energy system have to be discussed together with other technical changes of the whole energy system including to what extent electricity is produced by renewable energy [6,7] and the energy renovation of the building stock [6]. Replacing direct electric heating with air-to-air heat pumps are, however, always more energy efficient because heat pumps can provide 2-5 times more heat than the electricity they use as driving force [3]. In a scenario for future 100% renewable energy systems in Denmark

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individual heat pumps are thus also included for areas not covered by district heating [9]. From a socio-technical point of view it can, however, be expected that the full technical potential for energy efficiency will not be met because of changes in user practices towards still higher expectations and norms of comfort [1] as is also known from studies of other types of households' technologies [10]. Within a techno-economic perspective a corresponding phenomenon is known as the rebound effect focusing on how the economic gains that households get from implementing more efficient technologies will be used to increase consumption in other areas or within the same area resulting in higher standards and thus increased energy consumption. There has been a debate about the size of the rebound effect within the household sector and a recent review suggest a rebound effect on 20% meaning that 20% of the energy savings gained from efficient technologies within the household sector are transformed into increased energy consumption and thus not realised as energy savings [11, 12]. The purpose of the study presented in this paper was to analyse to what extent the potential reduction from installation of air-to-air heat pumps are realised or transformed into increased consumption. Furthermore, it was to go more into detail in explaining within which areas more precisely the increases in comfort is seen and to understand in more sociological terms why and how these changes occur.

Today, 8% of houses in Denmark [13] and 84% of summerhouses are heated by direct electric heating [14]. The majority of these are not placed near city centres and thus reachable by district heating and the most relevant future heating supply for these homes is thus individual heat pumps [9]. As these houses have not installed central heating based on water-borne systems, the economically most attractive choice will most often be to install air-to-air heat pumps. Another argument for looking at air-to-air heat pumps in relation to changes in comfort norms is that these can easily be used for air-conditioning as well. Air-conditioning has until now not been normal in Danish households, however, having available technologies installed in the home might contribute to change this.

In the following, we will first describe the methods of the study and then, in the main part of the paper, present findings and analysis for permanently occupied dwellings and summerhouse respectively. In the conclusion, results are discussed in relation to the implications for interaction between heating technologies and renewable energy systems.

METHODS

Data presented in this paper are based on a survey from 2010 among house owners in two Danish regions who have installed air-to-air heat-pumps. The survey population of 2793 households was drawn from the customer lists from two Danish regional energy companies that participated in this study. A sample of 681 house owners or 24.4% within the population completed the online-questionnaire with questions on heating technology, heating practices, other electric appliances and characteristics of the household before and after purchase of heat pump. The questions towards summerhouses differed slightly from those to all-year houses. People were asked to indicate the type and fabrication of heat-pump and only households which for certain have an air-to air heat pump are kept in the analysis. This includes 481 houses, whereof 76 are summerhouses. In order to detect changes in energy consumption following the installation of the heat pump, the questionnaires are combined with available energy consumption data from the years 1990 to 2009 delivered by the energy companies. Some questionnaires are removed from this part of the survey if the year of installation of the heat pump is unknown, or if the installation year is too recent or too old in order to have metering data for at least one year before and after installation. This results in a dataset of 138 questionnaires, whereof 42 are for summerhouses. Finally, a follow-up survey was carried out among the summerhouse owners asking questions on how they keep their summerhouse heated in wintertime as this turned out to be an important question (however, it was only possible to get in contact with 35 of the 76 summerhouse owners). These datasets are summarized in table 1.

Twelve respondents were selected for in-depth analysis including face-to-face qualitative interviews and technical inspections of their heat pump. The aim of the technical inspection was to detect to what extent technical issues could explain lacking reductions in electricity consumption. The technical inspections focused on visible conditions that might affect the efficiency of the heat pump: the condition of the evaporator/condenser (physical damages or dirt obstructing air flow) and risks of “thermal short-circuit” due to the placing of the evaporator/condenser. The aim of the 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. Respondents were chosen in order to ensure variety in the sample with regard to heating system, development in electricity consumption and household composition. The interviews, which lasted about one hour each and were carried out as semi-structured interviews [15], were recorded and afterwards thematically transcribed and analysed.

