IEA
OECD

heat pump programme

Annex 23

Operating Agent:

Canada

Heat Pump Systems for Single-room Applications

Final Report from Annex 23 of the IEA Heat Pump Programme

Heat Pump Systems for Single-room Applications

Annex 23

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The IEA Heat Pump Centre (HPC)

The IEA Heat Pump Centre (HPC) is the focal point for the Implementing Agreement on Heat Pumping Technologies of the International Energy Agency (IEA), also called the IEA Heat Pump Programme.

The IEA was established in 1974 within the framework of the Organisation for Economic Cooperation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster cooperation among its participating countries to increase energy security through energy conservation, development of alternative energy sources, new energy technology, and research and development (R&D). This is achieved, in part, through a programme of energy technology and R&D collaboration projects, conducted within the framework of more than 40 Implementing Agreements.

The seven member countries of the HPC form a network for exchanging information on heat pump technology. By increasing awareness and understanding worldwide, the HPC aims to accelerate the implementation of heat pump technology as a means to reduce energy consumption and thereby to limit harmful environmental effects. The functions of the HPC include:

- collecting, analysing and disseminating heat pump related technical, market, regulatory, and environmental information;
- fostering international cooperation in research and development;
- facilitating contacts and information exchange among those involved in research, development, design, manufacture, regulation, marketing, and application of heat pumps.

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Foreword

Single room heat pumps are the world's best kept secret, given the current emphasis on global warming issues and the climate change initiatives of many countries. The heat pump industry now needs to publicise and actively promote their technology as a green and renewable option. A conservative estimate of the renewable energy captured by room heat pumps is 100,000 GWh/year[1]. Heat pumps have enormous potential to make even greater contributions to global sustainable energy.

A growing number of heat pump systems are found heating and cooling single rooms. The shape of things to come will be small, compact, distributed systems. Many smart systems capable of providing space heat/cooling at affordable prices are emerging. Annex 23 has documented the market for these products and has identified many promising products and systems that can deliver cost-effective heat pump solutions in the future.

Significant opportunities will emerge as both building refurbishment and new construction increasingly focus on smart systems that integrate heating, cooling and ventilation in a reliable and cost-effective manner. Heat pumps are an excellent example of this integrated function. However, the number of heat pump systems will only increase when building owners can see for themselves that these systems are truly better with respect to operating costs, environmental performance, comfort and maintenance. Annex 23 has identified many existing heat pump systems that have demonstrated these advantages.

Single room heat pump devices demonstrate the advantages of distributed systems, in any building, in an incremental fashion. Room-by-room or zone-by-zone distributed systems have proven energy savings of 50% or more. Installation standards and better training of the design community are required to realise the full market potential of these systems. Support from utilities and government agencies is also critical to help everyone concerned to climb the learning curve. It is not a question of *if* room heat pumps will dominate space conditioning – only *when*.

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1 Based on a global estimate of 40 million room heat pumps, with an average output of 4 kW, operating for 1,000 hours/year in heating mode, at an average COP of 2.6.

Executive summary

This project was set up to define the world market for single-room heat pumps that can heat (and possibly cool) rooms in buildings not equipped with a ducted central system. Particular emphasis was placed on heat pumps that perform efficiently in cold weather. Technologies and equipment used to space-condition single rooms are listed, as well as current research and promising alternatives. Recommendations are also made on technical and market-related issues to help market growth. Many novel heat-pumping solutions are available on the market. Several new concepts and niche products need some form of assistance to help test their effectiveness and raise awareness of consumers to their benefits.

In summary, distributed heating and cooling systems have a tremendous potential to save energy and improve comfort in residential and commercial buildings. More needs to be done to support the distributed heat pump concept.

Local fuel availability and fuel cost ratios dictate, to a great extent, the market for single-room heat pumps. Fuel costs are listed in each country by region.

Keywords: electric demand reduction, electric resistance baseboard heaters, energy reduction, residential and commercial single-room space heating, single-room heat pumps

Contents

List of tables

Glossary

ASHP	Air-source heat pump
BAHP	Burner-assisted heat pump
COP	Coefficient of performance
DFF	Dual fuel furnace
DHP	Ductless heat pump
GSHP	Ground-source heat pump
HCFC	Hydrochlorofluorocarbons
HDD	Heating degree-days
HSPF	Heating seasonal performance factor
ODP	Ozone depletion potential
PTAC	Packaged terminal air conditioner
PTHP	Packaged terminal heat pump
SEER	Seasonal energy efficiency ratio

1 Introduction

Most research and development to date regarding heat pump applications in cold climates has focused on forced-air central (ducted) heat pumps. However, the majority of electrically heated homes in the USA and Europe use electric resistance baseboard-type heaters or hydronic (hot water) radiators. To take advantage of conventional ducted heat pumps, homes must have air ducts installed, at considerable cost and disruption. Single-room heat pumps have increased in popularity in recent years and could easily be retrofitted to baseboard-heated or hydronic-heated homes. Commonly found features include quiet indoor fan-coil units, air filtering, thermostat setback, multi-speed fans, and wireless remote control. However, as with many central air-source heat pumps, existing heat pumps for single rooms have limited or severely restricted cold-weather performance. There are also concerns about heat pump reliability at subfreezing outdoor temperatures. Development of new varieties of single-room heat pumps for cold climates will provide the difficult-to-retrofit market with a viable, cost-effective space-heating alternative. Such products with heating and cooling facilities would also prove useful in commercial office buildings. For homeowners, single-room heat pumps can reduce heating costs by as much as 60% and offer an environmentally superior system compared to conventional forms of space heating. For utilities, heat pumps for single-room applications increase revenues and reduce the overall global warming effect attributed to electric generation and fossil-fuel heating systems. Utility-sponsored research suggests that energy savings as high as 30% could be achieved just by moving from a central system to a distributed system with room-by-room controls [7]. Research by the Pacific Northwest National Laboratories suggests the number is even higher for many regions of the USA [8]. This is before applying the COP of the heat pump. Despite the plentiful supply of single-room products and the favourable economics for many of these products, they are far from achieving their market potential.

2 Objectives

Annex 23 compiled market information on the number of homes using single-room heating devices, including hydronic radiators, direct electric resistance room heaters, electric storage heaters, and single-room heat pumps. This market information tabulates the heating equipment used both in existing homes and new buildings. Documentation on the environmental and market requirements in each participating country specify their thermal efficiency, cost, size, and noise performance. One major aim of the project was to share the common experiences of electrical utilities in serving customers with single-room heating systems.

The Annex has also documented ongoing research directed toward solutions and options for the room-size heat pump market identified by the study. One goal of Annex 23 was to identify systems that retain the heat pump benefits at cold temperatures and avoid the peak-load problem of electric heat. Country reports give the market size, available equipment and installation options. A workshop held in Niagara Falls, Canada presented the results (see section 8.1).

Recommendations will be made with respect to extending Annex 23 to support testing the products identified in Phase I. Specifically, the objectives of the information-gathering activities are summarised below:

1. Determine the base number of houses that have hydronic or electric resistance baseboard heating systems. Tabulate these data based on heating-season severity. Also tabulate the number of single-room heating systems currently being installed in new buildings.

2. Catalogue details of any currently marketed heat pumps suitable for both single-room applications and cold- and warm-climate applications in existing hydronic or electric resistance baseboard-heated houses.

3. Catalogue details of any heat pumps being developed for both single-room applications and cold- and warm-climate applications as an alternative to hydronic or electric resistance baseboard heating systems.

4. Create an awareness of the advantages of heat pumps for single rooms by documenting the successes of member nations in the use of heat pumps for single-room applications as alternatives to conventional hydronic and electric baseboard heating systems.

5. Gather information on current or planned utility or government incentive programmes (such as demand-side management initiatives), and document ongoing research directed toward heat pump solutions for single-room applications.

3 The market

3.1 Market size

Roughly 55 million heat pumps are currently in operation worldwide, of which 39.3 million are installed in Japan and 10 million are in the USA [1]. These heat pump installations have an estimated total heating capacity of around 360,000 MW and supply 450 TWh of heat annually. Heat pumps currently deliver about 2% of the total heat demand in the five countries reviewed. In Japan and the USA virtually all heat pumps in the residential sector are small electrically driven units, known as reversible heat pumps. In commercial buildings multisplit systems (also reversible) are most common. However, in most of the European countries, with the exception of southern regions, residential heat pumps are generally used for heating-only purposes and for heat recovery [1].

The cost-effectiveness of heat pumps, and thus their penetration into different market sectors, is determined by many factors. Although climate is a major factor for the applicability of space-conditioning heat pumps, the heat pump market is influenced mainly by the initial cost of equipment, the price and availability of fuels and electricity, the performance of the equipment, and national or utility energy environmental policies [1].
Table 1 shows a breakdown of the number of heat pumps in service and number of annual sales. (This data has been obtained from the country reports.)

Table 1: Heat pump installations and sales in five countries.

	Canada	France	Sweden	Switzerland	USA
Number of heat pumps	429,600	120,000	1,000,000	35,000	10,000,000
Yearly sales	<5,000		10,000	4,000	1,000,000

3.2 Market difficulties

In the USA the current low cost of heating residential homes with conventional natural gas, oil, or electrical systems makes most heat pump systems difficult to justify. With the present low energy costs, and the cost of heat pumps up to five times that of conventional heating and air conditioning, end-users do not see the economic savings of purchasing heat pumps. Sweden does have higher electricity, oil, and gas prices than North America, which makes heat pumps economically attractive as an alternative to central hydronic heating systems (Annex 23 report, Sweden).

In Switzerland an economic analysis of the trend between 1974 and 1988 carried out by the Federal Institute of Technology in Zürich indicated the following:

"... there is a significant correlation between the price of oil and the distribution of electric resistance heaters. By contrast, the price of electricity, ascertained from a survey of all electrical utilities, has no influence and was more or less constant during the period. Although for an individual electricity company the price of electricity is the most important influencing factor, for individual consumers, it is not so much the price of electricity that is decisive as the difference between that and the price of oil" (Annex 23 report, Switzerland).

Table 2 shows the cost per kilowatt hour of various energy sources. (The data is taken from the Annex 23 reports from each country, except for Sweden's natural gas price per kilowatt hour ratio [2].)

Table 2: Cost per kilowatt hour of various energy sources (USD/kWh)[1].

	Canada	France	Sweden	Switzerland	USA
Electricity	0.056	0.128	0.121	0.153	0.084
Natural gas	0.013	0.037	0.021	0.04	0.021
Oil	0.022	0.037	0.103	0.027	0.023
Cost ratio: electricity to					
Natural gas[2]	3.4	2.8	4.6	3.1	3.2
Oil[3]	1.9	2.6	0.88	4.3	2.7

1 USD (US dollar) conversions used: CAD 1 (Canada) = USD 0.65, SEK 1 (Sweden) = USD 0.1255, FRF 1 (France) = USD 0.1614, CHF 1 (Switzerland) = USD 0.6609.

2 assume 80% conversion efficiency.

3 assume 75% conversion efficiency.

Another obstacle that is hindering heat pump sales is the lack of customer awareness, both of the product and its advantages. In France people continue to believe that heat pumps are noisy, need lots of maintenance, and are expensive to purchase or service. Furthermore they do not believe heat pumps can last more than 10 years. To increase sales in France, manufacturers have replaced the name heat pump with reversible air conditioner. Only 14% of the French population realise that heat pumps can both air condition in summer and heat during the winter (Annex 23 report, France).

Poor heat pump efficiency at low temperatures is another factor that limits the sale of heat pumps. This is prevalent in cold climates such as Canada, where the energy savings are lower. The minisplit system was originally designed for the moderate climate of Japan, with the primary emphasis being on quiet operation and cooling efficiency (Annex 23 report, USA).

3.3 Potential markets

Hotels, motels, and apartment suites represent one potential market for single-room heat pumps (Table 3). In Canada and the USA many motels and hotels have wall units that heat and cool. The heating is sometimes achieved using direct electrical resistance heaters. This is a broad-based market, offering many attractive heat recovery and water heating opportunities. The ideal single-room heat pump clients may be hotel and motel chains, if the right product exists (Annex 23 report, Canada). One manufacturer notes that ductless systems are preferred to traditional rooftop systems in new commercial construction "... because they are less expensive, more efficient for the application, and pose no problems of roof leakage ..." (Annex 23 report, USA).

Table 3: Number of hotels and motels.

	Canada	France	Sweden	Switzerland	USA
Hotels	9,234[1]	n/a	n/a	n/a	15,300[3]
Motels	5,519[2]	n/a	n/a	n/a	30,300[4]

1 More than 50 rooms;
2 less than 50 rooms;
3 more than 75 rooms;
4 less than 75 rooms.

The other potential market is in retrofitting electrical resistance heaters (Table 4). Resistance heating makes up 63% of Canada's electrical heating (Annex 23 report, Canada). In the USA there are 21million homes that use built-in or portable resistance heaters for all or part of the heating needs (Annex 23 report, USA).

Table 4: Number of homes with electric resistance baseboard heating.

	Canada	France	Sweden	Switzerland	USA
Homes with electric heat	2,234,079	n/a	1,320,000	229,400	21,000,000

Another way to promote the heat pump market is to introduce government policies. For example, in Switzerland, an Energy 2000 Action Programme is in place, with the following objectives:

- to stabilise the overall consumption of fossil fuels, and therefore CO_2 emissions, at the 1990 level in the year 2000, and to reduce these thereafter;
- to slow down the increase in electricity consumption and stabilise it from the year 2000 onwards;
- to promote renewable energy sources so that they can contribute an additional 0.5% to electricity production and 3% to heat generation in the year 2000;
- to increase the capacities of hydro power plants (+5%) and existing nuclear power plants (+10%).

This programme has encouraged people to invest money and resources into the development and marketing of heat pumps to meet the goals of the Energy 2000 Action Programme. In the retrofitting sector sales rose by 68% within a year (1994) in Switzerland. This was linked to the fact that the utilisation of environmental heat via heat pumps is regarded as a renewable energy source in the government's Energy 2000 Action Programme (Annex 23 report, Switzerland).

Air conditioning is found in only 1.2% of housing in France. An IPSOS (French Institute for Statistics) survey of over 1,000 people found that 5% of the population plan to purchase air conditioners in the next three years. This represents 1.25 million houses and apartments that will require air-conditioning units.

3.4 Climate

Table 5 presents the climate regions for the countries researched. Additional details for each country are available from the individual country reports. Climate conditions vary widely across the five countries. The details found in the Canadian report are repeated below. The heat pump market in all five countries is predominantly located in regions with moderate climates having cool winters and warm summers. The challenge is to expand the market into regions with colder winters and hotter summers.

Table 5: Climate regions.

