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Summary

In this report a literature survey has been carried out to find out the demand response (DR) potential in the near future in Northern Europe and some central European countries. In the Finnish case also the effect of heat pumps is taken into account when estimating the potential of demand response of electric heating. Also cost estimates for DR were surveyed.

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Preface

This report was written as part of tasks 5.1 and 7.4 of Smart Grids and Energy markets project. The report performs a literature survey of electricity demand response potential in northern Europe, Germany, Austria and the Netherlands. Also the factors affecting demand response of electric heating are explained. Cost estimates of DR were also surveyed in European countries.

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Authors

Contents

1. Introduction

Demand response (DR) is the ability of electricity demand to respond to variations in electricity prices in near real time. The response time can vary from seconds to hours. DR can be achieved through facility load reductions or utilizing alternative onsite generation sources. Thus its objective is to affect load shape to achieve cost reductions.

DR can be categorized according to the end use sector to residential DR, primary sector DR, industrial DR, and tertiary sector DR. Tertiary sector includes offices, schools, shops, and other services. There are a number of other ways to categorize DR, e.g. based on the method of control. Examples are direct control, price-based control and load frequency control.

In this report a literature survey has been carried out to find out the demand response potential in the near future in Northern Europe and some central European countries. Residential and tertiary sector DR is often limited by indoor conditions: thermal comfort or air CO_2 concentration. Industrial DR is again limited by the process characteristics, which vary widely from industry to another and plant to another. Therefore studying DR potential requires an in-depth study of each type of consumer.

In each case DR involves installation costs and variable costs, which depend on the amount of energy which is released by load shedding. There can also be fixed operation and maintenance costs. The installation cost, which is an upfront investment, depends on the method of control, size of the controlled loads, their already implemented control methods (e.g. building automation), etc. Variable costs are difficult to estimate

2. Demand response of electrical heating in Finland

2.1 Statistical background

In this chapter we try to evaluate the demand response characteristics of residential consumers in Finland. Demand response of residential customers is mainly comes from heating and cooling loads. It was evaluated based on several sources.

The most common types of electric heating are the direct electric heating and partial storage heating. Partial storage heating, implemented either by a hot water tank or directly heating the concrete floor of the house, is an efficient way to concentrate heating load at night. At its lowest partial storage electric heating in a typical single-family house in -8.7 ºC ambient temperature consumes about 1.1 kW and direct electric heating 2.6 kW. Unfortunately the exact numbers of directly heated houses and partial storage houses are not known. According to the national bureau of statistics the total number of electrically heated single-family houses in 2011 was 500,500. Their average floor area was 110 m2. In addition there are 115,000 electrically heated apartments in terraced houses and their average floor area is 69 m2 . In addition there is a small number of electrically heated apartments in apartment buildings. Evens et al. (2010) estimated that ⅔ of the electrically heated single-family houses have partial storage heating and ⅓ direct heating. This is reflected in the total heating load figure below, which shows the load of electrical heating for all types of electrically heated residential customers. However, they assumed that there were only 40,000 electrically heated apartments in terraced houses when the real number is 115,000.

Evens et al. (2010) estimated the potential based on load profiles prepared by the Finnish electricity association. The coldest temperature which these load profiles span is -8.7 °C, which is the average temperature of January in Finland. The load profiles are difficult to apply in colder temperatures. Figure 1 shows the estimated total heating load of electrically heated households on winter working day.

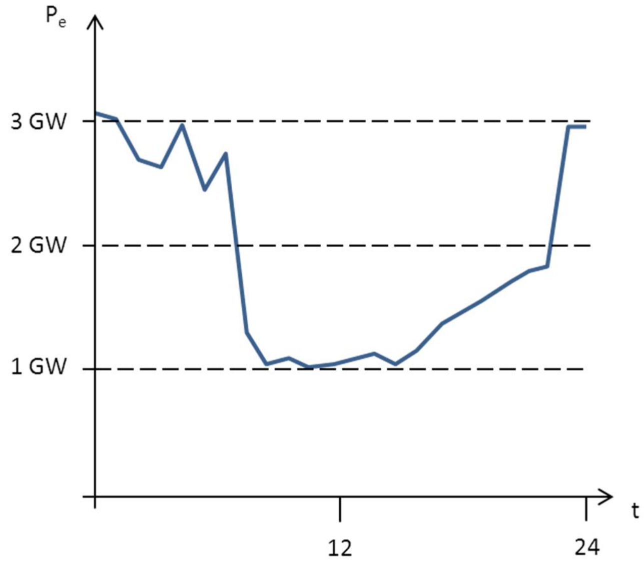

Figure 1: Estimated total heating load of electrically heated households on winter working day. The outdoor temperature was -8,7 ºC (Evens et al., 2010).

We used the VTT Talo simulation software to estimate the space heating load of a directly electrically heated single-family house. The annual electricity consumption of this model house was 26.3 MWh, considerably more than assumed in our later analysis below. The living area of the house was 138 m^2, 25 % more than the average area mentioned above, and the insulation level followed the year 1986 regulations. Figure 2 shows the simulated space heating power as function of moving average outdoor temperature.