Table 1. Number of households in dataset

	Total	Permanently occupied dwellings	Summer houses	Follow up on summerhouses
Questionnaire survey	481	405	76	35
Survey incl. electricity data	180	138	42	
In depth analysis	12	8	4	

Results from this project has previously been presented in two conference papers, one focusing on the qualitative material [16], and another focusing on the quantitative material [17], whereas this paper include both approaches. Analyses of the results are in the following divided into two sections dealing with permanently occupied dwellings and summerhouses respectively

ANALYSIS OF PERMANENTLY OCCUPIED DWELLINGS

From technical specifications of the effect of air-to-air heat pumps it should be expected that electricity for heating purpose is reduced by two third if the house was heated by direct electric heating before installation and only by the use of heat pump after installation (these calculations take into account reduced efficiency, COP, at low outdoor temperatures). If we assume that 64% of a households’ electricity consumption is used for heating, it should be expected to have approximately 43% reduction of households’ electricity consumption after installation of the heat pump. The rebound effect is then the difference between these 43% reduction and the actual measured reduction.

To estimate the actual reduction, electricity consumption has to be degree day correction. As electricity is used for other purposes than just heating, the share of electricity used for other purposes is estimated for each household on the basis of information about the number of people in the household and the size of the building and the rest of the electricity consumption is then degree day corrected. In figure 1 electricity consumption before and after installation of the heat pump is compared. It is seen that the slope is below one, indicating that for the majority of the households electricity consumption after installation of heat pump is lower than before, as would be assumed. However, especially households with lower levels of prior electricity consumption do in general not realise a lower level of consumption after installation.

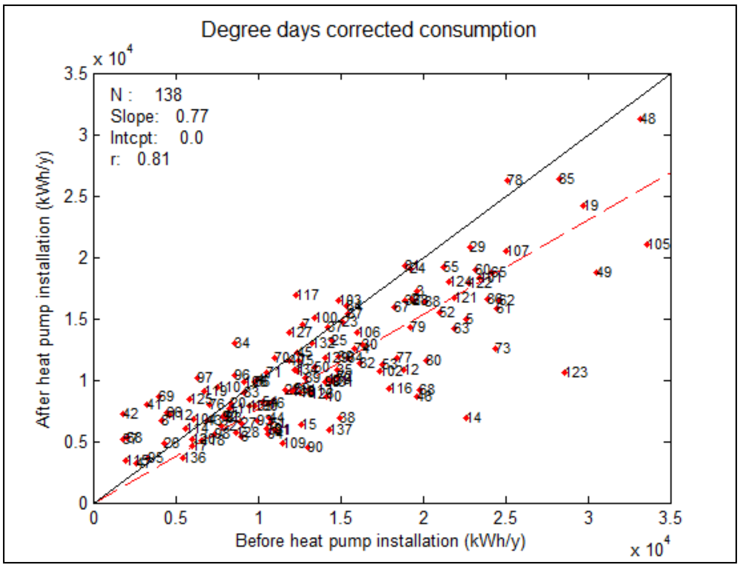
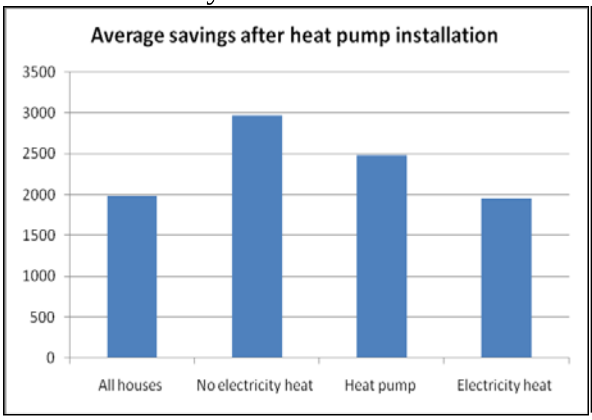


Figure 1. Comparing annual household electricity consumption before and after heat pump was installed. Electricity consumption for heating is degree day corrected.