	Canada	France	Sweden	Switzerland	USA
Polar climate	Along the coast of the Northwest Territories and in the Arctic Archipelago	None	Covering the northern parts of the country	None	Northern parts of Alaska
Subarctic climate	Covering the latitude from the Yukon to Labrador and descending near the inhabited region of Canada	None	Covering the central regions of Sweden	None	Most of Alaska
Mountain climate	Including the Canadian Rockies in British Columbia and the Yukon	Limited	None	Some Alpine Regions	Western mountain ranges e.g. Rockies
Continental climate	Representing the majority of the inhabited regions of Canada, from the Prairies to the East Coast	None	None	None	Most of the mid-west states
Moderate Maritime climate	Covering British Columbia on the Pacific coast, and New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland on the Atlantic coast	Three regions in France fall into this category	Covering the southern regions of Sweden	Most of Switzerland has a moderate climate with cool winters and warm summers	East and west coast areas

The practical implications of Canada's diverse climate is weakened by the demographic distribution of the population. The vast majority of the population live in the moderate maritime and continental climate zones. However, the variations in the continental climate zone are significant with respect to the heat pump market. For instance, the Prairie region has a much drier climate than the St. Lawrence region, but has colder winters. The St. Lawrence region experiences cold winters with heavy snow falls and humid summers. The Ontario peninsula has a more moderate winter climate but has hot and humid summer conditions. The average temperature varies extensively in each of Canada's climate zones.

In general, conventional air-source heat pump products in today's market perform best in the moderate maritime climate. If a single-room heat pump replaced an electric baseboard heater in a moderate climatic zone, one could expect energy savings of 40-50%. For the colder parts of Canada, identified as the continental climate, the energy savings are less for air-source equipment, e.g. 30-40%. For ground-source heat pump equipment with some form of earth coupling, either a buried ground loop or well water, the expected energy savings are higher, typically 50-60%. Few ground-source products are on the market for single-room heating and cooling. Sweden has several heating-only ground-source products built for the single-room or single-zone application. The majority of commercially available heat pump products are best suited to the warmer climate, predominately for cooling requirements.

4 Regional and economic considerations

The expected simple payback period for a given alternative is variable and differs from country to country, from region to region, and from home to home. Both regional climate and fuel costs affect payback periods, as do installed costs. Installed costs and installation quality vary significantly from one installer to another, as well as regionally, depending upon the availability and popularity of the heating option. Dealers will often add a novelty mark up to the installation to cover their unfamiliarity with the product (Annex 23 report, USA).

4.1 Cost factors

The main barrier to selling heat pumps for heating-only purposes is undoubtedly the additional cost of the equipment. A heat pump can cost two to five times as much as a gas- or oil-fired heater of the same capacity, depending on the country. The price differential for electric resistance heating is even greater.

Unfortunately, despite the heat pump's high efficiency, the reduction in energy costs can be moderate. In terms of energy value, the electricity consumed by a heat pump is typically about one quarter of the energy consumed by fossil-fuel equipment. The price ratio of electricity to fuel must therefore be less than four for financial savings to be made. At today's low oil and gas prices, daytime electricity-to-fuel ratios are 1:4 in most countries. Higher prices for fossil fuels would help the heat pump market as they reduce the electricity-to-fuel price ratio, even when fossil fuels are used for power generation. On the other hand, low electricity prices make resistance heating more attractive.

In 1990, the Decree on Energy Use was issued in Switzerland, which called for the efficient use of energy and the promotion of renewable energies. Among other things, a licence system was introduced for fixed resistance heaters. Heaters of this type may now only be approved under certain rather restrictive conditions. This is not a prohibition as such, but together with higher tariffs it has led to a considerable drop in sales of electric resistance heaters. Most electric resistance heaters that have reached the end of their service life are therefore replaced by other heating systems. The subsequent installation of hydronic distribution systems would severely reduce the economic efficiency of oil, gas, or central heat pump systems. This represents a major opportunity for single-room heat pumps to gain ground.

Sweden has also introduced a tax system on energy consumption which has led to an increase in heat pump sales, from 9,000 units in 1995 to 14,200 units in 1996.

4.2 Building factors

Heat distribution systems are another factor influencing heat pump markets. The traditional high-temperature hydronic heating systems, such as those prevalent in central and northern Europe, are not well suited to heat pumps. Even in new buildings traditions die hard, and considerable effort is needed to encourage building designers to install the low-temperature systems more compatible with heat pumps, such as underfloor or forced-air heating systems. For existing buildings, the best opportunity to expand the heat pump market is with systems that require a minimum of installation work. This factor has led to increased interest in the development of single-room space-conditioning applications. These systems do not require extensive renovations to install ductwork.

4.3 Emissions

Heat pump systems are recognised as key technologies for reducing SO_2, NO_x, and CO_2. The first two gases are harmful pollutants. Vast quantities of CO_2 produced by human activities are believed to cause global warming. Heat pumps reduce these gases by their ability to use natural, renewable, or otherwise wasted thermal energy resources; thus, they can reduce the demand for fossil fuels. Their impact on the energy demand for commercial, residential space conditioning (heating, cooling, and dehumidification), water heating, and industrial processes (including drying, heating, and waste heat recovery) can be profound. However, emission targets have not as yet had a positive influence on heat pump sales in Canada or the USA. These countries could follow the examples of Switzerland and Sweden, where stronger awareness programmes or environmental issues have had an excellent effect on the market for heat pumps.

A conservative estimate of the renewable energy captured by room heat pumps is 100,000 GWh/year[1]. The Heat Pump Centre estimated (1997) that 65 million residential heat pumps save 64 million tonnes of CO_2 per year. The estimated 40 million room heat pumps contribute a significant share. The market potential for energy savings and emissions reductions is at least a factor ten larger.

1 Based on a global estimate of 40 million room heat pumps, with an average output of 4 kW, operating for 1,000 hours/year in heating mode, at an average COP of 2.6.

5 Technologies

The use of wall-mounted fan-coil units commonly associated with ductless heat pumps (DHPs) may present some opportunities for use with low-temperature heat sources, such as hydronic heat pumps and domestic water heaters. For example, a single hydronic heat pump could be coupled to several of these fan coils via a piping loop. This system could provide most of a home's heating and cooling with backup heating provided by existing baseboard heaters or an electric or fuel-fired boiler included with the heat pump. The indoor fan-coil units would provide the same advantages as DHPs (e.g. quietness, controllability, ease of installation). This system would require only one single-speed heat pump unit, unlike multisplit DHPs which require either a variable-speed compressor or a compressor for each indoor unit. A minisplit hydronic heat pump using fan coils might have an installed cost for a mature product of around USD 5,000 and require no separate boiler for backup heating.

Similar to ducted fuel-fired options, the economic feasibility of the non-ducted fuel-burning boilers hinges on the local electricity-to-fuel price ratio, the size of the annual heating load, and the cost of installing the piping and convectors. However, customers would require separate equipment for air filtering, humidification, and cooling. The economics for fossil-fired hydronic systems appear best for customers with large heat loads, in countries where fuel price ratios are high.

Efforts to study existing product lines have uncovered many single-room cooling products. Many more single-room cooling products are available than heating/cooling products. Some of these cooling products use water as the heat sink. If these single-room products were reversible, customers might select the heat pump option. For the water supply to both heat and cool, the water temperature needs to remain above 5°C. For cooler water temperatures (<5°C), special design features are needed to protect against freezing.

The study of relevant technologies also identified a company marketing a quick-connect coupling to couple and decouple a split air conditioner. Such a product could promote the development of heat pumps designed for the do-it-yourself market. This may be a strategy to help reduce the installed costs associated with single-room heat pump equipment.

6 Research and development

6.1 Current R&D

Two Swedish companies recently won competitions in Sweden against competitors from Denmark, Finland, Norway, and Sweden. The heat pumps that won the competition consisted of heating-only ground-coupled equipment for residential applications.

The 3.9 kW heating capacity heat pump unit, designed by IVT Energy AB (Tranås, Sweden), is intended for homes with oil or electric backup heating. The other winning design, by Eufor AB (Härnösand, Sweden), was a single-room unit for use in homes without a heat distribution system, such as those using baseboard resistance heating. Suitable for wall mounting, the unit is designed for use with direct-evaporation ground coupling.

In Canada, Ontario Hydro researched single-room heat pumps. The direct expansion, heating-only heat pump has the compressor unit located outside and uses a hydronic fan coil for heat distribution. In Japan, variable-speed compressor technology is used to boost the thermal capacity of heat pumps operating in cold climates. This technique tends to increase the heat pump's overall energy contribution, thus increasing the energy savings.

A heating and cooling ground-source heat pump is currently being designed by the R&D Department of the Hokkaido Electric Power Company, in Japan. The heating capacity of 6.4 kW and cooling capacity of 5.2 kW is an average size single-room space-conditioning system.

In Switzerland, a single-room heating-only air-source heat pump with no condenser fan has been developed to reduce indoor noise.

6.2 Future R&D

Until recently, there was no single product in Switzerland that was able to meet the specifications for a replacement system for electric resistance heaters. For this reason the Federal Office of Energy decided to implement the development of a single-room heat pump and promote it up to its introduction onto the market. Requirements were laid down for the list of specifications that form the basis for developing a single-room heat pump in Switzerland. Meeting these requirements, there are three models of single-room heat pump with heating capacities of 600, 900, and 1,200 W, which are about to go into production. These have been undergoing tests to ensure that no shortcomings can prematurely damage their reputation. The tests were carried out at a facility specially designed for testing single-room heat pumps, and results will be published with the Annex 23 workshop proceedings.

The single most pressing research issue, driven by the agreement to phase out chlorofluorocarbons (CFCs) soon and hydrochlorofluorocarbons (HCFCs) in due course, is the research into alternative working fluids. Equipment manufacturers from the USA, Europe, and Japan have joined forces in the Alternative Refrigerant Evaluation Programme (AREP). The main aim of this programme is to find a good alternative for the popular HCFC-22. One potential refrigerant fluid alternative currently being tested is Alkitrate [3].

The governments of various countries are implementing programmes to increase the future market for the research and development and sale of heat pumps (Table 6).

Table 6: National environmental and energy programmes relevant to heat pumps [4].

Country	Programme	Goals
Canada	The National Action Strategy on Global Warming – "Canada's Green Plan"	To stabilise net emission of greenhouse gases not controlled by the Montreal Protocol at 1990 levels by the year 2000. Current measures include: • developing regulations for energy-using equipment (The Energy Efficiency Act); • developing a new energy code for buildings; • improving the R-2000 programme; • starting the Advanced House Programme.

	Demand-side management (DSM) heat pump programmes	To use grants in promoting ground-source heat pumps. To apply incentives for heat pumps in new/existing electrically heated houses (when natural gas is not available). The incentives vary according to the heat pump's efficiency. (This programme has been discontinued.) To apply dual-energy rate (above and below 12°C) and financial incentives for installating dual-energy systems, including bivalent heat pumps. This rate option is still available in the Province of Quebec.
France	None	
Sweden	Three-year energy programmes	Pre 1975: shift toward nuclear energy. 1975–1978: energy systems still oil dominated. R&D support for energy conservation projects. 1978–1981: development of new technology to replace oil; decision to phase out nuclear energy. 1981–1984: focus on rapid oil replacement, rapid build-up of new energy systems; investment support for a variety of existing but sparsely used technologies, including heat pumps. 1984–1987: focus shifts to long-term research; investment programmes abandoned after price drop. 1987–1990: programme oriented towards basic research at universities; focus on phasing out nuclear energy. 1990–1993: research at universities remains supported; development and demonstration projects are the responsibility of utilities and industry.
	Heat pump support programmes 1975–1985	To support development of heat pump technologies. To support experimental heat pump plants and demonstration projects. To provide investment subsidy at 10–15% of the installation cost (notably in 1984).
Switzerland	Energy 2000 Action Programme	To stabilise total fossil fuel energy consumption and CO_2 emissions at 1990 levels by the year 2000, and reduce thereafter. To stabilise electricity consumption by the year 2000. To increase use of renewable energy resources significantly, including heat pumps, by the year 2000.

	Energy 2000 Heat Pump Promotion Programme	To install 100,000 heat pumps with an average thermal output of 25 kW by the year 2000. To improve SPFs by 50% by the year 2000. To reduce investment costs subsequent to standardisation and industrial production of heat pumps. To create favourable supply conditions for heat pumps. To ensure high-quality products and systems. To finance smaller electric heat heating-only heat pumps for retrofitting installations. To finance pilot and demonstration heat pump manufacturing plants.
USA	Global Climate Change Title of the Energy Policy Act (EPAct)	To reduce emissions of greenhouse gases by evaluating the environmental costs and benefits of federal efficiency standards for greenhouse gas sources, including heat pumps.
	Utility Rebate Programme	Energy conservation: 92 current utility heat pump incentive programmes are promoting the use of energy-efficient heat pumps in residential, commercial, and industrial sectors. The rebate given (USD/kW installed capacity) is directly related to the seasonal energy efficiency ratio (SEER) of the heat pump.
	R&D programmes	To accomplish research and development of residential, commercial, and industrial heat pumps, including gas-engine driven, absorption, and high-efficiency electric vapour compression models.

7 Conclusions

Heat pumps for single-room applications could provide an energy-saving and cost-saving alternative to built-in or portable electric resistance heating in the residential market and for commercial buildings (e.g. offices, hotels/motels). They could be an effective retrofit solution for homes or offices where no ductwork for air distribution exists. Consumers' space-heating costs could be reduced by at least 50% compared to existing single-room electric heating equipment.

Even with these potential savings, in many countries the fuel mix for power generation is likely to shift towards more gas, and less coal and oil. The energy efficiency of new power stations is also improving continuously, and older stations are being retrofitted to run at higher efficiencies. Power production in small-scale combined heat and power plants (CHP, cogeneration) is expected to penetrate further. Renewable energy sources will be increasingly applied to generate power.

As a consequence of all these developments, the CO_2 emissions associated with electricity generation will fall, and this will improve the opportunities for the electric heat pump, as a greenhouse effect mitigating technology [5]. Growing concerns about the levels of CO_2 emissions, new developments in heat pumps, and government programmes will increase the number of heat pump sales in the years to come.

8 Recommendations

General recommendations are offered for increasing the market penetration of single-room ductless heat pumps.

- Implement more research and development activities to improve the cold-weather heating capacity and efficiency, and to reduce unit costs.
- Increase marketing, advertising, and education activities to raise dealer, contractor, and consumer awareness levels about ductless products and their advantages.
- Increase prices for fossil fuels with a fossil-fuel tax, to reduce the electricity-to-fuel price ratio, making heat pumps more attractive, while adding the same tax(tariffs) on electric resistance heaters to encourage the more efficient heat pump option.
- To achieve a significant penetration of space-heating heat pumps, establish a policy to address impediments. This effort stands the best chance of being successful if governments and utilities join forces and cooperate closely with market parties (including manufacturers, installers, consultants, and consumers) [6].
- Establish goals and targets for heat pumps, especially in government-controlled facilities and electric utilities.