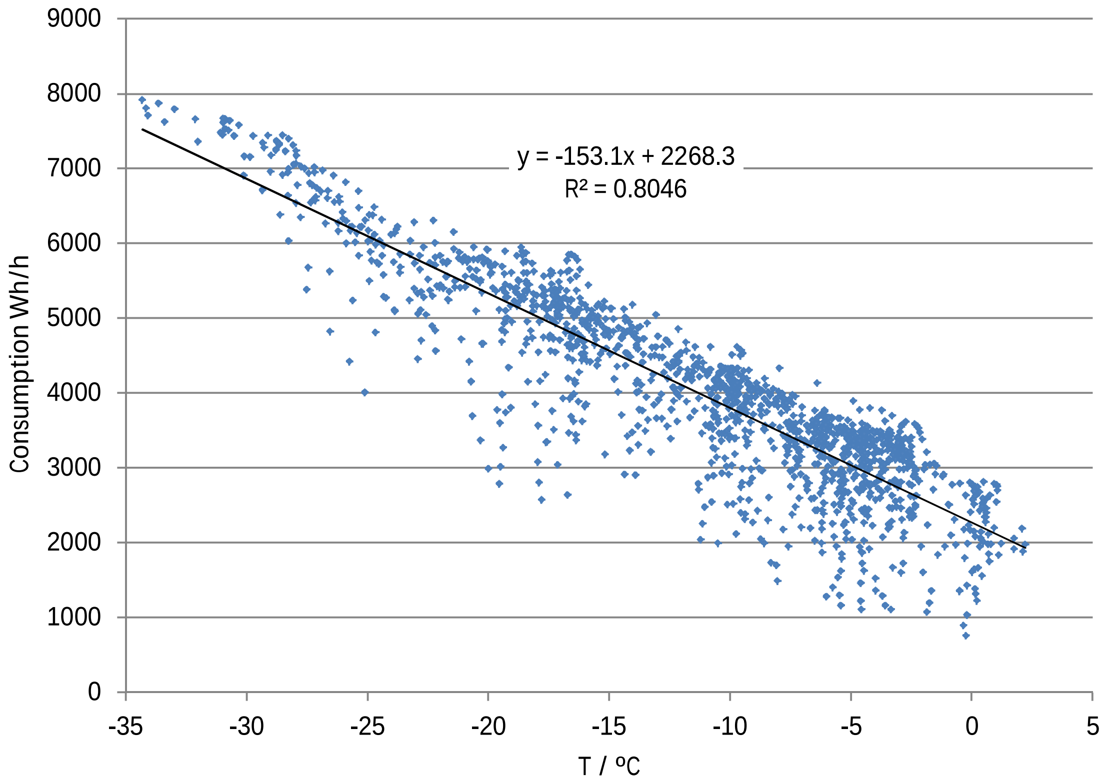

Figure 2:. Simulated space heating load of a directly electrically heated single-family house as function of moving average outdoor temperature (6 hours' delay) in January-February 1979. A linear regression line in shown with black.

Riihimäki et al. (2012) studied the daily energy consumption of electrically heated houses with full-storage heating. In a group of 185 houses the temperature dependency of daily electricity consumption was linear. In -15 ºC outdoor temperature the houses consumed an average of 160 kWh/d and in +5 ºC 90 kWh/d. The temperature used was the average outdoor temperature for 24 hours period prior to the consumption measurement.

Demand response characteristics of small customers can also be evaluated by performing load control tests. The DSO EON Kainuu performed a load control test of small customers on Tuesday February 9th 2010 from 2 pm to 3 pm (Jäppinen, Lindroos, & Ala-Nojonen, 2010). The type of electric heating was partial storage and direct electric heating (proportions are not known). The controlled branch circuits included electrical heating, electric water heating and electric sauna stove. However, neither electric water heating nor sauna was on at most consumers at that time. The test spanned 3594 consumers and outdoor temperature was -8 ºC. According to measurement the total load reduction was 4.4 MW, i.e. 1.2 kW per customer. On Wednesday February 17th from 9 am to 10 am they made a similar test when temperature was -26 ºC. In the second test the total load reduction was 7,5 MW, i.e. 2,1 kW per customer. Customers did not actually complain about low indoor temperature during the tests, although a few of them called the DSO's customer service. We can conclude that in these tests the load reduction was somewhat lower than what could be expected from the above results by Evens et al. The difference can be due to air-to-air heat pumps, which were not included in the controlled circuit. Also the abundance of high-efficiency masonry fireplaces can be higher than what it was when the type load curves were made.

In the Kainuu tests also the payback peak was monitored. In the first test (February 9th 2010) the returning load was about 6 MW (4 MW higher than the load just before the curtailment). In the second test the returning load was about 8 MW (1.5 MW higher than the load just before the curtailment). Especially in the second test the payback peak was very low.

2.2 Effects on thermal comfort

An important factor affecting the demand response potential of a residential customer is thus the heat storage capability of the house. If the house detains heat well so that indoor temperature drops only slowly, the DR potential is larger. However, if this is achieved by better insulation and other energy efficiency measures, the result will be that heating load is also decreased, which is a disadvantageous effect from the point of view of DR. Building mass is another factor affecting the rate of temperature change. Rate of ventilation, as well as ventilation heat recovery have an effect on the rate of temperature change. Below are shown some measurements of the operative temperature of a light-structure single-family house when the heating is turned off. We see that in this case a ½-hour curtailment is possible in -21 ºC temperature, 1-hour curtailment is barely possible in -10 ºC temperature and 2-hour curtailment is possible in -4 ºC outdoor temperature.

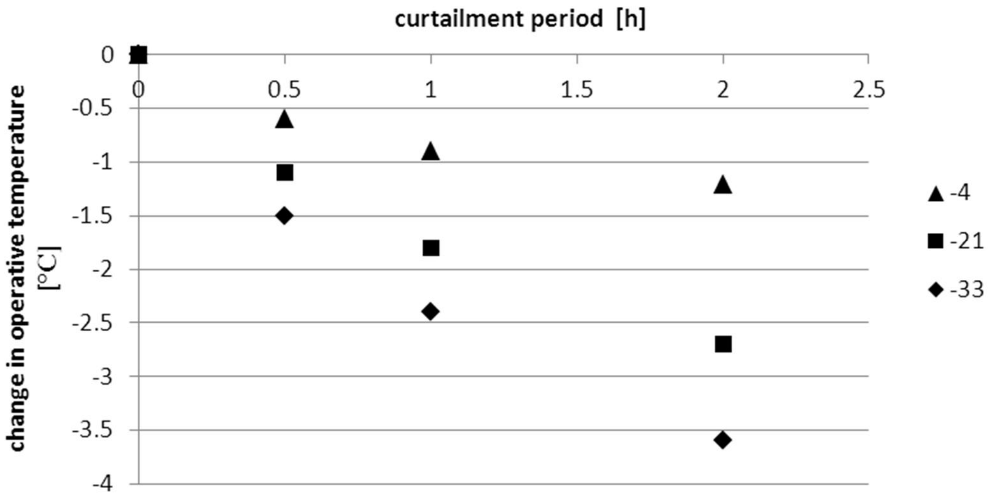

Figure 3: Measurements of cooling down of a light-structure 115 m² single-family houses in different outdoor temperatures (-4 ºC, -21 ºC and -33 ºC) as function of time after electric heating is turned off. Air temperature did not greatly differ from the operative temperature (Martikainen et al., 1987).