A major explanatory variable is expected to be the question of what the primary heating source was before and after installation of the heat pump. In figure 2 the average savings in all households are shown together with combinations of what the primary heating source was before and after installation of heat pump. Besides a degree day correction, these average saving values are also corrected for a yearly decrease in consumption of 5%. These 5% reduction are calculated on the basis of comparing one year with the following for the years where the surveyed households did not install the heat pump.



1. All houses: All houses degree day corrected and corrected for a yearly 5% general decrease (N=138)
2. No electricity heat: Houses using direct electricity heating before heat pump installation and no direct electricity heating after (N=16);
3. Heat pump: Houses using direct electricity heating before heat pump installation and using heat pump as primary heating source after (N=70);
4. Electricity heat: Houses using direct electricity heating before heat pump installation and after still using direct electricity as primary heating source. (N=32)

Figure 2. Average savings in annual household electricity consumption (kWh) before and after heat pump was installed, for different combinations of heat supply before and after installation of heat pump. For all four cases the savings are significantly different from zero.

In all four cases in figure 2 a paired samples test shows that the savings is significantly different from zero (not shown here), though there are big variations for the savings especially among the second case, which is also where we see the biggest average savings and where we have a low number of households. The biggest average savings (and the biggest variation) are thus not surprisingly seen in households where they used direct electric heating before they installed the heat pump, and where they do not use any direct electric heating after the heat pump is installed.

The group of households that used direct electric heating before installation of heat pump and primarily heated by heat pump after installation is thus the group that can be compared to the expected theoretical reduction of 43%. The slope of the red line in figure 3 indicates that on average the reduction in electricity consumption for these households is 26%. Comparing this with the expected 43% reduction thus suggest that 40% of the expected saving is used for increase in other consuming practices ((43-26/43=39,5%). In the following of the analysis we will go deeper into explaining this missing reduction or rebound effect of approximately 40%.

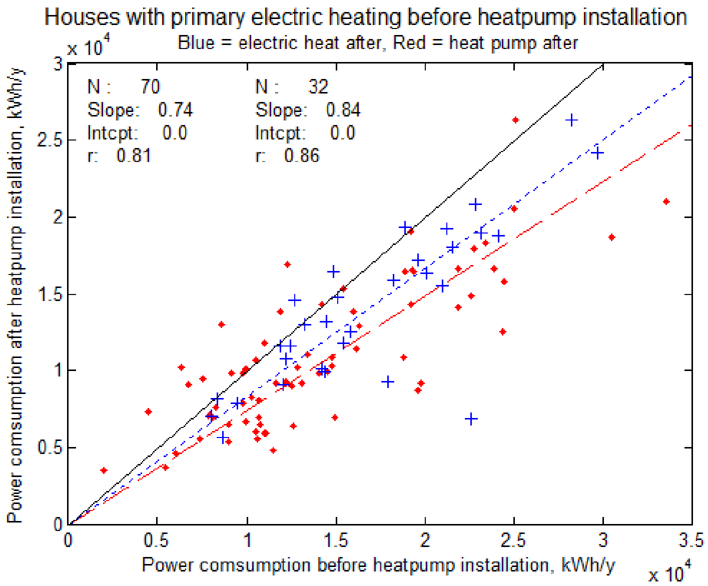


Figure 3. Comparing annual household electricity consumption before and after heat pump was installed for households that used direct electric heating before and divided on what type of heating they used after. Electricity consumption for heating is degree day corrected.