8.1 Results of the Annex 23 workshop in Niagara Falls, Canada

Approximately 80 participants from 10 countries assembled at a two-day workshop to discuss heat pump issues for single-room applications. The programme included 22 speakers, 10 poster papers, 10 exhibitors, plus a panel session which involved several of the attendees. The clear message was that distributed heating and cooling systems have a tremendous potential in residential and commercial buildings to save energy and improve comfort. Despite the plentiful supply of single-room products and the favourable economics for many of these products they are far from achieving their market potential. The workshop highlighted many of these issues. Some of the most important were captured in the form of questions. A summary of these questions and responses, which hopefully mirror the consensus of the attendees, are given below.

The main conference organiser was disappointed by the attendance. Given the energy-saving potential of distributed heat pumps, the representation and participation from various levels of government was less than it might have been. Although disappointing, the poor attendance was not a surprise. The heat pump community still has a lot of work to do (at least in Canada) to raise the level of awareness concerning the environmental benefits of heat pumping technology. In Canada this needs to be a long-term goal if improvement in heat pump sales is to be expected.

Are heat pumps a renewable energy technology?

Switzerland is the only country that has clearly identified heat pumps systems as a renewable technology. Even there, according to Mr Fabrice Rognon, of the Swiss Federal Office of Energy, the debate continues on including or excluding heat pumps from renewable programmes. In Canada many renewable programmes exclude heat pumps. The consensus at the workshop was that heat pumps are a form of renewable energy and should be given the same status as other renewable technologies. This takes on particular significance as many electric utilities begin to market "green" power (renewable energy) as an option for consumers. The energy saved by using heat pumps, in some cases, offsets the need to use electricity. Under these conditions the energy saved is equivalent to "green" power generation.

Should we raise the awareness of the greenhouse gas emission reduction credits that are associated with different types of heat pumps?

Again the workshop noted that the heat pump community is doing a poor job of marketing the environmental benefits of heat pumping technologies. In fact an astonishing number of government officials view heat pumps as an environmental liability, either because of a previous experience where heat pumps failed to meet their expectations or because of limited knowledge on the refrigerant issue. This again is an indication that the heat pump community must be more active in educating the public and promoting the environmental benefits of heat pumps.

The next three questions all deal with the refrigerant issue.

Is the accelerated phase-out of R-22 hurting the novel and new heat pump applications?
Should we maintain R-22 to help benchmark heat pump products?
What is more important, the global warming issue or ozone depletion?

All the Canadian manufacturers perceive that switching to alternate refrigerants would not benefit heat pumps at this time. The early phase-out of HCFC-22 (R-22) in some countries has created new problems in the field for some manufacturers introducing new products. These would not have occurred had R-22 been used. Clearly this is an issue that needs to be discussed further. In the 25 May 1998 special edition of *JARN* an article entitled, "Trends of Room/Packaged Air-Conditioners" identified 34 million air conditioners shipped in 1997, of which 24 million were room air conditioners. This number is orders of magnitude larger than the number of heat pumps shipped. Practically all these units use R-22 as the refrigerant. For the 1998 season, all of the nine major Japanese manufactures will release new products that use HFC as the refrigerant. Can air-conditioning manufacturers be allowed to develop these new refrigerants and can heat pumps be exempted from any early phase-out prior to 2020, as authorised at the Copenhagen meeting in 1992 on the Montreal Protocol? The Annex 23 workshop had many novel heat pump products on display, all using R-22. Some used refrigerant piping to distribute heat into several rooms. All these innovative products would require some re-engineering to operate with HFCs. Given the size of the market, can we afford to impose this restriction on these products? The consensus answer was no. The heat pump community needs to reaffirm the importance of R-22 in the introduction of new heat pump products. The reliability issues and high costs associated with the switch to alternate refrigerants would be detrimental to the development of heat pump technology.

Are current performance standards inhibiting product development?

Some of the exhibitors of room heat pump products suggested that existing performance standards do not accurately reflect actual field performance. Often, in central heating systems, poor duct design leads to significantly lower performance compared to rated specifications. Again the consensus was that a system of distributed heat pumps that provide single-room or single-zone coverage offers significant performance benefits that are not characterised in existing standards. The panel discussion raised the issue of third-party field testing as a way of helping to identify the actual savings in real rather than simulated conditions. This whole topic may need its own Annex to deal with the issue properly.

How do we reduce the price or increase the value to achieve shorter payback periods for heat pumps?

In some commercial applications, such as schools, motels, hotels and office buildings, water-loop heat pumps can have lower operating costs, lower maintenance costs, and lower initial costs than central heating/cooling systems. Optimum performance will be achieved when experienced professionals are involved with the installation.

For the residential market heat pumps face stiff competition from other heating systems. Simple payback periods are generally 5-15 years (on average, under 10 years). Nevertheless, heat pumps offer many unique advantages over the competition. With some support from key stakeholders (governments and utilities) new applications and new products will improve the economics for many residential customers. During the workshop, scenarios were discussed that would place limits on the use of electric resistance heating and air conditioning if the heat pump option was not specified.

What should we do about poor duct standards?

Representatives from the USA stressed the importance of reducing duct losses. A better understanding of the difference between ducted and non-ducted systems is necessary. For non-ducted systems the introduction of ventilation air is an important consideration. Efficient methods to introduce ventilation air need to be considered when deploying distributed heating/cooling systems. Since Annex 23 also covers single-zone heat pump applications, it is important to consider good ductwork when heating and cooling several rooms from one unit.

Are heat pump water heaters an application of a single-room heat pump?

The attendees had mixed opinions on this question. Some agreed that if a heat pump water heater conditioned a space such as a commercial kitchen and at the same time heated water, then it should be included in Annex 23 as single-room heat pump application. Others believed that it did not fit the criteria. Heat pump water heaters can save a significant amount of energy in applications where cooling and water heating are coincident. As such, their role needs to be made more widely known.

Are we interested in energy efficiency? Are we energy hogs?

With oil prices as low as USD 12/barrel and oil reserves at comfortable levels, it seems that energy efficiency is not as strong a driving force as it once was. However, concern for the environment and global warming is a growing issue with many governments. Consumers have shown a willingness to pay more for "green" products. It may be necessary for more emphasis to be put on the environmental benefits of heat pumps (CO_2 reduction) and less on their energy-saving potential.

Do we have trained designers, installers, and engineers to implement heat-pumping solutions for single-room applications?

Several papers and posters were presented that highlighted excellent case studies on distributed heat pump systems. Despite these good examples, many expressed concern that a lack of good information is inhibiting the greater use of heat pumps in commercial applications. It was suggested that more training and more workshops to raise awareness within the design community are needed.

Should we continue Annex 23 and test products identified in Phase 1?

Many favourable comments suggest that Annex 23 should continue or merge with the new Annex proposed by France. A submission will be made to the IEA to continue Annex 23 and test some of the novel products identified in Phase 1.

Appendix A

Air-source room heat pumps

First developed for the Japanese market, ductless heat pumps (DHPs) have increased in popularity in recent years. Sweden (with a climate similar to Canada's) has developed a market of around 1,000,000, increasing at approximately 10,000 units per year. Most of the North American manufacturers now distribute a line of DHPs.

Characterised by quiet (46–55 dB) room-size indoor fan-coil units with many control features, these systems are often installed for zone air conditioning instead of window air conditioners. Indoor units are sized from 2.6 to 5.2 kW (0.75 to 1.5 tons) in increments of 0.9 kW (0.25 ton). The most common wall-mounted indoor units can be installed easily on an outside wall, with wiring, piping, and condensate lines passing through a 7 cm hole to the outside. Indoor units are also available in console-, vertical-, and ceiling-mounted versions. A single outdoor cabinet can handle one to five indoor units with either multiple compressors or a single variable-speed compressor.

Since most installations provide space conditioning to only the main living areas of a home, recent work in Sweden has focused on the interzonal heating effects of DHPs. Researchers found that an adequately sized indoor unit could provide almost all the heat to an adjoining zone with a temperature of 2°C below the DHP zone setpoint. Heat flow through a doorway was found to vary according to the square root of the temperature difference. Another study investigated the interzonal heat flow through a variety of apertures and found the heat flow to vary at the 1.5 power of the temperature difference ($\Delta T^{1.5}$).

There are a limited number of window heat pumps available. These systems are based on standard window air conditioners with a reversing valve and controls to accommodate heating and defrosting.

Ductless heat pumps offer an electric space-heating option with a great deal of flexibility and a lack of disruption to the indoors. Advantages and disadvantages from a utility standpoint are similar to those for ducted air-source heat pumps (ASHPs). Energy and demand savings are comparable to those with central ASHPs for those zones of a house that could be directly affected by DHPs. Advantages to the customer include zoning, cooling, air filtering, sophisticated setback and fan-speed controls, as well as other desirable amenities infrequently found on even sophisticated central systems (electrostatic filters, wireless remote control). Ductless heat pumps would be most competitive for customers who desire cooling, and where ducting would be difficult to install. They are most effective in homes with large open areas where the heat pump can maximise its contribution and minimise the use of electric baseboard heaters. Window versions offer the advantage of do-it-yourself installation.

There are a number of barriers to increased use of DHPs in Canada. The installed costs of DHPs are higher per kilowatt (ton) than for central heat pumps, partially because of the novelty of these systems. Increased competition from domestic manufacturers should help reduce costs. Some wall space is taken up by the indoor unit and care must be taken to locate the indoor unit to minimise the build up of warm and cold air layers. Since an indoor unit could not be provided for every room in the house, not all of the heating load could be displaced with these machines. Energy and demand savings may therefore not be as great as with central systems of comparable efficiency. Most DHPs provide only a limited amount of backup resistance heating. Electric baseboard heaters would provide backup heat, but should be upgraded with better thermostats to avoid conflicting with DHP thermostats. Piping and wiring run along the outside walls of the house may be aesthetically unacceptable to some customers. With window heat pumps, some consideration must be given to noise reduction and adequate sealing of the window penetration.

The greatest barrier to DHPs in Canada is their limited energy and demand savings in cold weather (even more limited than ducted units). Test results for a variety of DHPs show the coefficient of performance (COP) approaches unity at about -15°C. Today's ducted ASHPs have improved controls, larger outdoor coils, better compressors, and better cold-weather performance. Ground-source heat pumps and burner-assisted heat pumps are also available which avoid the cold-weather limitations of ASHPs. To date, only a limited amount of work has been done to improve the cold- and warm-weather performance of DHPs. The operation of many DHPs is restricted to temperatures above -7°C. As with central ASHPs, defrosting systems can defrost unnecessarily and be unreliable.

Research and development initiatives should focus on reducing costs and improving cold- and warm-weather performance. Reduced costs will come with greater competition from domestic manufacturers. Cooperative efforts among cold-climate utilities and industry allies (e.g. Canada, Sweden, northern USA utilities, Electric Power Research Institute [EPRI], International Energy Agency [IEA]) could offer enough of a market incentive to interest manufacturers to improve cold- and warm-weather performance and defrosting control.

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Heat Pump Systems for Single-room Applications in Canada

Annex 23

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IEA OECD heat pump programme

Summary

This report describes the Canadian market for single-room heat pumps that can heat (and possibly cool) rooms in buildings not equipped with a ducted central system. Particular emphasis is placed on heat pumps that perform efficiently in cold weather. Technologies and equipment used to space-condition single rooms are included. Current research and promising alternatives are also presented. Recommendations are made on technical and market-related issues to promote market growth of this technology.

Local fuel availability and fuel cost ratios largely dictate the market for single-room heat pumps, so fuel costs are listed for each province.

Keywords: single-room heat pumps, electric resistance baseboard heaters, residential and commercial single-room space heating, energy reduction, electric-demand reduction

1 Introduction

Most cold-climate heat pump research and development to date has focused on forced-air central (ducted) heat pumps. However, the majority of electrically heated homes in North America and Europe use electric resistance baseboard-type heaters or hydronic (hot water) radiators. To take advantage of conventional ducted heat pumps, homes must have air ducts installed, at considerable cost and disruption. Heat pumps for a single room have increased in popularity in recent years and could easily be retrofitted to baseboard-heated or hydronic-heated homes. Commonly found features include quiet indoor fan-coil units, air filtering, thermostat setback, multi-speed fans, and wireless remote control. However, as with many central air-source heat pumps, existing heat pumps for single rooms have limited or severely restricted cold-weather performance. There are also concerns about heat pump reliability at subfreezing outdoor temperatures. Development of new varieties of room-type heat pumps for cold climates will provide the difficult-to-retrofit market with a viable, cost-effective space-heating alternative. Such products with heating and cooling facilities would also prove useful in commercial office buildings. For homeowners, room-sized heat pumps can reduce heating costs by as much as 60% and offer an environmentally superior system compared to conventional forms of space heating. For utilities, heat pumps for single-room applications increase revenues and reduce the overall global warming effect attributed to electricity generation and fossil-fired heating systems.

2 Objectives

Annex 23 aimed to collect information on the number of homes that could use single-room heat pumps to replace hydronic radiators, direct electric resistance room heaters, or electric storage heaters. With room-size market information, manufacturers could determine the product features that would best address the market needs.

One major aim of the project was to share the common experiences of electrical utilities, manufacturers, and consultants in each participating country, who were supplying single-room heating systems.

The Annex has also documented ongoing research directed toward solutions and options for the room-size heat pump market which was identified by the study. One goal of the Annex was to identify systems that retain the benefits of heat pumps at cold temperatures and avoid the peak-load problem of electric heat. In the summary report recommendations were made to extend the Annex to test products identified in Phase I.

3 The market

The driving forces behind the Canadian heat pump market are the environmental and financial benefits. The present low cost of heating residential homes with conventional natural gas systems makes most heat pump systems difficult to justify. However, in most commercial buildings and non-gas-heated residential areas, heat pumps are economical if properly designed and installed. The space cooling benefit is often used to justify the initial cost of a reversible heat pump. The need for mechanical ventilation in new buildings could create a market for exhaust-air (heating only) heat pumps, as it has in Sweden.

A survey of Canadian utilities to determine the distribution of baseboard heating in Canada was conducted in 1993 [1]. Those utilities with significant numbers of baseboard-heated residences are shown in Table 1.

Table CA 1: Canadian market for electric baseboard heaters.

Utility	Baseboard-heated homes (n = 2,234,029)	Annual heating consumption (131,306 kWh)
Maritime Electric, PEI	529	12,000
Newfoundland Power	93,338	13,566
Nova Scotia Power	73,164	8,650
New Brunswick Power	128,000	17,000
Hydro Québec [1,5]	1,325,000	14,340
Ontario Hydro [2-4]	341,000	15,700
Manitoba Hydro	41,953	17,050
Sask Power	16,800	17,000
BC Hydro	214,295	16,000

The concentration of homes with baseboard heaters can range from almost none to nearly 100% for a given location or utility. Hydro Québec has just over half of the market, with varying distribution across the rest of Canada. The Alberta baseboard heater market is almost nonexistent and has not been included in Table 1. Statistics Canada 1985 census shows that the all-electric heating market is comprised of 63% baseboard heating, 33% forced air, and 4% other electric options. The local price, availability, and acceptability of fuels affect the distribution of the baseboard heater market. Natural gas is widely distributed and cheap throughout the West, although pockets exist where natural gas is still unavailable (e.g. Vancouver Island, northern areas). In the Province of Ontario, natural gas companies are increasing the distribution network to displace higher cost electricity, whereas in the Province of Quebec electricity rates are lower, thus limiting natural gas predominantly to commercial uses. Natural gas is less available in the eastern provinces, where electricity competes with oil, propane, and wood. These fuel supply considerations must be kept in mind when the regional applicability of alternative technologies is being considered. Table 2 shows relative prices of the major fuels for the 10 Canadian provinces.