2.3 Effect of heat pumps on DR

Air-to-air heat pumps are quite common in electrically heated houses and reduce the electrical power needed especially in mild winter temperatures. Also, even if electric heating in the house can be controlled remotely, the heat pump usually cannot be. In this case they have a similar effect on demand response as fireplaces. However, the effect is diminished during cold periods -as shown below.

Table 1 below shows that every year about 50,000 air-to-air heat pumps are installed. The forecast of the total number of all types of heat pumps in Table 2 may be a bit optimistic.

Table 1: The forecast number of annually installed heat pumps in Finland according to the Finnish Heat Pump Association. 2015 and 2020 are estimates.

Type	*2010*	*2011*	*2012*	*2015e*	*2020e*
Ground source	8 091	13 700	13 000	15 000	20 000
Exhaust air	1 988	2 000	1 900	3 000	4 000
Air-to-water	1 150	1 000	1 000	5 000	6 000
Air-to-Air	53 821	55 000	45 000	50 000	40 000

Total amount of annually installed heat pumps	67 752	65 050	76 000	73 000	70 000

Table 2: The forecast total number of heat pumps in Finland according to the Finnish Heat Pump Association. Years up to 2012 are based on statistics of numbers of sold heat pumps.

	2009	*2010*	*2011*	*2012*	*2015e*	*2020e*
Total amount of heat pumps	340 000	390 000	470 000	540 000	750 000	1 000 000

Tuunanen (2009) estimates in Figure 4 that most heat pumps have been installed in single-family houses although in the future summer cottages are also an important target group. This result is from a study which deals with a rural DSO Parikkalan Valo oy. However, we don't expect the results to differ much from other areas in Finland, although the proportions of different types of buildings can vary. Furthermore, he estimates that in 2009 20 % of single-family houses with direct electric heating had a heat pump, of which 75 % were air-to-air heat pumps (Figure 6). In 2020 he estimates that even 95 % of single-family houses with direct electric heating will have a heat pump. For storage electric heating he only estimates the total number of all types of heat pumps to be 30 % in 2009 and 95 % in 2020.

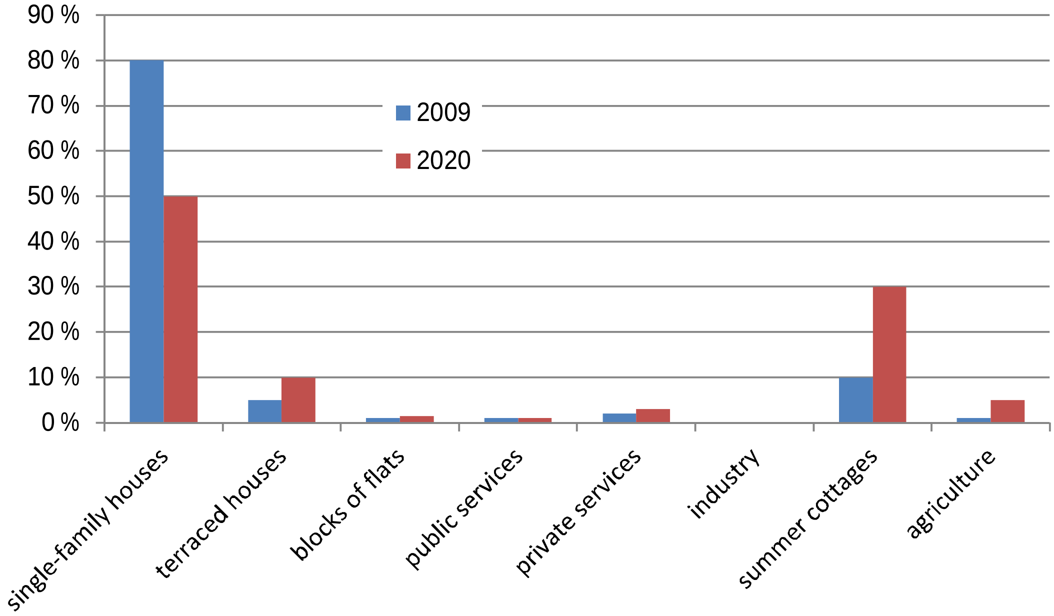

Figure 4: The distribution of heat pumps among different types of buildings (Tuunanen, 2009). The figure includes all types of heat pumps.

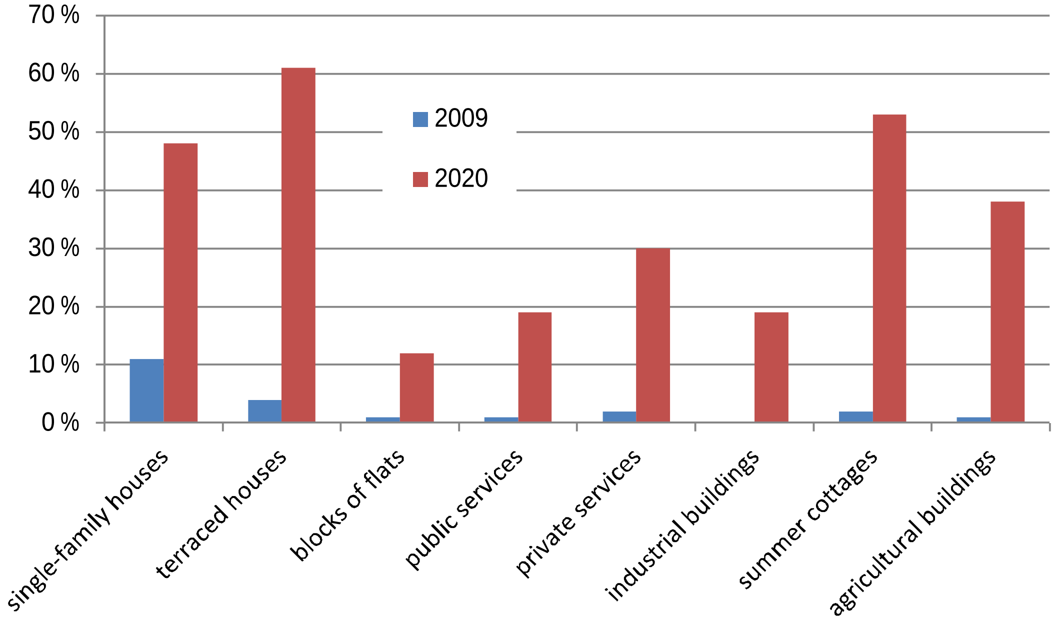

Figure 5: The distribution of heat pumps among different types of buildings (Tuunanen, 2009). The figure includes all types of heat pumps.