As there are numerous variables which might influence change in electricity consumption other than the installation of the heat pump, the following will show results of regression analysis with all available and relevant variables from the survey. These variables include change in primary heat supply, number of household members, number of rooms, heating period, heating temperature, cooling days, electrical appliances, house insulation, consumption of firewood and installation of wood burning stove. Furthermore there are some descriptive variables on the household members such as number of children and adults and household income as well as descriptions of the house such as size and age and heated area. The regression analysis can be described by the equation:

$$Xafter_i = a + b \cdot Xbefore_i + \sum_{j=1}^{N} c_j \cdot X\,\mathrm{cov}_{i,j} + \varepsilon_i$$

Where *Xafter* is the electricity consumption after heat pump installation, *Xbefore* is the consumption before, and Xcov are the different other variables. Results of the full regression analysis are shown in appendix. The *b* coefficient to *Xbefore* is a measure for the heat pump effect and possible other effects not included in *Xcov*. No variables from the *Xcov* matrix are found significant. Using forward selection and stepwise regression noisy variables are removed from the regression thus revealing that three variables are significant, which are household income, cooling days and change of appliances. Thus the equation for the significant explaining variables is:

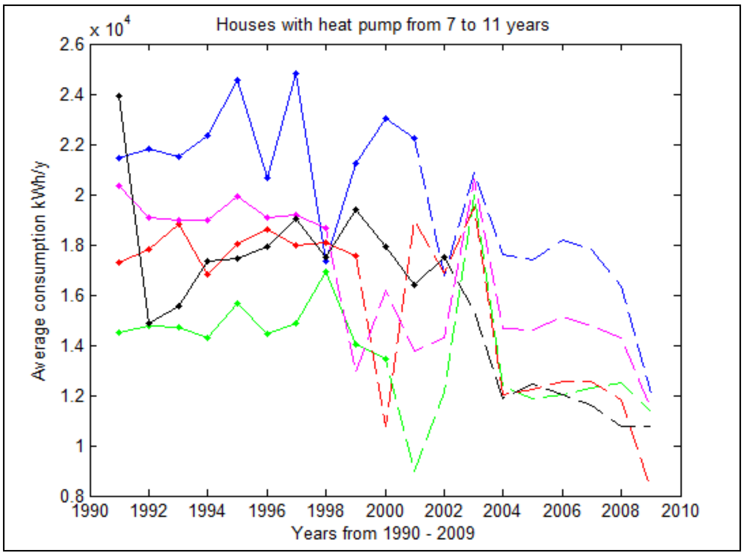
$$Xafter = 0.60 * Xbefore + 2.7 * Income\_household + 199 * Cooling\_days + 616 * Appliances\_chng$$

where the intercept remains insignificant. The coefficient for change in appliances (white goods) is rather high and this may be interpreted as the variable cover for a more general increase in wealth and not only for the white goods. This prediction model also turns out to offer an improved explanation of the electricity consumption as the correlation coefficient r is 0.86 as compared to figure 2 where we had r=0,81. However, the number of observations decreases to 67 because some answers to the explaining variables are missing.

It is thus interesting that what seem to explain change in electricity consumption other than the installation of the heat pump are variables related to general wealth and to change in heating practices represented by the Cooling_days variable. The combination of these three variables is the best explainable combination we can get on the available data. This does not mean that the excluded variables do not have any influence for some of the specific cases. However the amount of independent variables in the study compared to the amount of households included is a limitation in this analysis.

Still, the main effect arising from *Xbefore* is strongly significant and the corresponding coefficient is estimated to 0.6 as seen from the equation. This means that the effect of the heat pump together with the 5% general annual decrease gives a reduction of 40% of the electricity consumption. Thus the heat pump alone gives a 35% reduction in electricity consumption.