Table CA 2: Residential energy prices (USD cents/kWh).

	Nfld	PEI	NS	NB	Qué	Ont	Man	Sask	Alta	BC
Electricity	5.1	7.1	5.8	4.4	4.2	6.1	3.6	5.3	4.4	4.1
Natural Gas	-	-	-	-	1.8	1.4	1.3	0.97	0.91	1.4
Oil	2.1	2.0	2.1	2.2	2.2	2.3	2.5	2.1	1.95	2.48
Electricity Price Ratio To[1]:										
Natural Gas	-	-	-	-	1.23	2.4	1.49	2.8	2.6	1.55
Oil	1.2	1.8	1.4	0.97	0.97	1.4	0.78	1.3	1.2	0.8

Legend: Nfld = Newfoundland, PEI = Prince Edward Island, NS = Nova Scotia, NB = New Brunswick, Qué = Québec, Ont = Ontario, Man = Manitoba, Sask = Saskatchewan, Alta = Alberta, BC = British Columbia.

Source: Energy Statistics Handbook, Statistics Canada/Natural Resources Canada, Ottawa, July 1995. Includes goods and service tax, and provincial sales tax, where applicable. Residential electricity price approximations for monthly bills of 2,500 kWh. Fuel prices assume higher heating values of 10.4 kWh/m^3 for natural gas and 10.85 kWh/L for heating oil.

1 Fuel price ratios assume 80% annual fuel utilisation efficiency (AFUE) for natural gas furnaces and 75% AFUE for oil furnaces.
Assume CAD 1 = USD 0.65.

Hotels, motels and apartment suites represent a potential market for single-room heat pumps. In Canada and the USA many motels and hotels have wall units that need to heat and cool. The heating is sometimes achieved with direct electrical resistance. This market is broad-based, offering many attractive heat recovery and water heating opportunities. The ideal client for the single-room heat pump may be hotel and motel chains, if the right product existed. Table 3 shows the number of hotels and motels by province.

Table CA 3: Hotel and motel accommodations across Canada.

Type	Nfld	PEI	NS	NB	Qué	Ont	Man	Sask	Alta	BC
Hotels[1] (n=4,656)	96	32	111	83	956	1,096	316	411	631	846
Motels[2] (n=2,776)	45	50	114	115	934	756	64	129	308	628

1 Includes hotels and motor hotels with six or more units.
2 Motels that have more than six units.

The number of rooms in the Canadian accommodation industry is estimated at 210,000 (Table 4). The estimate is over 2 million rooms for the North American market where heating and cooling is required. This represents a great opportunity for marketing of single-room or single-zone heat pumping equipment. At the Annex 23 workshop, held in Niagara Falls, Ontario, several examples were given showing how distributed heat pump systems could dramatically cut operating costs in the hotel and motel industry [2, 3].

Table CA 4: Number of hotel and motel rooms in Canada.

	50 or less rooms	50-199 rooms	200 or more rooms
Hotel rooms (n = 179,219)	15,328	82,825	81,066
Motel rooms (n = 29,294)	6,190	15,564	7,540

Source for both Tables CA 3 and CA 4: Market Research Handbook, 1993-1994; Statistics Canada/Natural Resources Canada, Ottawa, Cat. No. 63-224, Tables 3-5.

3.1 Climate

Climate conditions in Canada can vary drastically, owing to its large size. Geographically, the territory can be divided into five major zones:

1. **Polar climate**, along the coast of the Northwest Territories and in the Arctic Archipelago.
2. **Subarctic climate**, covering the latitude from the Yukon to Labrador and descending near the inhabited region.
3. **Mountain climate**, including the Canadian Rockies in British Columbia and the Yukon.
4. **Moderate Maritime climate**, covering British Columbia on the Pacific coast, and New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland on the Atlantic coast.
5. **Continental climate**, representing the majority of the inhabited regions, from the Prairies to the East Coast.

This diversity in climate is attenuated in its practical implications by the demographic distribution of the population. The vast majority of the population live in the moderate maritime and continental climate zones. However, the variations in the continental climate zone are significant with respect to the heat pump market. For instance, the Prairie region has a much drier climate than the St. Lawrence region, but has colder winters. The St. Lawrence region experiences cold winters, with heavy snow falls, and humid summers. The Ontario peninsula has a more moderate winter climate but has hot and humid summer conditions. The average temperature varies extensively in each of Canada's climate zones.

Table 5 shows the heating load and heating degree-days for each Canadian province.

Table CA 5: Average annual heating load and heating degree-days by province.

	Nfld	PEI	NS	NB	Qué	Ont	Man	Sask	Alta	BC
Average annual heating load (MWh/yr)	13.6	12	8.65	17	14.3	15.7	17	17	17	16
Heating degree-days (18°C-base)	4,700	4,500	2,450	5,000	4,750	4,250	6,000	6,000	5,600	3,500

4 Market conditions

4.1 Cost factors

Undoubtedly the main barrier to selling a heat pump for heating-only purposes is the additional cost of the equipment. A heat pump can cost 1.5 to 5 times as much as a gas- or oil-fired heater of the same capacity. Moreover, price differential between electricity and fossil fuels is also a factor.

Unfortunately, despite the heat pump's high efficiency, the reduction in energy costs can be moderate for many residential applications. In terms of energy value, the electricity consumed by a heat pump is typically about one quarter of the energy consumption of fossil-fuel equipment. The price ratio of electricity to fuel must therefore be less than four for financial savings to be made. At today's low oil and gas prices, daytime electricity-to-fuel ratios are 1.5 to 3.7 in most provinces. This differential in energy costs is often the reason that heat pumps are not chosen over fossil-fired heating equipment. Heat pumps could be designed to use off-peak electricity to improve the energy cost differential. In commercial applications, the efficiency gains of having a distributed heat pump system that offers room-by-room control offsets the differential in energy costs. A distributed heat pump system is less expensive to operate compared to a central fossil boiler with high distribution losses or high costs associated with running the auxiliary equipment (fans and pumps required to operate the central system).

Higher prices for fossil fuels would help the heat pump market, because they reduce the electricity-to-fuel price ratio. Low electricity costs also improve the electricity-to-fuel price ratio. However, lower electricity prices tend to encourage greater use of electric resistance rather than heat pump systems.

4.2 Building factors

Heat distribution systems are another factor influencing heat pump markets. The traditional high-temperature hydronic (wet) heating systems, such as those prevalent in central and northern Europe, are not suitable for heat pumps. Heat pumps are more suited to producing moderate temperatures. Output temperatures are generally below 50°C. Designing a distribution system for these moderate temperatures is not difficult in new installations. However, even in new buildings, traditions die hard, and considerable effort is needed to encourage building designers to install the moderate temperature systems which are more compatible with heat pumps, such as underfloor or forced-air room systems.

For existing buildings, the best opportunity to expand the heat pump market is with systems that require minimum installation work. This factor has led to increased interest in the development of single-room space conditioning that can be installed quickly and easily by end-users or semiskilled installers. These kinds of systems have two advantages:

- they do not require extensive renovations for installation;
- they can be marketed as standard consumer products.

4.3 Emissions

Canada has established a Pilot Emission Reduction Trading (PERT) programme to help reduce greenhouse gases such as carbon dioxide (CO_2) and pollutants, e.g. sulphur dioxide (SO_2), nitrogen oxide (NO_x), and volatile organic compounds (VOCs). The programme is an industry-led multi-stakeholder environmental initiative that is evaluating emission reduction trading as a tool to help reduce emissions of the listed gases. The PERT project is developing rules and guidelines for creating, recognising, and trading emission reduction credits (ERCs) as a commodity, readily marketable and applicable for voluntary emission limits or future regulatory requirements. The use of emission reduction trading between companies and jurisdictions is intended to complement existing legislation and help make it more cost effective to proceed. Heat pump systems are recognised as key technologies for reducing CO_2 emissions and cutting primary energy consumption. This environmental initiative is expected to be primarily responsible for the greater use of heat pumps in the future. Ontario Hydro has produced a spreadsheet program to calculate the emissions reduction credits for heat pumps with different coefficients of performance.

5 Technologies

The use of wall-mounted fan-coil units commonly associated with room heat pumps (ductless heat pumps) may present some opportunities for use with low-temperature heat sources such as hydronic heat pumps and domestic water heaters. For example, a single hydronic heat pump could be coupled to several of these fan coils via a piping loop. This system could provide most of a home's heating and cooling with backup heating provided by existing baseboard heaters or an electric or fuel-fired boiler included with the heat pump. Indoor fan-coil units would provide the same advantages as conventional room heat pumps (e.g. quietness, controllability, and ease of installation). This system would require only one single-speed heat pump unit, unlike multisplit room heat pumps, which require either a variable-speed compressor or a compressor for each indoor unit. A minisplit hydronic heat pump using fan coils might have an installed cost for a mature product of about USD 5,000 and require no separate boiler for backup heating. Ontario Hydro has investigated systems of this kind [3]. They are also found in Sweden in relatively small numbers.

A Canadian manufacturer has developed a distributed heating/cooling system that connects multiple fan coils to one single-speed outdoor compressor unit. The system uses refrigerant piping to transfer heating or cooling to multiple rooms.

6 Research and development

6.1 Current R&D

Table 6 shows current activities in marketing and research for each province. Many of the provinces are working on heat pumps in general, but none are currently involved with single-room applications.

Table CA 6: Summary of the Canadian utility marketing and research activities.

Utility	Marketing	Research
Maritime Electric, PEI	-	-
Newfoundland Power	Insulation	HP
Nova Scotia Power	-	HP
New Brunswick Power	-	HP
Hydro Québec [1,5]	HP, DFF	HP, Hydronic
Ontario Hydro [2-4]	HP, Windows Insulate	HP, Hydronic
Manitoba Hydro	-	-
Sask Power	-	GSHP
BC Hydro	Gas	-

HP = heat pump, DFF = dual-fuel furnaces, GSHP = ground-source heat pump

Two Swedish companies recently won competitions in Sweden against competitors from Denmark, Finland, Norway, and Sweden. The heat pumps that won the competition utilised heating-only ground-coupled equipment for residential applications.

The 3.9 kW heating capacity heat pump unit, designed by IVT Energy AB, is intended for homes with oil or electric backup heating. The other winning design, by Eufor AB, was a room unit for use in homes without a heat distribution system, such as those using baseboard resistance heating. Suitable for wall mounting, the unit is designed for use with direct-evaporation ground coupling. These two units are for heating purposes only. A cooling and heating GSHP is currently being designed by the Department of Research and Development of the Hokkaido Electric Power Company in Japan. The heating capacity of 6.4 kW and cooling capacity of 5.2 kW is an average size single-room space-conditioning system.

7 Comparison of promising alternatives

Natural gas heating will continue to displace electric heating in regions where fuel price ratios are favourable enough to overcome the inconvenience of having ducting and/or gas piping networks installed. However, increased gas demand may translate into increased gas prices. In many areas, electric heating will retain its attractiveness due to its simplicity and cost effectiveness. These electric heating areas should provide a good market opportunity for heat pumps.

Research and development efforts in Canada should focus on ductless ground-source heat pumps. These types of systems are the only heating options that can provide energy savings of up to 65% and significant peak demand reductions. Ground-source heat pump systems are most attractive in areas with high heating loads and electricity costs and where the application of open-loop (well-water) systems can keep installed costs down. These systems are effective for a larger portion of Canada compared to air-source heat pumps. Reduced installed costs could significantly increase heat pump sales, especially in regions that have already established reasonable markets (east of Saskatchewan). Development of a multisplit ductless GSHP could reduce installed costs and provide an easily retrofitted solution for the baseboard-heated home.

8 Conclusions

The Canadian heat pump market is dictated largely by local fuel availability and fuel cost ratios. In the western provinces, natural gas is readily available and few heat pumps are in existence. In remote areas and toward the east, gas becomes less available. The Province of Ontario sits on an imaginary borderline where gas availability is increasing and electricity rates have increased to the point where natural gas is about half the cost of electricity. In Québec gas is not marketed as extensively, and the gas-to-electricity price ratio does not favour gas-burning appliances. Gas is not available east of Québec and electricity competes with oil, propane, and wood for space heating.

The Canadian electric baseboard heating market consists of around 2,200,000 homes, with over half of the Canadian market in Québec. Ideally, retrofit alternatives for the baseboard-heated market will reduce demand and provide good electricity sales for utilities, and offer the customer an inexpensive, reliable alternative heat source. Much of the existing heat pump equipment can provide energy savings in Canada. Further development is required to meet the needs of the Canadian market.

Hydronic heat pump heating is a good option in Canada when there is no desire for cooling, central humidification, or air filtering. The quietness and radiant heating nature of these systems is believed to appeal to many customers.

Heat pumps have the potential to become an important option in Canada as an alternative to electric-resistance heating. Heat pumps are well known but are not as readily accepted as they could be due to high cost and perceived unreliability. Air-source heat pumps have poor cold-weather performance, limiting their applicability mainly to southern Ontario. Of the all-electric options, ground-source heat pumps can provide the largest operating cost and energy savings (65%) and have fewer climatic limitations than air-source heat pumps.

Room heat pumps could have niche markets where zoning and other amenities (cooling, air filtering) are desirable and where duct installation is difficult. A typical room heat pump installation would not directly service all the rooms in a house because of the costs and aesthetics associated with running piping to multiple units and having multiple outdoor compressor units. However, it has been shown that room heat pumps provide significant heating to adjacent zones whose set-points are 2°C lower than the zone in which the heat pump's fan coil is located. All air-source room heat pumps have poor cold-weather performance and require a backup system. Cold-climate ductless heat pumps, such as those using enhanced air-source, ground-source, or burner-assisted heat pump components are needed for the Canadian and other northern climates.

A good heating-only solution is to circulate hot water to fan-coil units and have a hydronic heat pump supply the hot water. This would allow a single hydronic outdoor heat pump, with its own backup boiler, to effectively heat most areas of a home at a lower cost than installing central ductwork.

One Canadian manufacturer has developed a burner-assisted room-by-room heating and cooling system, using refrigerant-filled distributed fan-coil units and an external burner/heat pump. This system closely matches the Annex objectives of finding a low-cost heat pump with good low-temperature performance.

9 Recommendations

Much of the work recommended below could be carried out in cooperation with manufacturers and cold-climate utilities that may have similar interests and experience with the technologies. The recommendations are ranked in decreasing priority.