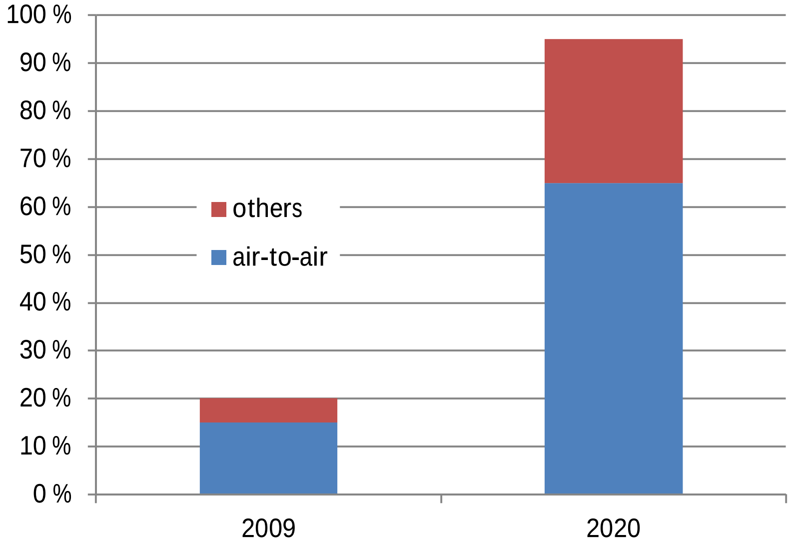

Figure 6: The estimated percentage of heat pumps in single-family houses with direct electric heating (Tuunanen, 2009).

In mild winter temperatures (> -5 ºC) a typical air-to-air heat pump can totally replace direct electric heating. In very cold temperatures (< -20 ºC) the power saving is smaller and often the air-to-air pump is switched off. Figure 7 shows the maximum heating power of a typical "9-series" (indicates the power class of the heat pump) air-to-air heat pump, which is common in single-family houses. The maximum heating power in warmer conditions is usually not interesting because it exceeds the heating need of the house.

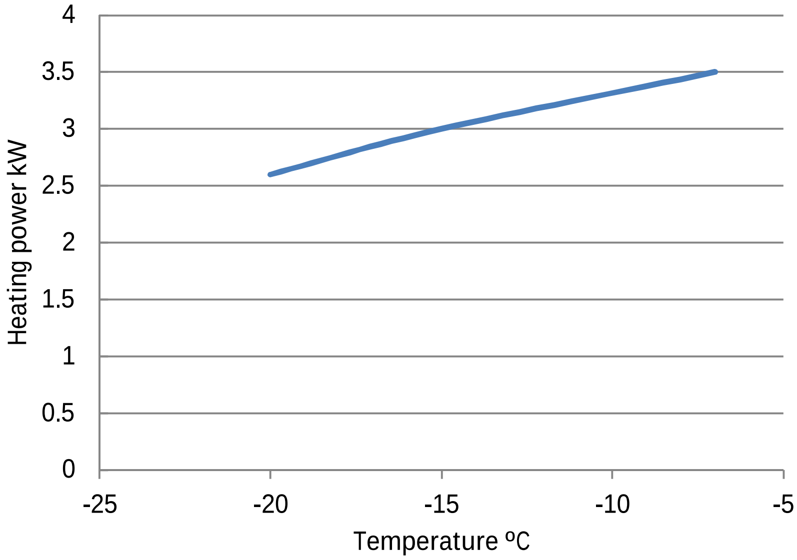

Figure 7: The typical maximum heating power of an 9-series air-to-air heat pump as function of outdoor temperature.

The energy agency Motiva studied energy saving enabled by air-to-air heat pumps in electrically heated single-family houses. In a group of 78 houses the average saving was only 2500 kWh/a, about 12.5 % of the average total consumption of the houses prior to installing the heat pump. There are at least two reasons for such low saving. Firstly, the air-to-air heat pump does not heat the whole house because the warm air produced by the heat pump does not circulate in the whole house. This limits the power and energy saving potential. Naturally, this effect depends on the interior design of the building. Secondly, the users do not use the heat pump in an optimal way. If the setpoints in the main heating system (e.g. radiators) are not adjusted downwards, the heat pump will work in parallel with the main heating system, reducing the possible saving.

We assume that in houses with direct electric heating the heat pump reduces the power drawn by the main heating system

$$p_d(t) = p_{d,0}(t) - \boldsymbol{min}\left[\eta p_{d,0}(t), p_{max}(T_{amb}(t))\right] \tag{1}$$

Here $pd,0(t)$ is the power drawn by the main heating system in absence of the heat pump, η is the factor describing the share of the building which the heat pump can heat due to suboptimal air circulation, $pmax(Tamb)$ is the maximum heating power supplied by the heat pump in ambient temperature $Tamb$. We use the value η = 0.5. The electrical power drawn by the heat pump can then be determined from the last term of the above equation by dividing it by the coefficient of performance (which also depends on ambient temperature). For example, if ambient temperature if -10 °C, and the heating need of the building in this temperature is 3.5 kW, the heat pump should supply 0.5·3.5 kW = 1.75 kW, which is possible for a 9-series heat pump. The main heating system would then supply 3.5–1.75 kW = 1.75 kW.