In the previous analysis electricity before and after installation has been summarized for several years from 1990 to 2009 depending on when in the period the heat pump was purchased. Another approach to study the impact on electricity consumption after installing a heat pump is to analyse how electricity consumption develops in the years after the purchase. Figure 4 show how the average annual consumption develops year by year after installation separated into which year the household purchased the heat pump. In this figure all households independent on their primary heating type before and after installation is included. We see that electricity consumption is rather low the first year after installation, and then the following years it rises. This is potentially interesting as it might indicate that people save more the first year after installation, and then when they have got used to the lower electricity consumption, they start to use more. Furthermore it is seen that year 2003 is a year where all lines (except the black representing those who just installed the heat pump) has a peak. When looking for characteristic of this year it should be remembered that data are already degree day corrected, so extreme winters are taken into account. Instead, the peak in 2003 might be explained by the fact that it was actually an extraordinary hot summer, where many people might have used the heat pump for air conditioning. If we discard the 2003 point in figure 4, the tendency seems to be energy savings within the first year after the installation, which is followed by a small increase, then a stable period and finally a new reduction of consumption. In general it is seen that there are several increases and decreases which are not related to purchase of heat pump.



Year of installation of heat pump (HP):

Black = HP in 2002 (n=10)
Blue = HP in 2001 (n=3)
Green = HP in 2000 (n=7)
Red = HP in 1999 (n= 9)
Magenta = HP in 1998 (n= 11)

Figure 4. The average household electricity consumption, distinguishing between the years of installation of heat pump. Dotted line indicate purchase of heat pump.

In the following, the results from the survey and the qualitative interviews will be analysed in order to provide a more detailed understanding of changes in heating practices. As described in the methods section, there are more households in the survey than in the dataset with electricity metering data, and it is therefore interesting to analyse the survey more detailed.

Respondents have been asked why they purchased the heat pump. As seen in table 2, the majority has done this to save money and energy, and to a lower degree to improve their comfort. More than two-third of the respondents indicate that they are very satisfied with their heat pump and only one per cent that they are very unsatisfied with it (not shown in table).

Table 2. Reasons to purchase the heat pump

	Number	Per cent
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%

The qualitative in-depth interviews provide a more detailed picture of how the use of heat pumps is experienced. Seven out of eight interviewees in permanently occupied dwellings explain that the indoor air quality and comfort have improved since the installation of the heat pump. The interviewees typically mention benefits like less moisture, “cleaner air” and better air “circulation”. For instance, a couple in their seventies experience that they do not need to air their living room as often as before. The interviewees in general emphasised the non-economic advantages of the heat pump, while the energy saving aspect was put more in the background. This indicates that even though the economical aspects seem to play an important role for the decision to purchase a heat pump (cf. table 2), other aspects like better indoor comfort play a more central role for the interviewees' later experience of the heat pump.

The survey results shows that the majority (86%) of the respondents used electricity for heating before they bought the heat pump and most of them (approximately 60%) use the heat pump as primary heat source now, though only 11% indicate that the heat pump is their only source for heating purpose. Approximately 50% of the households combine heat pumps with a wood burning stove and the majority use electric heating, with either heat pump or direct electric heating, as the primary source. 164 respondents had a wood burning stove before they got the heat pump and among those there are 39% who indicate that they use less wood after they got the heat pump, 39% indicate that it has not influenced their firewood consumption, 31% do not know and only 3% indicate that they use more wood after they got the heat pump. It seems thus that heat pumps in some households have substituted wood rather than electricity for heating purpose.

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

	Number of households	per cent
No change	206	50,9%
Shorter heating period of the year than previous	93	23,0%
Longer heating period of the year than previous	69	17,0%
Not applicable, Heat pump installed before we moved in	37	9,1%
Total	405	100%

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

	Number of households	Per cent
Same temperature as previously	223	55,1%
Temperatures are generally kept higher than previously	123	30,4%
Temperatures are generally kept lower than previously	19	4,7%
Not applicable, Heat pump installed before we moved in	40	9,9%
Total	405	100%