Burner-assisted heat pumps
Burner-assisted heat pumps connected to multiple indoor fan-coil units are available in Canada. These units meet many of the objectives of the Annex and need to be field tested to verify their savings potential.

Hydronic room heat pump
Develop a ground-source hydronic heat pump system, which supplies hot water or glycol to multiple wall- or floor-mounted indoor fan-coil units.

Cold-climate room heat pumps
Optimise room heat pumps for use in cold climates, including the development of ground-source and burner-assisted or enhanced air-source heat pump versions. Conduct field tests to determine actual demand and energy savings, interzonal heating effects, and baseboard room heat pump thermostat interactions.

Ground-source heat pumps
Reduce installed costs of ground-source heat pumps to allow greater market penetration. Of all options, ground-source heat pumps provide the greatest energy savings (up to 65%) for the Canadian climate.

References

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2. Henderson H.; CDH Energy Corp.; *North American monitoring of a hotel with room size ground-source heat pump*; Presented at the Annex 23 Workshop, Niagara Falls, Ontario, 18-19 June 1998.

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Heat Pump Systems for Single-room Applications in France

Annex 23

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IEA OECD heat pump programme

Summary

This report presents an overview of the energy supply situation in France and describes how the heating requirements are met in existing, as well as new housing. The heat pump market is examined, and the regional distribution of reversible air-conditioning equipment is described in detail, including statistics on retrofitting. Market difficulties and factors that inhibit the dissemination of heat pumps are outlined, and an initial-cost comparison is presented. A summary of the situation in the commercial sector is included, along with potential opportunities. Recommendations are made on possible solutions to promote the use of single-room heat pumps in France.

1 Introduction

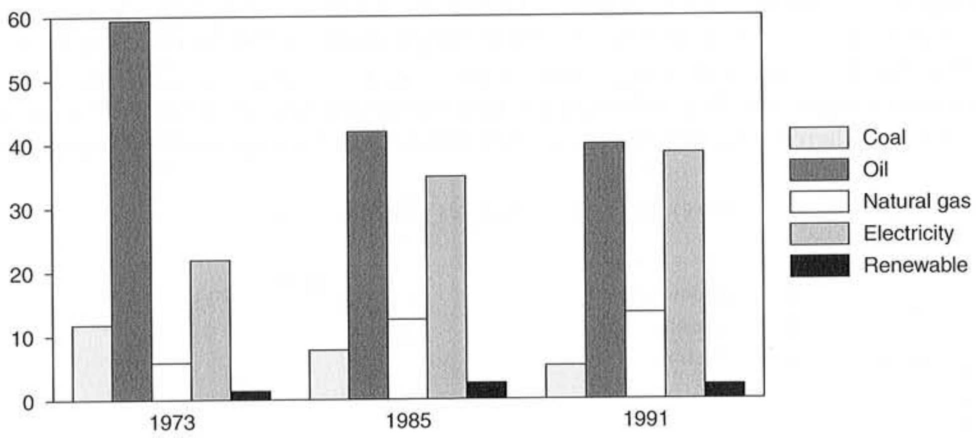
Heating in the residential and business sectors accounted for almost half the end-use energy consumption (48%) in France in 1991 [1]. The relative market share of space heating has dropped drastically over the past two decades, mainly because of regulations issued following increases in the price of oil. With a large supply of electricity, and a third of the residential market (more than 6 million homes in 1993) relying on this energy source, heat pumps offered a viable and cost-saving solution.

2 Energy overview in France

2.1 Energy supply in France

The structure of the energy supply in France is probably unique in the world. In the 1970s oil was the predominant source (Figure 1) [1]. Following the oil price increases of the 1970s and early 1980s, Electricité de France (EDF, the national electrical utility company), invested in nuclear plants in an effort to reduce France's dependence on oil imports. This move dramatically increased the electric energy market share, boosting it from 22% in 1973 to 39% in 1991; oil dropped from 59% of the market in 1973 to 40% in 1991; whereas, the market share of natural gas has more than doubled to 13.4%. It is worth noting that the share of renewable energy sources has changed little in the past 20 years; coal has been marginalised as an energy source (5.5% in 1991). Nevertheless, and in spite of huge investment in nuclear plants, France is still dependent on fossil fuel imports, which provide about half its energy requirements.

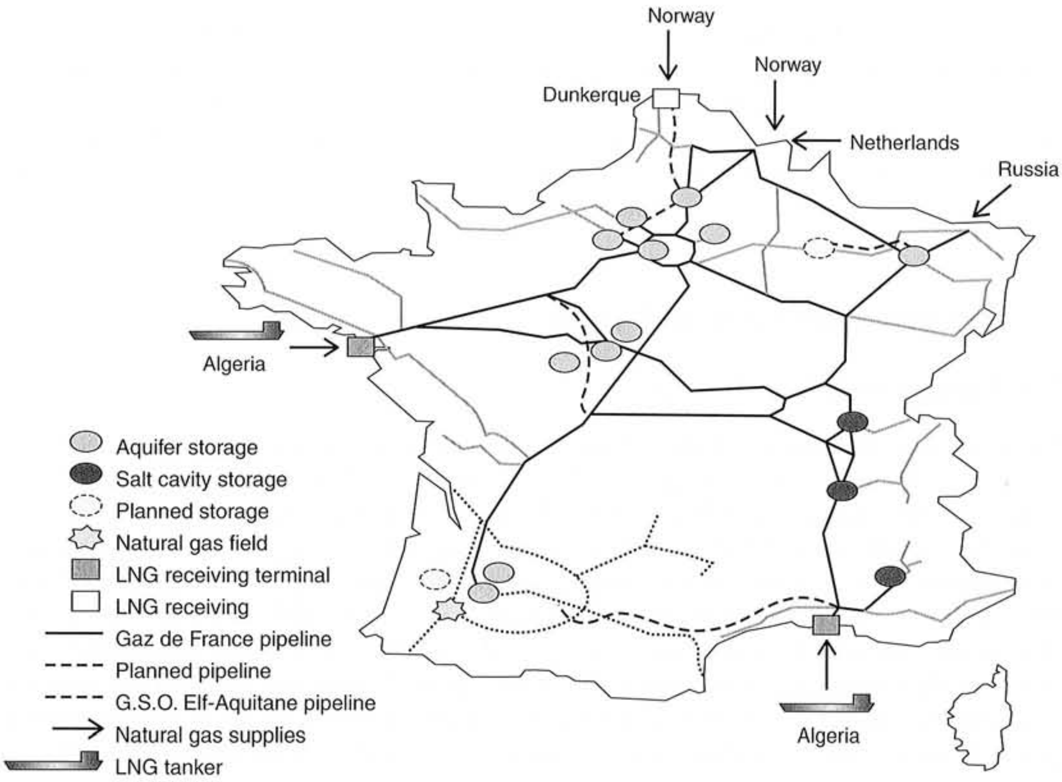
Figure FR 1: Evolution of the structure of end-use energy consumption in France [1].



2.1.1 Natural gas supply

France has diversified its natural gas sources. Russia, Algeria, Norway, and the Netherlands are the major suppliers (Figure 2). The distribution network extends to most of the country; only low population density, or mountainous regions and a few suburban areas are not linked [2].

Figure FR 2: Natural gas supply and distribution network in France [2].



2.1.2 Electrical energy supply

Development of nuclear power plants in France drastically increased the nuclear energy share, boosting it to 73% of the total electrical energy supply in 1992 and 77% in 1996 [3]. The tremendous changes in energy sources that occurred over the past two decades are presented in Figure 3 [3]. Fossil fuel sources have been marginalised and accounted for only 11% in 1992, whereas hydraulic energy accounted for 16% of energy sources (Figure 4) [4].

Figure FR 3: Electric energy production sources in France [3].

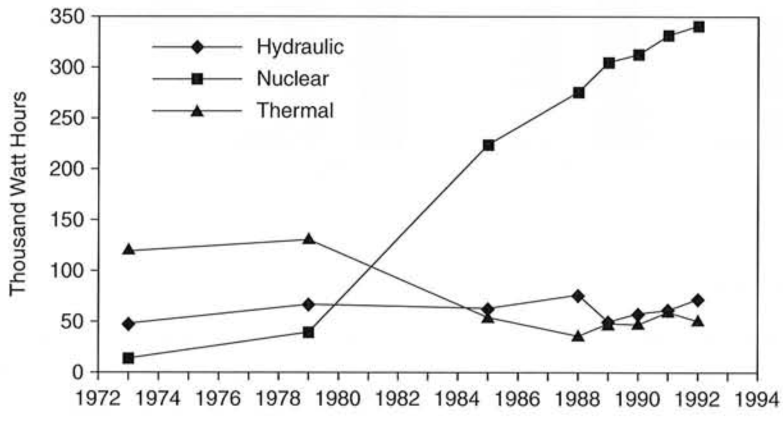
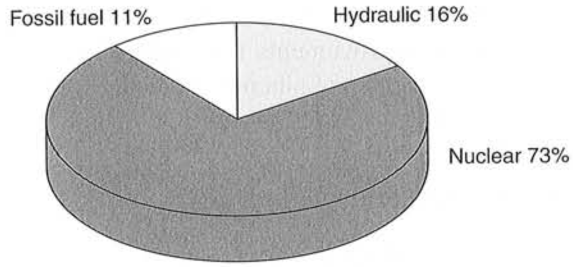


Figure FR 4: Structure of electric energy production in France, 1992 [4].



3 Domestic heating market

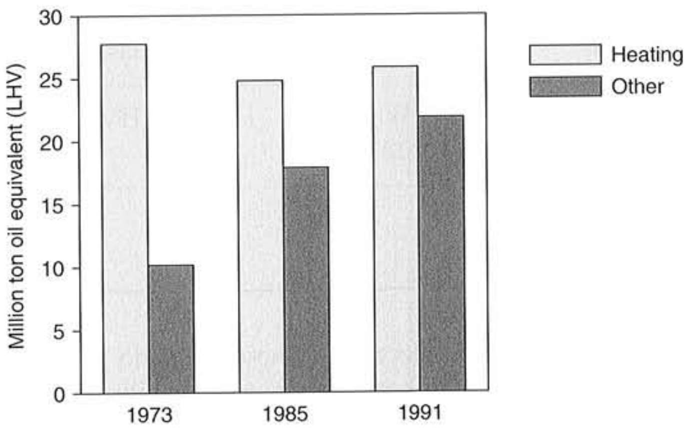
3.1 Demand and energy requirements

Overall building stock amounted to 22.2 million 'main residences' and 5 million secondary homes in 1993. Of the main residences, 56% are detached houses; apartment buildings make up the remaining 44%. Energy consumption in the domestic sector is related to two categories of use: heating and other.

3.1.1 Heating

The relative share of energy required for heating has been drastically reduced, from 73% in 1973 to 54% in 1991 (Figure 5). This is mainly due to improved equipment and building practices, including better insulation. The results are direct consequences of strict applications of regulations and standards for new housing put forward in 1974, 1982 and 1989. These regulations, which aimed to reduce heating energy consumption by 25% from 1974 to 1982, 25% from 1982 to 1989, and another 25% after 1989, contributed to the reduction of energy consumption by 50% in new structures, compared to pre-1974 buildings. Tax incentives encouraged homeowners to reduce energy use by improving insulation in existing homes.

Figure FR 5: Domestic heating energy requirements [1].



3.1.2 Other uses

The relative share of energy required for domestic hot water, cooking, lighting, electronic equipment, etc. has increased. This is due to improvements that reduce heating energy consumption, but also to the emergence of new consumer requirements and the ever-increasing number of electrical appliances in homes (washing machines, dryers, microwave ovens, etc.).

3.2 Cost comparison of various heating energy sources

Table 1 lists the consumer price of energy from different sources (provided that minimum ordering conditions are met). Electricity is about three times more expensive than energy from other sources. Note that these rates are not sufficient for heating sources comparison when evaluating the alternatives. However, Table 2 presents unit conversion factors based on the heating value of various energy sources. This will be examined later in the report.

Table FR 1: Consumer energy prices for residential use in France.

	USD (cents) per kWh[6]	Variation over 1 year (%)
Coal[1]	3.95	1.7
Natural gas[2]	3.73	1.7
Oil[3]	3.68	11.2
Electricity[4]	12.83	1.7
Propane[5]	5.95	4.4

Specific quantity conditions when ordering:

1 1 or 2 tonnes/year;

2 25,000 kWh/year;

3 2,000-4,999 L/order;

4 13,000 kWh/year, of which 5,000 is during off-peak hours;

5 700-1,300 kg/delivery.

6 Prices at 31 March 1996: USD 1 = FRF 6

Table FR 2: Energy sources unit conversion factor based on heating value.

Source	Coal[1]	Oil[2]	Electricity	Natural Gas
quantity	1 ton	1	1 MWh	1 MWh HHV
toe	0.667	1	0.222	0.077

1 Average value;

2 Approximate value for liquid fossil fuels.

Table 3 presents energy price ratios based on electricity. These ratios do not account for initial investment costs for equipment and may not reflect consumer bills. Generally, the efficiency of electrical heating equipment efficiency is 100%, whereas the efficiency of fossil fuel systems depends on age of equipment and type of fuel, with values around 90% for new equipment and 50-70% for equipment in service. A conversion efficiency of 65% was assumed when generating Table 3. Approximate equipment costs are discussed in Section 6.

Table FR 3: Energy price ratios based on electricity.

Comparison[1]	Price Ratio
Electricity to natural gas	2.2
Electricity to oil	2.3

[1] Assuming 65% conversion

3.3 Heating energy sources

3.3.1 Existing housing

The type of energy source for domestic use depends, to a large extent, on the nature and location of the housing. In the existing residential building sector, covering all types of housing, natural gas and electricity equally meet 66% of the heating requirements (Figure 6). Overall, the number of electrically heated homes (main residences) is about 6.2 million. Although oil meets around 20% of the housing heating needs, this national average is not really representative because fuel oil is not used equally in all sectors. For instance, oil is used more often in detached houses, meeting over 25% of the heating requirements for 1994, as indicated in Figure 7. The figure also shows the predominance of electricity and natural gas for detached housing (more than 50% of the needs). Wood or coal sources are also used more often in this type of housing [5].

Figure FR 6: Domestic heating energy sources (1993) for main residences [1].

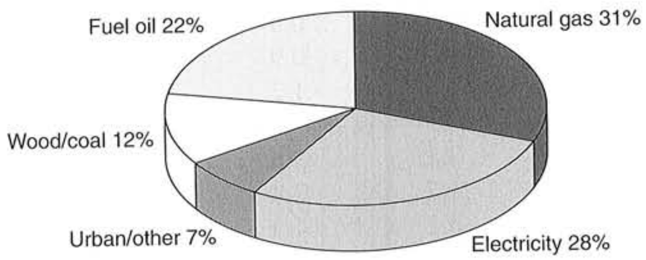
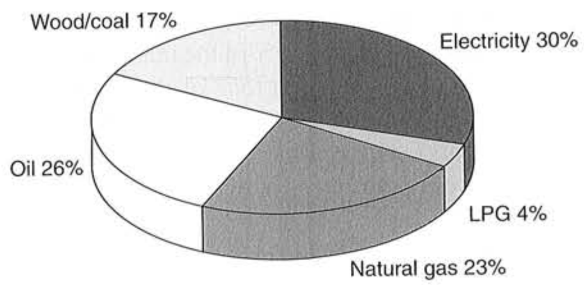


Figure FR 7: Heating energy sources for existing detached houses (1994) [5].