Applying this model of air-to-air heat pump use to the single-family house with direct electric heating simulated with VTT Talo software, and using weather data from Jyväskylä in 1979, the result will be that the heat pump can provide 8200 kWh of heat per year and annual electricity consumption will decrease by 4900 kWh. In the Motiva study 8 of the 78 houses could reach this saving level or better.

2.4 Cost of residential demand response

The variable cost of DR in storage electric heating is normally zero because the storage can make load shifting transparent to the residents: there is no effect on indoor temperature. In partial storage electric heating and especially in direct electric heating indoor temperature can fluctuate during load control. If the temperature changes and also the rates of temperature change are kept low, the effect on thermal comfort is small. In many cases the effects go unnoticed.

One way to estimate a lower bound for the cost of inconvenience is to compare to the stable year-round savings resulting from lower indoor temperatures. Most electric heaters wish to keep the indoor temperature around +21 ºC at current electricity prices. Assuming that they would save 4 % by decreasing the indoor temperature by 1 ºC, the electricity bill of a typical single-family house would decrease by 86 €/a (18000 kWh/a consumption, 12 c€/kWh). How many hours per year the residents would have to suffer from the lower indoor temperature depends on how much time they spend at home annually. Assuming that they are at home 2500 hours per year (sleeping time not included), the hourly benefit from the 1 ºC temperature decrease would be 86 € / 2500 h = 3.4 c€/h, which is thus not enough to stimulate saving. A short temperature reduction is likely to be more inconvenient per hour than permanent reduction and hence price insensitivity is likely to be higher. This is reflected in Figure 8, which starts from price insensitivity of 1. Considering the effect of short-term load reductions on indoor temperature, a relationship between the curtailed energy and inconvenience cost can be built.

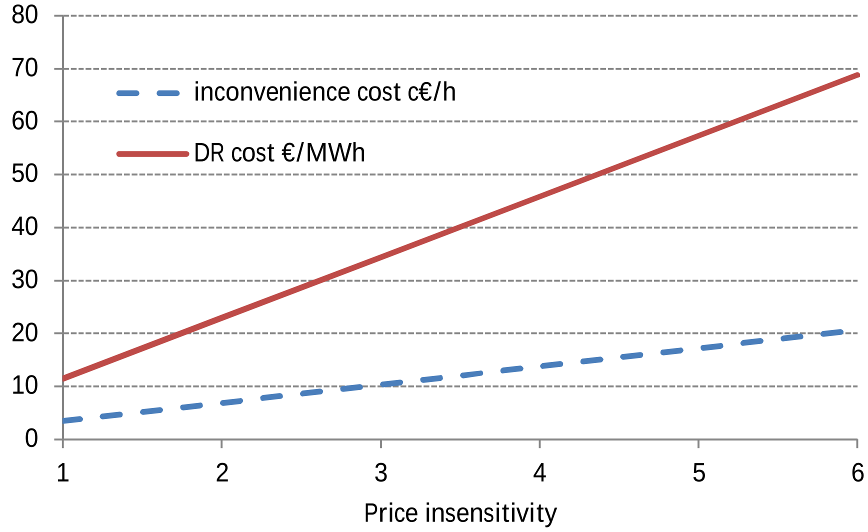

Figure 8: Estimated cost of DR of electric heaters when the load control action causes a temperature deviation of 1 ºC for 1 hour and the energy curtailed is 3 kWh. The abscissa shows the price insensitivity of electric heating load in relation to the required price increase that would be enough to compensate for the indoor temperature loss.as the relationship of electricity price which is enough to stimulate decreasing indoor temperature by 1 ºC and the current price.

3. Demand response potential in Finland

This chapter deals with the potential of DR in Finland. The most important source of DR is, if fully activated, electric heating in the residential sector. Second most important source, and currently the most important, is the energy intensive industry.

3.1 Residential demand response

According to evaluations made by a working group for the Finnish Ministry of Employment and Economy demand response potential from electricity heated houses to be about 300 MW (Työ ja elinkeinoministeriö, 2008). Bröckl et al. (2011) assumed a DR potential of 1–2 kW per home and calculated the total potential with 600,000 homes to be 600–1200 MW.

Below we account for the effect of air-to-air heat pumps. These are not usually controlled because they are normally installed afterwards by a third party, who is not communicating with the DSO or any DR aggregator. However, there is no reason the heat pumps could not be controlled if they are equipped, preferably by the manufacturer, by a suitable plug-and-play control electronics.

3.1.1 Typical winter day of -8.7 ºC ambient temperature

Directly electrically heated single-family houses draw about 2.6 kW for space heating. In case an air-to-air heat pump has been installed, it can easily heat half of the house (η=0.5). Thus the regular heating system needs to provide 1.3 kW. Homes with partial storage heating draw about 5.6 kW during the night and 1.1 kW during the day for space heating. With air-to-air heat pump installed the regular heating system should be properly adjusted to take maximum advantage of the heat pump. Heating in the rooms which the heat pump is able to heat should be turned down. If we assume that the daytime space heating power is reduced as dictated by η and the daily energy saving provided by the heat pump is the same as in the directly electrically heated house, we end up with daytime consumption of 0.5 kW and night-time consumption of 3 kW. With full-storage heating, if we assume that the daily energy saving provided by the heat pump is the same as in the directly electrically heated house, night-time consumption would become 5 kW (9.5 kW without heat pump). For dwellings in terraced houses we estimate 1.6 kW for electric space heating without heat pump and 0.6 kW with heat pump.

Table 3: The estimated average power drawn by space heating in different types of typical homes equipped with different types of electrical heating systems at ambient temperature -8.7 ºC.

home type	*heating type*	*night (22-07) kW*	*day (07-22) kW*
single-family	direct	2.6	2.6
	partial storage	5.3	1.1
	full storage	9.5	0
terraced	direct	1.6	1.6

Table 4: The estimated average power drawn by regular space heating in different types of typical homes equipped with different types of electrical heating systems and air-to-air heat pump of the "9-series" at ambient temperature -8.7 ºC.

home type	*heating type*	*night (22-07) kW*	*day (07-22) kW*
single-family	direct	1.3	1.3
	partial storage	3	0.5
	full storage	5	0
terraced	direct	0.6	0.6

We see that the partial storage heating system can store about 24 kWh of heat to be released during daytime. Full storage system can store in this ambient temperature 54 kWh of heat to be released during daytime. Most full storage systems can store at least 100 kWh of heat. Direct electric heating is possible to curtail for about 1 hour, so it can store 2.6 kWh. If sufficient time is available to raise the indoor temperature, the heat capacity can be 4–5 kWh.