The question if people change their heating practices and norms of comfort after purchase of the heat pump is a main research question in this paper. In table 3 it is seen that 50% of respondents do not believe that they have changed habits in relation to how much of the year they heat their house, and more people (23%) believe they heat for a shorter period after they have got the heat pump than the percentage (17%) who believe they now heat for a longer period than before. There is thus no reason to believe that the heat pump in general entail a longer heating season in permanently occupied dwellings. If we look at table 4, there is however indication that approximately one-third of the households established a higher temperature setting after they purchased the heat pump, while only 5% think they keep a lower temperature. The in-depth interviews indicate that this temperature increase might be closely related to the understanding that heat pumps is a less expensive form of heating compared with direct electric heating, which most of the interviewees regarded as very expensive. This can be illustrated by one of the interviewed families (a couple aged 49- and 55-years with two children) whose heat pump replaced direct electric heating in their kitchen and living room. However, their electricity consumption had only been reduced moderately by 10%, which might partly be explained by higher indoor temperatures. As the couple explains:

> Husband: We have probably got a higher temperature in here.
> Wife: Yeah, previously we were satisfied with 20 degrees (...)
> Husband: (...) now it's 21.5, so we have actually raised the indoor (...) temperature since we have got the heat pump. In a way, we have allowed ourselves a bit of luxury.

This quote illustrates how the users' understanding of economical characteristics of different heating forms influences their heating and comfort practices.

Another way of raising the comfort is to enlarge the heated area, e.g. start to heat rooms which were not previously heated. 13% of the respondents indicate that more rooms are heated after the purchase of the heat pump, and these rooms are typically 10-30 m^2. Two of the interviewed families had installed their heat pump in connection with a new-built extension to their house. One of them had built 30 m^2 extension (garden room) to their house. They choose a heat pump as this was cheaper than radiators (due to costly piping work) and more simple than a wood burning stove that needs a chimney. Also, they liked that the heat pump can be used for air conditioning in the summer as the garden room can be very hot on sunny days. The household's electricity consumption has increased by 60% since the installation (the rest of the house is still heated by district heating).

Following this example a last issue to be raised relates to the question to what extent people use their heat pump for air conditioning. First question is if people know about the possibility that their heat pump can be used for air conditioning. 76% of the respondents indicate that their heat pump can be used for air conditioning, 22% state that it cannot (which is probably wrong) and only 3% say that they do not know. Among the 306 respondents who know that their heat pump can be used for air conditioning, 21% of households have actually used it and those 64 households have furthermore estimated how much they use it for air-conditioning. In table 5 it is seen that one-third use it only a few days and that 17% uses it more than 15 days during a normal summer.

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

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

ANALYSIS OF SUMMERHOUSES

When combining survey results on summerhouses with data on electricity consumption we have 42 cases. This number is unfortunately too small for proper statistical analysis including all available variables. Figure 5 shows a comparison of electricity before and after purchase of the heat pump for these 42 summerhouses. It is seen that the slope of the line is below 1 thus showing an over-all reduction in electricity consumption after installing the heat pump. Even though we detect a slope by the regression, a pair-wise test shows that the mean difference is not significant different from zero. The slope thus arises from high consumption cases having high leverage. Among summerhouses with low electricity consumption there seems to be a tendency that they have an increase in electricity consumption after purchase of the heat pump. Regression analysis including supplementary variables confirms that it is a significant relation that summerhouses with low levels of electricity consumption experience an increase in electricity consumption, an increase which cannot be explained by any of the supplementary variables. It is reasonable to assume that some summerhouses with electricity consumption below 3000 kWh only to a limited degree did heat their house with electricity during the winter before installing the heating pump, and that the increase in electricity consumption partly is a result of an increase in heating season and temperature in wintertime.