3.3.2 New housing

Around 300,000 new homes (including detached houses and apartment buildings) were built annually in France (OE, 1992) for the period 1990-95 [6]. From 1996 onwards, the total number of new homes built amounted to around 200,000 per year. Table 4 shows important trends in new housing heating methods. For detached houses, electricity provides 50% of the required heating energy, natural gas around 25%, and heating oil is used more than for other types of new housing (20% vs. 8% nationwide). Semidetached houses are heated mainly by electricity and natural gas in approximately equal proportions. Liquid fuels (LPG and oil) are virtually absent in new apartment buildings [7].

Table FR 4: Market shares for various energy sources used in residential heating for new housing.

New housing	Year	Detached houses	Semi-detached houses	Public apartment buildings	Private apartment buildings	Global
Electricity	1992	58.0	55.6	30.8	76.4	58.3
	1993	46.1	50.8	30.4	77.2	51.2
	1994	45.4	48.3	25.5	76.7	49.0
Natural Gas	1992	18.9	40.0	62.0	21.6	30.7
	1993	23.9	46.5	65.5	21.9	36.3
	1994	25.0	46.6	67.8	20.6	37.6
Oil	1992	13.1	0.4	0.5	0.2	5.0
	1993	17.5	0.3	0.4	0.5	6.6
	1994	19.5	0.4	0.2	2.1	8.0
LGP	1992	6.0	0.9	0.9	0.1	2.5
	1993	7.3	0.7	0.9	0.1	3.0
	1994	6.5	1.5	1.2	0.2	3.2
District	1992	4	3.1	5.8	0.7	1.3
	1993	5.2	1.7	2.8	1	0.4
	1994	3.4	3.2	4.3	2.2	1.8

From EDF, Départment Applications de l'Electricité [7].

Perhaps the most striking differences can be observed for new multi-family apartment buildings. The public sector uses mainly natural gas (66% of the market vs. 33% for electricity), whereas the private sector has an opposite strategy (75% of the market for electricity vs. 20% for natural gas). The reason is the low cost of investment and installation for electric heating (i. e. basic electrical convectors). This solution is preferred by private contractors, whereas public investors choose a lower operating cost, even if the investment cost is higher.

Figures 8 to 10 show plots of the information provided in Table 4. They show that the situation is levelling for the three sectors shown, and within the proportions previously discussed, i. e. natural gas and electricity meeting most of the energy requirements, except for the detached housing market, which still relies on oil to a certain extent (20%).

Figure FR 8: Evolution of the heating energy sources in all new housing.

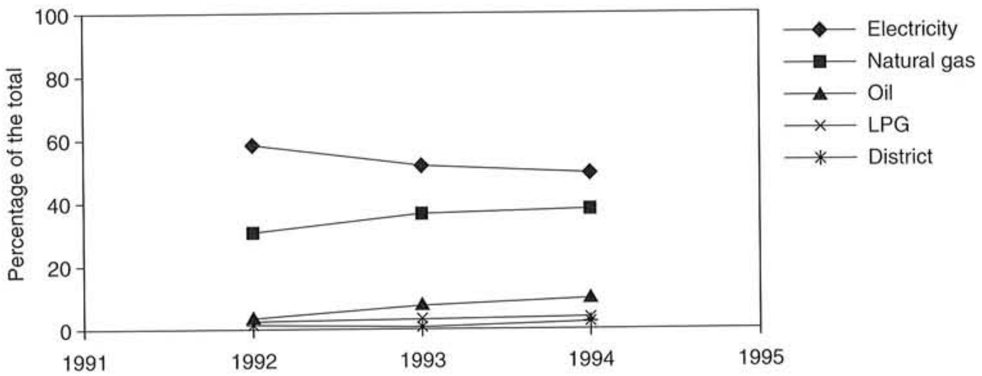


Figure FR 9: Evolution of all heating energy sources in new detached housing.

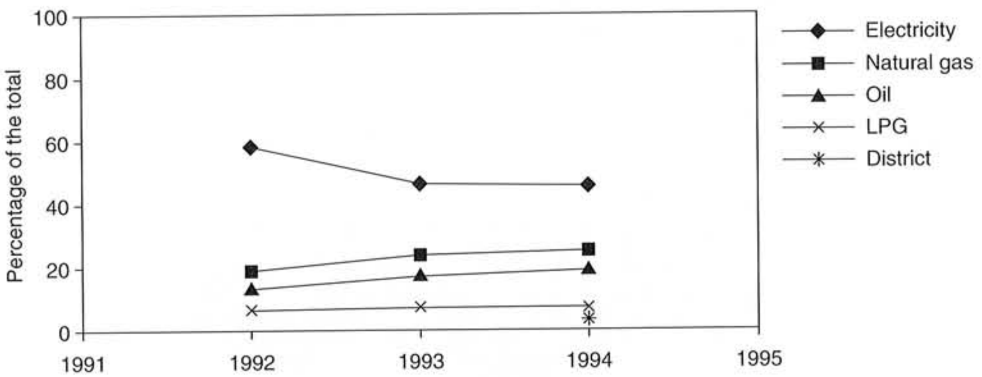
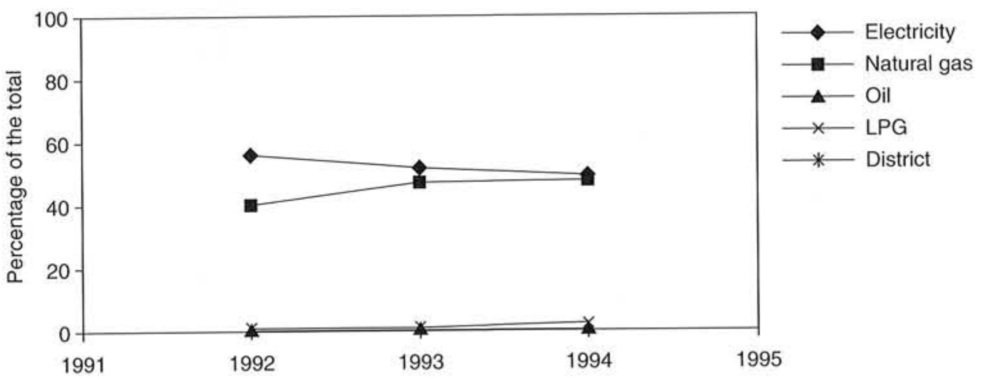


Figure FR 10: Evolution of the heating energy sources in new semidetached housing.



4 The heat pump market

4.1 Climate

France is divided into three climate zones. Figure 11 shows the geographic limits of these zones (numbers in the map correspond to the administrative divisions called 'départements', and are irrelevant to our study) [8]. The characteristics of these climate zones are described in Table 5.

Figure FR 11: Climate zones in France.

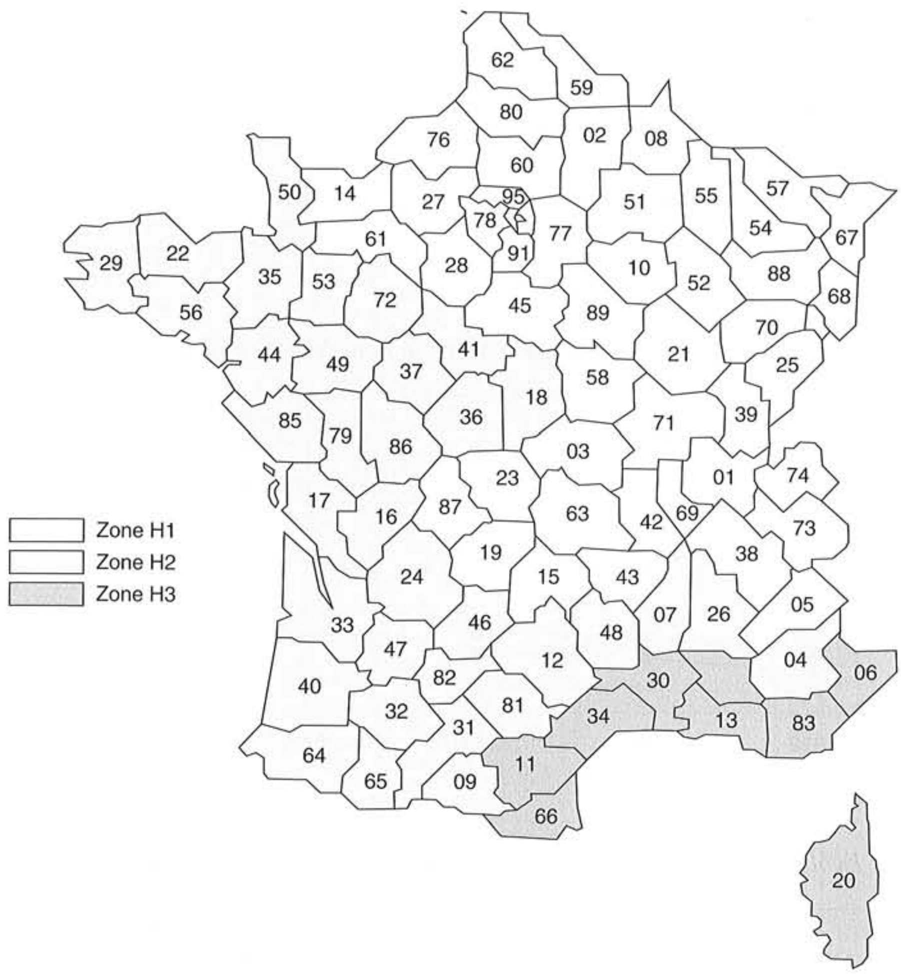


Table FR 5: Characteristics of climate zones in France.

Climatic zone	Main characteristics
H1	Temperate climate with cool, somewhat wet winters and wet, warm summers
H2	Temperate climate with cool, wet winters and hot, somewhat wet summers
H3	Mediterranean climate with mild, wet winters and hot, dry summers

4.2 Heating requirements

A survey by EDF in 1985 provided an analysis of hourly and daily outdoor temperature frequencies [9]. The report contains degree-days for 11 selected towns and four heating periods. Figure 12 shows the location of the 11 selected towns, and Table 6 shows the degree-days for the chosen periods.

Figure FR 12: Location of selected towns.

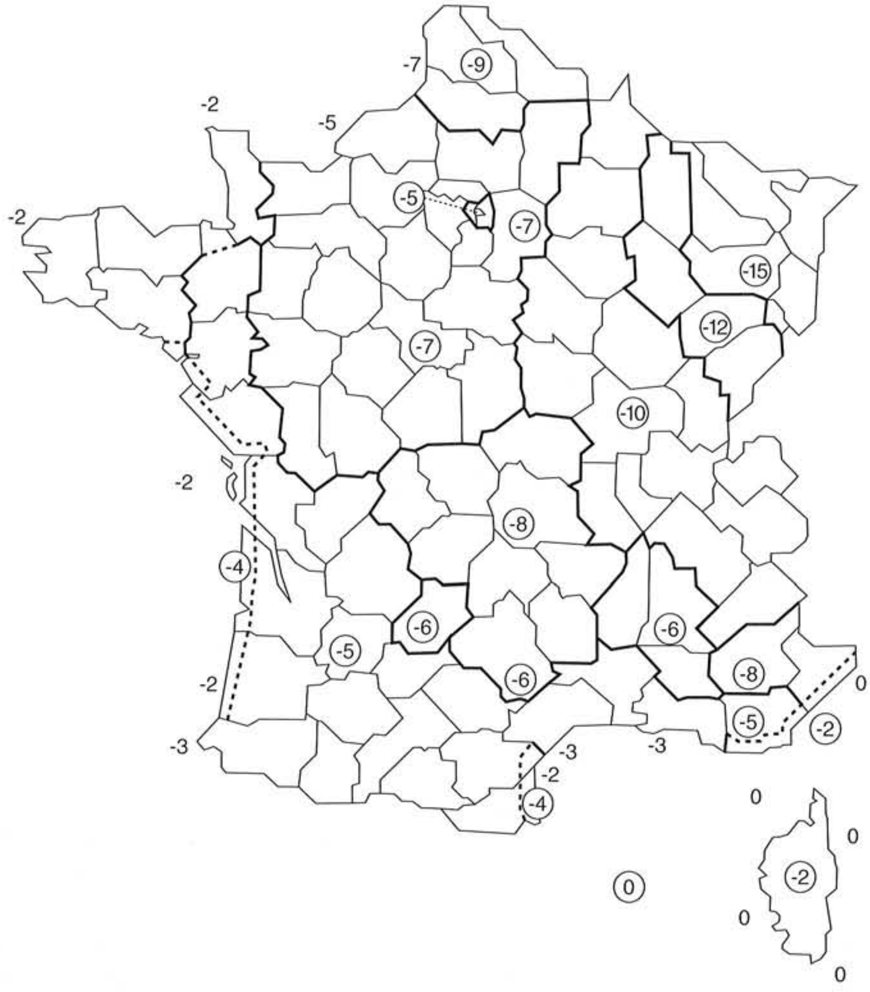
Table FR 6: Degree-days for selected towns in France.

Town	Climatic zone	Yearly average		Heating season (1 Oct-20 May)		Peak season (1 Dec-28 Feb)		Winter Season (1 Nov-31 Mar)	
		HDD	Temp[1]	HDD	Temp[1]	HDD	Temp[1]	HDD	Temp[1]
Agen	H2	2,412	12	2,277	8.2	1,149	5.2	1,758	6.4
Ajaccio	H3	1,638	14.4	1,611	11.1	831	8.8	1,274	9.6
Carpentras	H3	2,161	12.9	2,081	9.1	1,067	6.1	1,642	7.1
La Rochelle	H2	2,214	12.3	2,071	9.1	1,059	6.2	1,585	7.5
Limoges	H1	2,918	10.3	2,605	6.8	1,273	3.9	1,943	5.1
Macon	H1	2,858	10.6	2,656	6.6	1,391	2.5	2,045	4.5
Millau	H2	2,941	10.2	2,749	6.2	1,310	3.4	2,060	4.4
Nancy	H1	3,194	9.5	2,866	5.6	1,433	2.1	2,190	3.5
Nice	H2	1,559	14.6	1,542	11.4	822	8.9	1,209	10
Rennes	H2	2,746	10.6	2,454	7.4	1,164	5.1	1,829	5.9
Trappes	H1	3,009	9.9	2,699	6.4	1,325	3.3	2,019	4.6
Average		2,514		2,328		1,166		1,778	

1 Average temperature in degrees Celsius; base temperature = 18°C.

Figure 13 (AICVF, 1990) shows the outdoor temperatures taken as reference values for calculating standard heating requirements (temperatures are shown inside circles) [10]. A correction factor is normally used to account for the effect of altitude.