Below in Table 5 shown is the power drawn by the different electric heating systems in absence of demand response on the national level. The assumption is 40 % penetration of air-to-air heat pumps in terraced houses and 60 % in single-family houses.

Table 5: The estimated average power drawn by regular space heating in different types of typical homes at the national level equipped with different types of electrical heating systems at ambient temperature -8.7 ºC. Air-to-air heat pump penetration was 60 % except for terraced houses 40 %.

home type	*heating type*	*night (22-07) MW*	*day (07-22) MW*

single-family	direct	283	283
	partial storage	1180	234
	full storage	198	0
terraced	direct	120	120
total		1781	636

3.1.2 Typical autumn day of 0 ºC ambient temperature

We perform the above analysis using the 23rd 2-week load profile prepared by the Finnish electricity association, corresponding to early to mid-November. The reference temperature for November in the load curves was -0.8 ºC and for October +3.8 ºC. The effect of sunshine in this case is minimal.

Directly electrically heated single-family houses draw about 1.5 kW for space heating. In case an air-to-air heat pump has been installed, it can easily heat half of the house (η=0.5). Thus the regular heating system needs to provide 0.7 kW. Homes with partial storage heating draw about 3.4 kW during the night and 0.6 kW during the day for space heating. If we assume that the daytime space heating power is reduced as dictated by η and the daily energy saving provided by the heat pump is the same as in the directly electrically heated house, we end up with daytime consumption of 0.3 kW and night-time consumption of 1.5 kW.

Table 6: The estimated average power drawn by space heating in different types of typical homes equipped with different types of electrical heating systems at ambient temperature 0 ºC.

home type	*heating type*	*night (22-07) kW*	*day (07-22) kW*
single-family	direct	1.5	1.5
	partial storage	3.4	0.6
	full storage	5	0
terraced	direct	0.9	0.9

In this case the partial storage heating system stores about 16 kWh for daytime consumption and full-storage system about 28 kWh.

Table 7: The estimated average power drawn by regular space heating in different types of typical homes equipped with different types of electrical heating systems and air-to-air heat pump of the "9-series" at ambient temperature 0 ºC.

home type	*heating type*	*night (22-07) kW*	*day (07-22) kW*
single-family	direct	0.7	0.7
	partial storage	1.5	0.3
	full storage	2.5	0
terraced	direct	0.3	0.3

Below shown is the power drawn by the different electric heating systems in absence of demand response on the national level. The assumption is 40 % penetration of air-to-air heat pumps in terraced houses and 60 % in single-family houses

Table 8: The estimated average power drawn by regular space heating in different types of typical homes at the national level equipped with different types of electrical heating systems at ambient temperature 0 ºC. Air-to-air heat pump penetration was 60 % except for terraced houses 40 %.

home type	*heating type*	*night (22-07) MW*	*day (07-22) MW*
single-family	direct	159	159
	partial storage	713	133
	full storage	105	0
terraced	direct	66	66
total		1043	357

3.2 Industrial demand response in Finland

Pihala (2005) has surveyed industrial demand response in Finland. We updated the results based on production volumes of mechanical pulp. It has decreased 22 % between 2004 and 2010. Thus the DR potential of mechanical and thermomechanical pulp production was decreased by 173 MW. The DR potential in industry for 1–3 hours curtailment with zero activation time would be 887 MW instead of 1060 MW.

3.3 Tertiary sector

Electric cooling and ventilation in office, shop and educational buildings provide an amount of DR. Cut-off time of ventilation should be quite short to keep indoor air quality at a good level.

There is some potential in freezer and refrigeration storages but no proper estimates have been made.

3.4 Primary sector DR

Assimilation lighting in greenhouses represent a maximum potential of about 100 MW, concentrated in winter and at night.

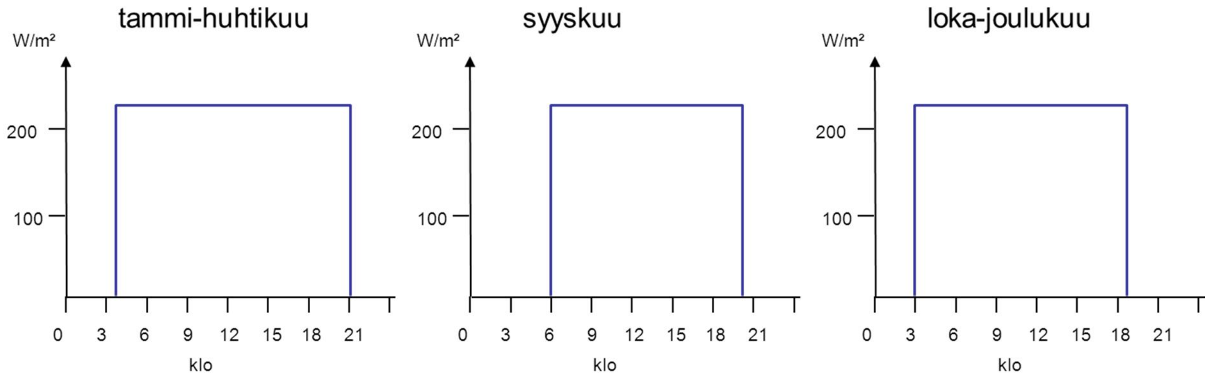

Figure 9: Example of electricity consumption of assimilation lighting in a Finnish tomato greenhouse. The first graph is for January–April, second for September and the third for October–December. There are 280,000 m^2 of tomato greenhouses with assimilation lighting in Finland. In summer the lights are kept off. Abscissa shows the time of day.