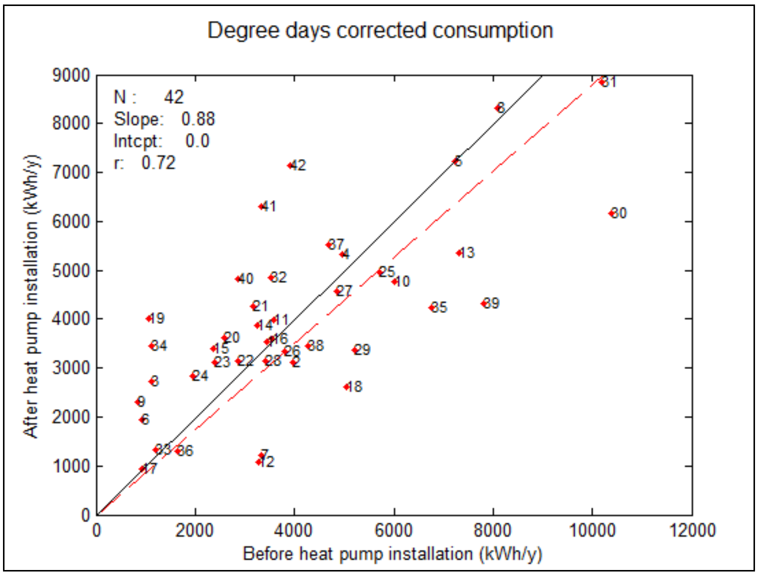


Figure 5. Comparing annual household electricity consumption before and after heat pump was installed in summerhouse. Electricity consumption for heating is degree day corrected.

Table 6. Reasons to purchase the heat pump in summerhouse

	Number of households	Per cent
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%
Heating system needed renewing	0	0%
Not applicable, Heat pump installed before we moved in	2	3%
Others	6	8%

In table 6 are listed the answers to the question of why people have purchased their heat pump for the summerhouse. A majority of 61% indicate to save energy as a reason, and the second and third most often indicated options are to increase comfort and to frost-proof the summerhouse in wintertime. Half of the respondents indicate saving money on heat consumption, and if we compare with table 2 we see that 72% of owners in permanently occupied dwellings indicate that the reason to purchase a heat pump was to save money on energy. It thus seems that there are slightly different reasons involved when purchasing a heat pump for the summerhouse and for the permanently occupied dwelling, which is also displayed in the qualitative answers respondents have filled in under “Others”. These includes: “Having a nice temperature when we arrive at the summerhouse”; “Better use of the summerhouse in winter time”; “Higher temperatures in wintertime with lower consumption”. The qualitative interviews with owners of four summerhouses show that in all four cases, the owners used the heat pump to keep the house heated during the winter, and this had actually played an important role for the informants’ original decision about purchasing a heat pump. Before the installation of the heat pump, the interviewees had either “shut down” their summerhouse in the winter or kept it heated up to 5 deg. C by use of direct electric heating. The interviewees explained that the low temperatures in the winter had resulted in problems with moisture and mould. Now, their houses are heated to 16 deg. C the entire winter, which makes it more comfortable to use the house also in the wintertime. As a consequence, most interviewees use their house more often during the winter.

The survey show that in more than two-third (72%) of the summerhouses the heat pump is the primary heat supply and more than half of the respondents indicate that they used direct electric heating as their primary heat supply before installation of the heat pump. Furthermore, 80% indicate that they also use firewood for heating, and among those who had firewood burning stove both before and after installation of the heat pump half of them (47%) indicate that they use less firewood after purchase of the heat pump. The respondents were asked about changes in their heating practices and norms of comfort following the purchase of the heat pump. Table 7 and 8 summarise the answers. Here it is seen that more than half of the respondents indicate that they heat for a longer period and keep a higher temperature after purchase of the heat pump.

Table 7. Changing heating practices related to heating season after purchase of heat pump

	Number of households	Per cent
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%
Total	76	100%

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

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

In the follow-up survey it is confirmed that 23 out of 27 people heat their summerhouse to more than 10 deg. C after purchasing the heat pump, whereas all of these, except one, closed the house completely or kept it heated to a lower temperature before installation of the heat pump. This supports the previous mentioned findings from the qualitative interviews. It is interesting to notice that for the majority of the types of heat pumps, which people have installed, it is not technically possible to have a set-point temperature lower than 16 deg. C, meaning that many of the summerhouses now are heated to 16 deg C the entire winter.

The respondents were also asked if they were aware that their heat pump could be used for air conditioning. Only about half of the respondents are aware of this, and among these, less than half (41%) has actually used it for air conditioning. In table 9, it is seen that only 6 households indicate that they have used the heat pump for air-conditioning more than 5 days a year.