Figure FR 13: Reference outdoor temperatures (°C).



4.3 Market size

4.3.1 Historical development of the heat pump market

In France, the market for heat pumps for single-room application per se is small. However, the air-conditioning market is growing and contributes greatly to the heat pump market. Marketed products are nevertheless not limited to air-to-air systems, but also include water-based systems (either floor heating or fan-coil units).

At the end of the 1970s and the beginning of the 1980s, when oil prices sky-rocketed, heat pumps received extensive support and advice from the national utility company (EDF) and the French Environmental Agency (ADEME), either for research and development or for installation. At the time, dependency on oil imports in France was a significant factor.

The so-called PERCHE and PERCHE GTI programmes dealt with the implementation of a heat pump in series with an existing oil boiler (for central heating systems using hot water). So for the mid-range temperature levels, the high coefficient of performance (COP) of the heat pump resulted in energy and cost savings, at a time when the price of oil was continuously rising. These actions opened the market, even if the reliability of the installation and its servicing were not fully satisfactory. More than 10,000 heat pumps were installed, often with substantial subsidies from EDF. Lack of awareness by the users and insufficient experience of the installers contributed, to some extent, to the demise of these promotion programmes. In addition, fossil fuel energy prices decreased (Figure 14), and heat pumps became a less cost-effective alternative. Manufacturers now prefer to use the term 'reversible air conditioner' instead of 'heat pump' to promote their equipment.

Figure FR 14: Evolution of consumer heating energy prices.

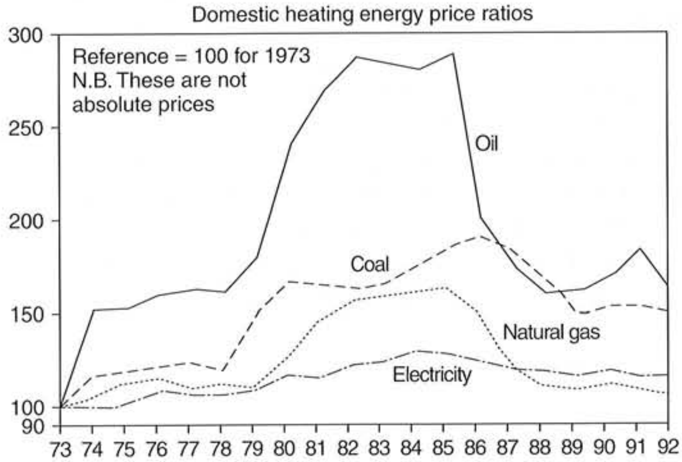
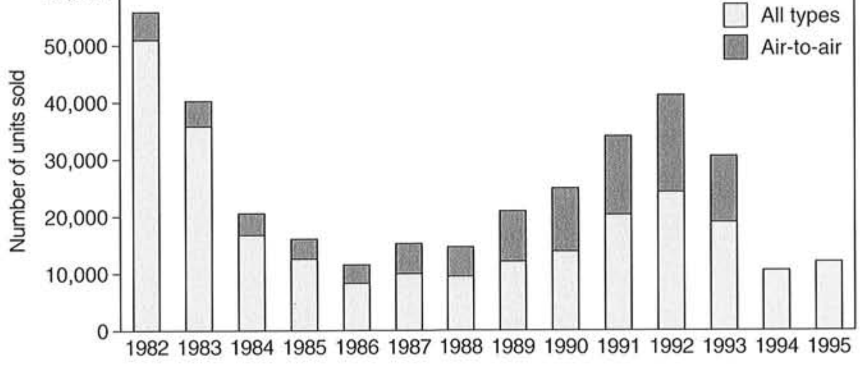


Figure 15 shows the numbers of heat pumps manufactured in France (Mr Dreuillet, French manufacturers trade Association, UNICLIMA, private communication, 23 October 1997) [11]. These figures include all reversible units manufactured in France and used for domestic heating; it can be assumed that most of the French production was marketed in France. However, the numbers do not refer to installed equipment.

Figure FR 15: Heat pumps manufactured in France.



The effects of the promotion programmes can be observed for the beginning of the 1980s, when French annual production reached 50,000-60,000 units (figures for installed heat pumps are not available for this period). As fossil fuel energy prices dropped (see Figure 14), interest in heat pumps was lost, and production fell to around 12,000 units. From the mid-1980s, there was some renewed interest in heat pumps, but production never reached the high numbers generated by the promotion programmes. Nevertheless, air-to-air heat pumps are penetrating the market, even if the recession experienced in France in the mid-1990s has slowed production. This evolution is due to the growth of the air-conditioning market; in fact, more air-to-air heat pumps are reversible air conditioners, with capacities around 6 kW. Figure 15 also indicates that the proportion of air-to-air heat pumps is growing fast.

4.3.2 Air-conditioner market share

Only 1.2% of French housing is currently equipped with air conditioning and, according to a survey of over 1,000 people conducted by the French Institute for Statistics (IPSOS), 5% of the population intend to purchase air conditioners in the next three years (representing 1.25 million houses and apartments). In February 1996 EDF initiated a study of air conditioners (reversible and non-reversible) by sending questionnaires to 3,500 installers and dealers. Results were classified according to technology, capacities, regions, etc. The EDF survey results are used in the following analysis. Figure 16 shows the selected regional breakdown. Of particular interest is the southern Mediterranean coastal region, which represents the warmest climate zone (H3). Figure 17 shows estimates of the number of air conditioners installed in France from 1990-95, with capacities below 40 kW.

Figure FR 16: Regional breakdown for the EDF survey.

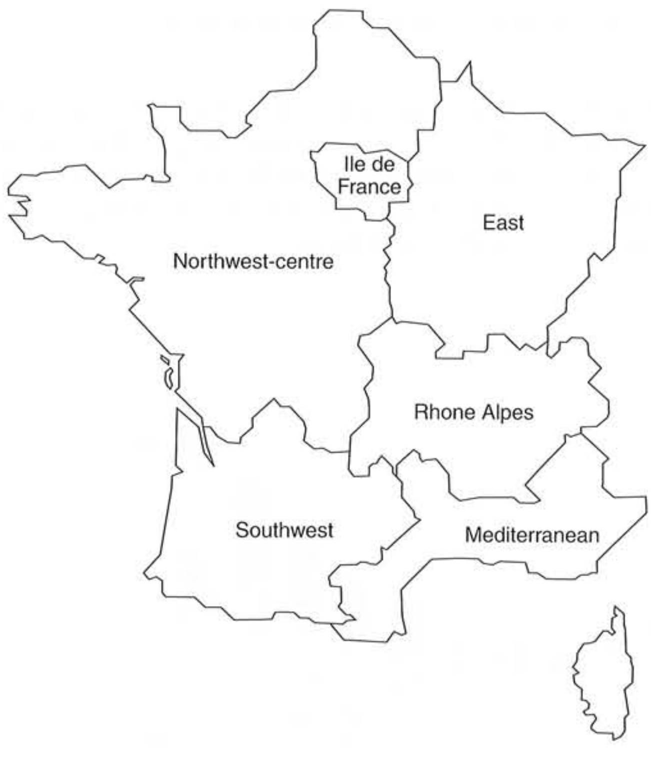
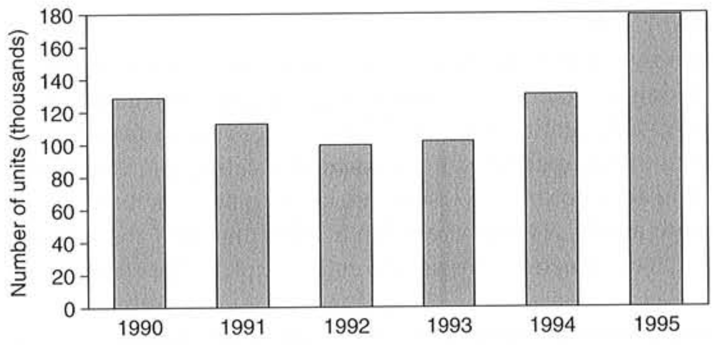


Figure FR 17: Market estimates for cooling capacities below 40 kW.



The split-type unit dominates in the air-conditioning market, with a national average of 70%. Figure 18 indicates the growing number of installed single-room split units (up to 40 kW), both cooling-only and reversible types. Levels remain constant (except in the recession years) in the early 1990s, but increased during the mid-1990s.

Figure FR 18: Market estimates for split units.

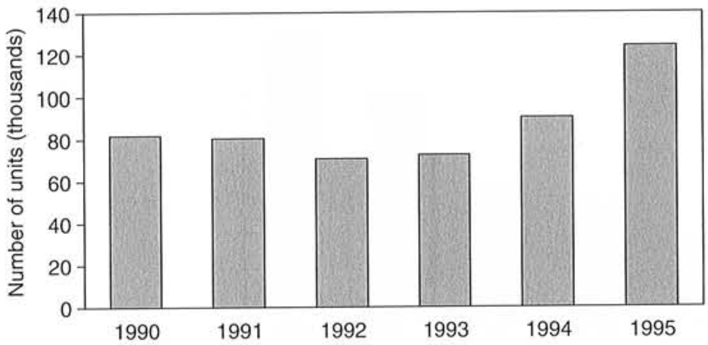
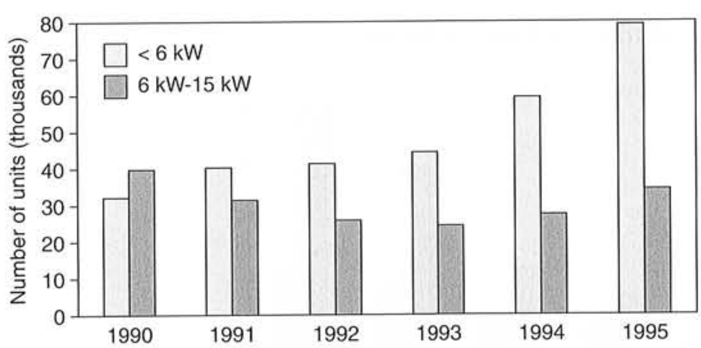


Figure 19 shows the division of the market for capacities below 15 kW. The market share for units above 15 kW is small and does not offset the domestic and commercial markets. Hence, these are not included in the analysis. The market growth for small-capacity units is strong.

Figure FR 19: Market estimates for split units (below 15 kW).



4.3.3 Heat pump market share

As previously mentioned, the French heat pump market is closely linked to the air-conditioning market. Reversibility is not only a way to introduce heat pumps into residential housing but is also considered an advertising argument. Air-conditioning equipment is marketed with the main argument that 'it can provide heating too'. Only 14% of consumers realise that an air conditioner is not only useful in summer but can also provide heating and can save money during the winter. It is useful to note that reversible air conditioners include not only air conditioners with a thermodynamic reverse cycle for heating but also those appliances equipped with an electric resistance, which can provide the entire (or part of the) heating required.

The EDF survey gives a breakdown in capacity levels for the entire domestic sector. It is assumed that the same division prevails for the single-room split unit market. Figure 20 shows the market evolution for heat pumps (which are assumed to be reversible single-room split-type units for the analysis) for capacities less than 15 kW. This figure clearly indicates that the market started to pick up in the mid-1990s.

Figure FR 20: Reversible heat pump market (units with no supplementary electrical resistance).

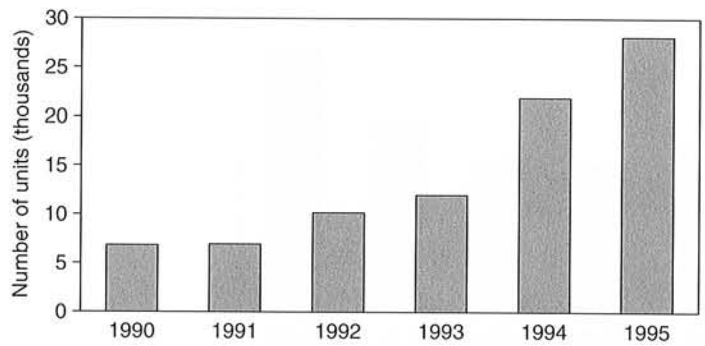
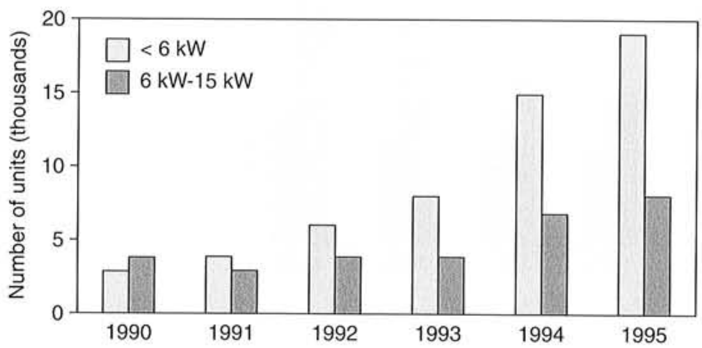


Figure 21 shows the market evolution of reversible heat pumps, for two levels. Note that only heat pumps that are not equipped with electrical resistance are considered. The market evolution for units of less than 6 kW is striking. Even when the market for other types of air-conditioning equipment slowed down or even decreased, the market for small-capacity heat pumps has been vigorous.

Figure FR 21: Heat pump market evolution in France.



4.3.4 Market difficulties

The EDF survey also included questions related to problems faced by installers and dealers. Ninety percent of installers had no problem with air-conditioning equipment sales. The level of satisfaction with respect to assistance from equipment manufacturers increased from 1994 to 1995, with the dissatisfaction rate dropping from 7% to 3%. All installers were satisfied with the equipment; half considered it reliable, efficient, and technically sound; and 20% felt it had a promising future. Another 18% thought it was economical, but 14% stated that it was not sufficient to meet all heating requirements.

Asked about market development difficulties, respondents ranked equipment price first (76%), followed by the lack of information about the product (25%). Climate considerations were the next concern (8%), along with possible health problems (7%). Surprisingly, noise caused little concern (5%). The response to this last section was above 100%, since several answers were possible.

The most important sales factors were considered to be word-of-mouth (51%) followed by customer requests (30%), and proposals to clients (9%). Advertisements, mailings, and telephone marketing techniques scored 5%. Suggestions by EDF were rated at 2% of the sales factors.

5 Regional considerations

Consumer energy prices in France are uniform throughout the country, so that heating equipment choice is not dictated by regional location where economics are concerned. The uniqueness of the situation in France lies more within the link between the air conditioner and the heat pump markets. This presents a situation in which most of the homes equipped with heat pumps lie within warm climatic zones. As a direct consequence of the geographic location, heating requirements are relatively small, and small heat pumps are sufficient to meet heating needs. Information from the EDF survey is again used to illustrate this section.