4. Demand response potential in Germany

4.1 Residential DR

In Germany, utilities began to distribute night storage heating facilities in the 1960's in order to influence the load pattern which peaked during the day. They are charged during night time (21:00 to 06:00) with low demand. The storage heating system is charged until the energy content is about the amount that is forecasted to be used during the next day. However, it is also possible to charge them during any time when it is economically beneficial from the energy market point of view. Thus they are an important source of DR.

The maximum DR potential (load decrease) available from the storage heating systems is about 14 GW (Stadler, 2008). The storage capacity of these systems is about 250 GWh when ambient temperature is below +8 ºC. In higher temperatures the capacity drops because it is not efficient to store excess heat in the systems.

Electric water heating is another flexible load, which can provide an average of 750 MW load reduction.

Household freezers represent an 1.4 GW DR potential (load decrease), available for 4 hours. Thus, their storage capacity is about 5.6 GWh. They can also provide a load increase of maximum 3.5 GW for 1.5 hours. Household refrigerators represent an 1.5 GW DR potential, available for 10 hours. They can also provide a load increase of maximum 4.2 GW for 3.5 hours. Thus, their storage capacity is about 15 GWh (Stadler, 2008).

Apart from using electricity-consuming devices with intrinsic storage capacity, further flexible demand can be obtained by influencing the user behaviour of residential customers. For example washing machines, clothes dryers and dishwashers often have some flexibility with regard to when they are run. These machines are normally used between 07:00 and 23:00, and the average power drawn is about 2.3–2.5 GW (Stadler, 2008). If one third of this load could be affected by dynamic prices or other incentives, it would provide 700–800 MW of flexible power. However, it is not clear how many hours users are willing to shift the operation time of these machines.

4.2 Industrial DR

2800 MW DR potential has been estimated in German industry (Klobasa, 2010). The opportunity cost of this DR is between 30 and 500 €/MWh depending on industry, electricity price and duration of activation.

4.3 Tertiary sector DR

DR from tertiary sector is mainly sourced from real estate management HVAC. Tertiary sector includes retailing, wholesale, public and private offices, schools, hospitals, etc. The cost of DR could be as high as 1500 €/MWh.

Ventilation uses a maximum of 6 GW during daytime 07:00-20:00. However, it can only be switched of for about 30 min (Stadler, 2008). If it is controlled in blocks, the DR potential for one hour could be 2–3 GW.

Refrigerators in food stores represent an 1.1 GW DR potential (load decrease), available for 1.5–2 hours. They can also provide a load increase of maximum 2.7 GW for 40 min. Thus, their storage capacity is about 2 GWh (Stadler, 2008).

Air conditioning represents a potential of more than 5 GW in warm weather (Klobasa, 2010).

5. Demand response potential in Austria

5.1 Residential DR

There are about 260,000 electrically heated dwellings in Austria. In 2009/2010 they consumed 48 kWh/m^2 of electricity for space heating. This low value must mean that most households have an auxiliary heating system such as fireplace. Electricity represented only 4.4 % of the fuels used for heating.

It is difficult to estimate the DR potential from electric heating without information about storage properties and auxiliary heating systems. The number of storage heating systems is proportionally lower than in Germany.

5.2 Industrial DR

DR potential in Austrian industry is about 660 MW (Table 9). However, the maximum duration of load reduction in different industries, maximum frequency of calls, etc. are not known.

Table 10 shows the estimated opportunity cost of DR for some specific large industrial companies in Austria. The values have been calculated by assuming shutting down a whole process. If intermediate storages can be used to avoid disturbing production, the costs can be considerably lower.

Table 9: Load reduction potential in specific industries in Austria (Gutschi & Stigler, 2008)

Industry	*DR opportunity cost €/MWh*
paper and printing	148
iron and steel industry	126
non-ferrous metals	26
chemical	64
quarrying and glas	104
engineering	40

mining	100

Table 10: Opportunity costs of load reduction in specific industries in Austria (Gutschi & Stigler, 2008).

Industry	*DR opportunity cost €/MWh*
paper industry (mechanical pulp)	190–200
paper industry (chemical pulp)	400–470
cement industry	500–580
steel industry (mild steel)	210
steel industry (stainless steel)	570
iron and steel casting	730
copper smelter	950
wood processing	1340
aluminium casting	1370
aluminium rolling mill	2330

6. Demand response potential in Sweden

6.1 Residential DR

In 2009 there were 1,859,000 single-family houses in Sweden, of which 27 % relied on electric heating (both direct and with water storage) and 22 % on combination of electric heating and biofuels. Furthermore 7 % relied on combination of ground-source heat pumps, electricity and biofuels. The consumption of electricity for space and water heating in single-family houses was 14.6 TWh and in other types of buildings 3.3 TWh.

A rough estimate brings the consumption of electrically heated homes in Sweden to 10 000 MW when the electricity demand is at its highest (Fritz, 2006). DR potential of 10–20 % of the maximum outtake is not unrealistic. Of course, this figure is for the coldest weather and for typical winter temperatures a lower value must be used. Figure 10 shows some measurements of reactions to outdoor temperature of different types of electric heaters in Sweden. The dependency of especially direct electric heating on outdoor temperature is extremely small in this study: only 2.3 %/ºC at 0 ºC. One reason for this was the errors brought by fluctuating outdoor temperature together with the heat capacity of the buildings. Power drawn by the water storage electric heating household drops by 31 % between the coldest temperature in the study (-18 ºC) and the average January temperature in Eskilstuna -4 ºC (representing climate zone 2 of Swedish department of housing; most inhabitation in Sweden is concentrated on zones 1 and 2). According to the VTT house direct electric heating model, the power drawn by the heating system alone drops by 45 % in the same temperature interval.