Table 9. Number of days the heat pump has been used for air conditioning in summerhouses

Number of days	Number	Per cent
1-4 days	10	63%
5-9 days	4	25%
10-14 days	2	13%
Total	16	100%

TECHNICAL INSPECTIONS

In relation to the qualitative interviews in both permanently occupied dwellings and summerhouses a technical inspection of the heat pumps was carried through. This, however, only revealed few examples of technical problems that might have influenced the efficiency of the heat pumps: In two cases there were a risk of thermal air short-circuits in relation to the condenser and evaporator respectively, which potentially could result in an estimated 10-20% increase in electricity consumption. In a third case, dirt on the evaporator could potentially increase energy consumption by app. 10%. No visual problems were observed in the other 9 cases. Also, almost 60% of the survey respondents indicate that they have regularly servicing for their heat pump (buyers of heat pumps from the electricity utilities are normally offered a yearly servicing scheme). Therefore, it can be expected that the heat pumps covered by this study in general have a high maintenance-standard, and there are no indications of technical defects being an important factor in explaining the missing energy savings.

CONCLUSION AND DISCUSSION

In this paper it is shown that expected reductions in electricity consumption by substituting direct electric heating with air-to-air heat pumps in individual households are only to some extent reached in real life settings. It is found that in many cases households expand their comfort practices rather than realise energy savings or expand other energy consuming practices. This on one hand confirms the expectations based on socio-technical research indicating that new technological solutions are always accompanied by new norms and practices. In a techno-economic perspective this has been discussed within the frame of the rebound effect. Previous research indicates a direct rebound effect of 20% in households [12]. Based on the results presented in this paper the rebound effect for air-to-air heat pumps installed in summerhouses can be estimated to 100% as on average there is no realised reduction, whereas in permanently occupied dwellings there is seen on average a 26% reduction, which indicate a rebound effect of app. 40%. In future energy planning it is important to be aware of these socio-economic processes which entail growing energy consumption when introducing new and more efficient technologies. There are basically two different approached to deal with this. Either the rebound effect and the growing consumption following from new norms have to be included in modelling and planning. Or, preferably, measures which have proven successful in real life on how to introduce new efficient technologies to users without carrying changes in practices towards higher norms and expectations and thus growing energy consumption, have to be developed. One way of doing this could be by introducing progressive energy tariffs and soft loans together with the more efficient technologies [18].

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Appendix: Full regression analysis and t-test to determine which variable are significant.

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	19814.026	31685.786		.625	.537
	Xbefore	.502	.085	.649	5.915	.000
	Adults	-70.960	810.033	-.010	-.088	.931
	Children	-422.075	677.919	-.081	-.623	.538
	House_size	15.712	19.902	.097	.789	.436
	House_age	-10.594	15.900	-.064	-.666	.510
	Person_changes	-738.384	1702.737	-.038	-.434	.668
	HeatPump_only	-1852.963	1117.192	-.159	-1.659	.108
	HeatedArea	15.238	18.933	.084	.805	.427
	NewRooms	.426	23.776	.002	.018	.986
	Fireplace	-477.153	1027.360	-.050	-.464	.646
	HeatPeriod_chng	-1024.791	823.045	-.122	-1.245	.223
	HeatTemp_increase	-428.353	893.299	-.056	-.480	.635
	Cooling_days	191.214	128.039	.156	1.493	.146
	Appliances_chng	399.078	337.810	.133	1.181	.247
	CFL	-731.567	818.226	-.077	-.894	.379
	Appliances_new	430.671	418.707	.101	1.029	.312
	Settopbox_new	392.997	710.540	.051	.553	.584
	TV_exstra	951.408	1290.617	.087	.737	.467
	PC_extra	433.857	900.332	.048	.482	.634
	InsolateHouse	486.183	911.352	.047	.533	.598
	Income_household	2.919	2.316	.136	1.260	.218
	Firewood_save	64.071	1193.305	.006	.054	.958

a. Dependent Variable: Xafter