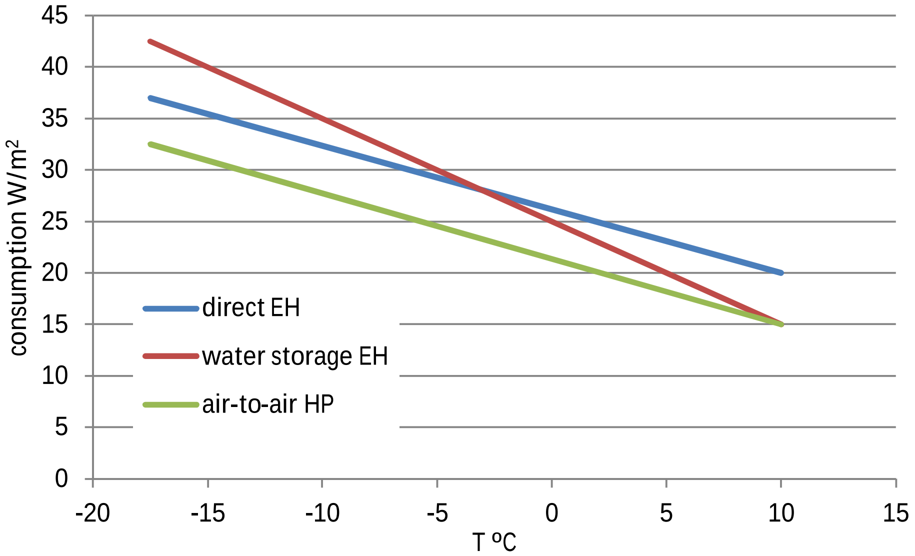

Figure 10: Temperature dependency of different types of electric heating in southern Sweden. The consumption measurement is the average at night from 01:00 to 05:00 (Lindskoug, 2006). The figure shows total consumption; the share of household electricity was estimated to be 2 W/m^2.

6.2 Industrial DR

Industribud found about 900 MW DR potential in Swedish energy intensive companies. The figure include the 350 MW demand adjustments that can already be activated at price peaks. Most of the measures could be in force for an hour, but 10–20 % could last from a couple of hours to a full day (Fritz, 2006). Full activation of this DR potential requires high prices up to 13 SEK/kWh (1500 €/MWh). At prices of 10 SEK/kWh (1200 €/MWh), the activated potential could be 700 MW.

The potential among mid-sized consumers has also been investigated. The companies interviewed represented a variety of business areas; iron, steel, forge, heat treatment, chemical, foundry and foods. Large real estate management companies were also interviewed (Cronholm, Forsberg, & Stenkvist, 2006). The total potential of load reductions within the studied categories of electricity customers is estimated between 300 and 340 MW, of which more than 200 MW is found within real estate management. The large potential of real estate management can be explained by ability to provide DR without large investments

7. Demand response potential in Norway

The theoretical potential of industrial DR is about 3500 MW in total; 3000 MW metallurgical and 500 MW wood and paper. Of this up to 1400–1500 MW has already been contracted in the regulating power option market, where the industry is paid for availability over limited periods. The option implies that the volume also shall be bid into the regulating power market. Balancing resources from demand are seldom activated due to high activation price.

In the residential sector the potential is estimated to be at the maximum 1750 MW.

8. Demand response potential in Denmark

8.1 Residential DR

There are 125,000 electrically heated homes in Denmark. The theoretical DR potential on a cold winter day could then be up to 400 MW for one hour duration, if DR were enabled in all of these homes. The assumption here is that no auxiliary heating systems such as air-to-air heat pumps have been installed. A more realistic estimate is 150–200 MW.

In the EFFLOCOM project a pilot study was carried out about residential DR (Kärkkäinen, Kofod, Ikäheimo, Grande, & Koreneff, 2004). Based on actual costs in the pilot and evaluation with the manufacturers of hardware and software as well the installers, the cost of equipment, software and installation was evaluated to be 800 € per house in case the installation includes 1000 houses. In the pilot load reductions in electric heating were stimulated with bonuses ranging from 1 to 3 DK/kWh (at the time 130–400 €/MWh).

8.2 Primary sector

Greenhouses represent an important source of DR in Denmark. The maximum potential is~~t~~ estimated to be 80 MW, which is available in winter nights from 21:00 to 08:00 (Marienlund, 2006). Less power is available on winter days and considerably less in summer. The maximum duration of interruption is 1–3 hours.

8.3 Industrial and tertiary sector DR

DR potential could be 385 MW plus electric heating of maximum 270 MW (Togeby, 2009). The opportunity cost of the commercial and industrial sources is not known.

9. Demand response potential in the Netherlands

There are four customer segments which can provide DR in NL: industry, the horticultural sector, commercial properties and residential customers. The most important industrial sectors in terms of DR potential and its opportunity cost are chemical and metal industry. Table 11 shows the potentials in the most important industrial sectors. Further characteristics such as maximum duration of the interruption~~,~~ and maximum frequency of calls are not known. 350 MW of the industrial DR is already traded on short-term basis and there are longer contracts for 425 MW of DR. This means that the majority of industrial DR is already activated, especially if the most expensive resources are subtracted.

Table 11: DR potential and cost in some industries in the Netherlands (Kamphuis, 2005).

Industry	*DR potential MW*	*DR opportunity cost €/MWh*
chemical	350	1100
metal	650	700
food	70	2600
rubber	30	1500

In the horticultural section the dominant use of electricity is assimilation lighting. This can provide 425 MW demand response after the power generated on-site has been subtracted. About 100 MW of this has already been activated (Kamphuis, 2005).

10. Summary

In this report a literature survey was performed about the demand response potential in the near future in northern Europe , Germany, Austria and the Netherlands. Residential, primary sector, industrial and tertiary sector DR were all taken into account when information was available. The importance of the different sector varies from country to another. For example in Germany the volume of industrial DR according to (Klobasa, 2010) is rather small compared to the other sectors. For most of the sectors and countries information about the temporal variation of the DR potential was not available. A notable exception is the DR potential of electric heating in Finland.

A more detailed calculation of the DR potential of electric heating in Finland was performed. The effect of air-to-air heat pumps on DR potential was estimated. Currently most of the electric heating power is drawn at night. Updating the control electronics would enable heating during any time of the day. In the current situation we estimate that the DR potential of electrically heated single family and terraced houses in typical winter day temperatures (-8.7 ºC) is about 600 MW if they are controlled in one group.

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