Table 7 presents a division of the reversible heat pump market, according to the selected regions, for 1995. The following can be observed.

1. The Mediterranean region has the highest proportion of reversible equipment.
2. The share of mid-range capacity equipment is almost uniform throughout France.
3. Small-capacity equipment dominates the market, with high shares in the Mediterranean region (47%).

Table 8 shows the market shares for reversible heat pumps according to the different modes for supplying heat, per region. The market shares for heat pumps that meet the entire heating requirement indicate that nationwide, only around half the reversible equipment (or only 20% of the air conditioners) meets all the heating requirements. Please note that this includes heat pumps equipped with electrical resistance. In the Mediterranean region, 67% of the reversible heat pumps meet all the heating requirements (with or without electrical resistance).

Table FR 7: Division of reversible heat pump market according to capacity and reversibility, 1995[1].

Region	Capacity Less than 6 kW (%)	6-11 kW (%)	12-40 kW (%)	Market share (%)
Ile de France	53	32	16	35
East	61	35	4	27
Rhone-Alpes	63	29	8	25
Mediterranean	81	17	2	47
Southwest	57	33	10	36
Northwest-centre	55	34	10	35

1 Includes heat pumps with electrical resistance. Note: average percent share of reversible units = 37; total number of split units sold in 1995 = 122,800; national average split-type market share = 70%.

Table FR 8: Market shares in various regions and according to heating method, 1995.

Region	Percentage of share supplying entire heating		Back-up heating method of reversible A/C units		
	All reversible type A/C units	All A/C types	No electrical back-up component	Electrical back-up only	Both electric and fossil-fuel back-up
Ile de France	39	14	45	11	44
East	29	8	63	6	31
Rhone-Alpes	35	9	58	10	32
Mediterranean	67	31	84	9	7
Southeast	42	15	56	22	22
Northeast-centre	56	20	49	23	28
National	53	20	66	13	21

The heating method for reversible heat pumps indicates that, for the Mediterranean region, 84% do not require an electrical component. Nationwide, 66% of the heat pumps are not equipped with electrical resistance. It should also be pointed out that 76% of all new housing air-conditioning equipment was installed in the Mediterranean region. The installation rate in existing housing (apartment buildings and detached houses) was also high (71%).

Table 9 shows the type of heating equipment replaced by heat pumps (retrofitting). Nationwide, heat pump installation replaces electrical heating in 70% of the cases, the highest figures being observed for the Mediterranean and Southeast regions.

6 Economic considerations

6.1 Energy costs to the consumer

The main barriers to the dissemination of heat pumps are cost and inability to meet all the home energy requirements.

It has been pointed out that energy cost ratios based on electricity are around 3.5 for natural gas and oil. However, in evaluating alternatives, consumers are more concerned about the final heating energy bill, so system efficiency is of utmost importance. Other factors influencing heating energy costs for the end-user are applicable subscription rates, servicing fees, equipment rental (if any) or deposits (e.g. for LPG tanks), etc.

Table FR 9: Share of heat pumps for retrofit, 1995.

Region	Share of substituted heating equipment (%)		
	None (new housing)	Electrical heating	Other
Ile de France	28	62	10
East	41	51	8
Rhone-Alpes	14	70	16
Mediterranean	13	77	10
Southeast	14	76	10
Northeast-centre	9	49	42
National	15	70	15
Number of units	5,200	24,500	5,200

To promote heat pump installations, dealers often compare the various alternatives. A Lyon-based company (THERMATEC) calculates values for a 100 m^2 home located in Lyon (see Table 10). Although electricity costs around three times as much as natural gas or LPG (see Table 1), the final consumer bill does not reflect this. The THERMATEC calculations assume a 65% efficiency for fossil fuel heating systems, which explains the (relatively) favourable rates for electricity when compared to fossil fuels.

Table FR 10: Heating systems annual cost of a 100 m^2 home (USD 1 = FFR 6).

Energy	Electricity	Natural gas	Propane	Oil	Proposed heat pump system
Cost per year (USD)	1,420	820	1,230	720	370

Annual costs include subscription and servicing fees plus energy costs, but exclude equipment depreciation.

The system proposed by THERMATEC (7 kW) consists of a heat pump to heat water (used for floor heating) and uses a ground-based evaporator. The assumed average COP value is 3.2.

This system (including installation) costs around USD 10,000, which yields a payback period of about 10 years (if replacing an existing electric heating system), even with this high COP value. Payback periods would be much longer with natural gas and oil.

As an indication, the average cost of an air-to-air 6 kW heat pump is around USD 3,300 and approximately USD 2,200 for a 3 kW unit, including installation. Expected COP in heating mode is around 2.

Costs for water-to-air systems are higher. An air-cooled reversible chiller (10 kW heating capacity) with six fan-coil units would cost around USD 8,600, including installation; the advantage is that it also provides cooling (8.5 kW cooling capacity).

In comparison, a complete natural gas-based system (25 kW boiler and water radiators) providing full heating and hot water production can be obtained for approximately USD 4,000, including installation. An equivalent electric system based on convectors would cost around USD 700.

6.2 Building factors

In France, the structure of the domestic heating sector is dominated by central heating. This includes genuine centralised systems (e.g. using water), but also the so-called integrated electrical heating for new housing. In 1993, 83% of main homes were equipped with central heating. It is estimated that the housing saturation level for central heating systems will reach 90% in the year 2000. This important share will certainly hinder single-room applications of heat pumps.

6.3 Promotion programmes

EDF's objective is a 'more rational use of energy'. This uses the synergetic effects of the capabilities of reversible equipment to provide cooling as well as heating to promote marketing. EDF sponsors nationwide promotion programmes, one of which (Vivrelec Four Seasons) targets electrically heated new housing (estimated to be 140,000 homes each year). The objective is to achieve a 15% share of the market. Reversible equipment with a 12 kW maximum capacity is one of the leading heat pump products.

7 Environmental considerations

7.1 Emissions

Nuclear power's overwhelming share of the total electrical energy supply has important consequences for carbon dioxide emissions from energy generation. Although average global CO_2 emission values are around 0.5 to 0.6 kg CO_2 per kWh of electricity produced, this value in France is approximately 0.2. A report on the energy situation published by ADEME, gives an average annual emission rate of 1,900 kg CO_2 per inhabitant (1991) in France [4]; values for other developed countries range from 5,400 kg (USA) to 2,000 kg (Italy).

The CO_2 emission rate could nevertheless be used as a promotion argument in favour of heat pumps, particularly for equipment installation or replacement in areas where fossil fuels are predominantly used for heating purposes.

7.2 Regulations

There is currently no particular regulation applicable to single-room heat pump applications in France. More general regulations apply to air-conditioning equipment (e.g. working fluids), and France follows European directives. The new national regulation on noise control has been enforced since the beginning of 1997, but imposes noise limits only on equipment delivered with housing ('fixed' equipment); they do not apply to equipment installed after construction. Regulation enforcement is gradual, and the intended severe noise-level restriction (30 dB acoustic pressure in bedrooms) is not applicable until 1999. Another regulation relates to the noise emitted by the outdoor unit, and aims at limiting the extra noise generated by any outdoor equipment (limits are 5 dB for daytime and 3 dB for night-time).

8 The commercial sector

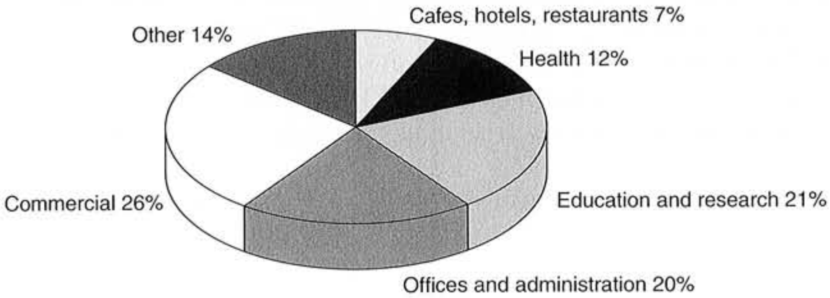
The commercial sector requires heating of a total surface area of 652 million square meters, which represents about 25% of the total surface area, on a national basis (including residential, industrial, and agricultural buildings). In 1991 space heating accounted for 36% of the energy requirements in the commercial sector versus 61% in 1973 [1]. These figures confirm that there has been an improvement in insulation and heating systems.

The commercial sector offers great opportunities for single-room heat pumps (Figure 22). Targets could be not only hotels, cafes, and restaurants (HCR), which account for only 7%, but also educational and commercial buildings, which together account for 47% of the total commercial heated surface area. Furthermore, a study of the typical consumption ratios for each type of activity reveals large differences. For an average consumption rate of 35 kg of oil equivalent in heating value (keo)/m^2/yr for the entire commercial sector (1 keo 4.5 kWh), the HCR branch consumes 55 keo/m^2/yr against 18 keo/m^2/yr for educational buildings [3]. Therefore, the high HCR consumption rate could be a convincing promotion argument for using heat pumps.

9 Research and development

There is currently no research or promotion programme on a national scale in France. Development programmes are being conducted and sponsored by EDF in efforts to improve the COP for low ambient temperatures. Particular emphasis is placed on frosting/defrosting cyclic operations and optimising outdoor coils.

Figure FR 22: Commercial sector heated surfaces.



10 Conclusions

The heating market in France is dominated equally by natural gas and electricity, which provide 66% of the energy requirements, and, to a smaller extent, by oil, in isolated detached housing. The heat pump market is small, and grows mainly within the air-conditioning market. Geographic location plays an important role, and heat pumps find a niche in warm areas (southern France). Low annual heating requirements are further incentives in this coastal area, because no extra heating is needed.

In addition to climate, barriers to the dissemination of single-room heat pumps can be summarised as follows:
- bad past experience;
- low prices for oil and natural gas;
- high equipment costs;
- low efficiency in cold areas, not justifying the investment;
- lack of awareness by the customer;
- lack of information and insufficient promotion;
- inability to meet required heating capacity without supplemental equipment.

Many of these barriers can be overcome. Research and development will certainly enhance system efficiency and render the product more attractive. Initial costs can be reduced only through the 'scale factor', which means increased sales. An important requirement is to increase customer awareness and confidence through better and more effective information.

Almost half the new detached housing is electrically heated, in spite of the potential energy savings offered by heat pumps. For this particular sector, building contractors and air-conditioning equipment dealers and installers are closer to the end-user and can provide information on all alternative heating solutions. Specific education campaigns targeting customers will certainly be a key factor in market growth.

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Heat Pump Systems for Single-room Applications in Sweden

Annex 23

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IEA OECD heat pump programme

Summary

This report defines the Swedish market for single-room heat pumps that can heat (and possibly cool) rooms in buildings not equipped with a ducted central system. The number of houses with electric baseboard heaters is presented and tabulated according to heating season severity. Details are given of currently marketed heat pumps suitable for both single-room and cold-climate application, as well as units being developed. Particular emphasis is placed on heat pumps that perform efficiently in cold weather. Technologies and equipment used to space-condition single rooms are listed. Current research and promising alternatives are discussed. Recommendations are made on technical and market-related issues to help market growth. Local fuel availability and fuel cost ratios dictate, to a great extent, the market for single-room heat pumps. Therefore fuel costs are also listed.

Keywords: electric demand reduction, electric resistance baseboard heaters, energy reduction, residential and commercial single-room space heating, single-room heat pumps

1 Introduction

Owing to favourable electricity rates and well-insulated houses, electric heating has gained a substantial share of the Nordic market for heating systems in single-family houses. In Sweden alone, with a population of 8.5 million people, around 1.2 million houses use electric heating. Approximately half a million of these houses use electric resistance baseboard heaters; consequently there is a lack of traditional heat distribution systems. The Swedish annual electricity use for residential heating purposes amounts to 20-25 TWh, with peak loads of 5-10 GW.

Heat pumps for single-room applications could provide the difficult-to-retrofit market of electric baseboard heated houses with a viable, cost-effective space-heating alternative. Such products with heating and cooling applications would also prove useful in commercial office buildings. For homeowners, room-size heat pumps can reduce heating costs by as much as 60% and offer an environmentally superior system compared to conventional forms of space heating. For utilities, heat pumps for single-room applications increase revenues and reduce the overall global warming effect attributed to electricity generation and fossil-fired heating systems.

However, a number of important obstacles hinder the fast growth of the single-room heat pump market in Sweden. As with many central air-source heat pumps, existing heat pumps for single rooms have limited cold weather performance. The outside air-source heat pump cannot reduce the high peak loads during cold periods. There are also concerns about reliability of the air-to-air heat pump functioning in severe climate conditions. In addition, the electricity rates are still too low to make the usually expensive heat pump application attractive in an electric baseboard-heated house.

2 The market

From the mid-1970s to mid-1980s heat pump technology went through a boom phase in Sweden. Market growth was strong for many different types of heat pump applications, from small 1 kW units to 30 MW district heating heat pumps. Over a 10-year period, from 1975 to 1985, the average market growth was 25,000 units per year.

It is estimated that there are currently over 290,000 heat pumps registered in the Swedish residential sector. Approximately 90,000 of these are liquid/water heat pumps, 20,000 air/water heat pumps (mostly fitted in houses with central hydronic heating systems), 90,000 exhaust-air heat pumps in houses built after 1980 with exhaust-air ventilation systems, and finally 90,000 air/air heat pumps, mostly in houses with electric baseboard heating (see Table 1).

Table SE 1: Number of different kinds of heat pumps used in Sweden.

Heat pump categorised by heat source and heat sink	Units in use (n = 290,000)
Liquid/water	90,000
Exhaust air	90,000
Outside air/air	90,000
Outside air/water	20,000

These relatively high numbers can be explained in different ways; all however, in some way or other, depend on the financial benefits of the heat pump compared with other heating systems. Energy costs in Sweden have been high enough to motivate investment in heat pumps, at least in retrofit situations. Also the energy-to-cost ratio between the two dominating heating systems, oil and electricity is, and has traditionally been, approximately 0.5:1, which makes heat pumps an economically attractive alternative in houses with central hydronic heating systems using either oil or electricity. The higher investment cost for the heat pump system, usually 1.5 to 3 times the cost of an oil or electric boiler, will be recovered in 2-5 years because of the substantially lower heating costs. In the mid-1980s a period of substantial government subsidies for investing in heat pumps resulted in increased sales. The sudden drop in sales to a very low level coincided with the ending of these subsidies and the drop in oil prices.

A new building code requiring better ventilation in new buildings created a market for exhaust-air heat pumps to keep down the increased heating costs that accompany increased ventilation. This market depends on construction activities in general, which currently are slow. In recent years there has been increased use of single-room air-to-air heat pumps, mostly imported from Japan and the USA. As a result of international competition, sales of small ground-source heat pumps have increased substantially (1995: 3,000 units, 1997: 14,000 units). Owing to the number of direct baseboard heating systems in the residential sector, the potential market for the single-room application is large. Since the mid-1970s, total sales of electric resistance baseboard heaters for detached houses, offices, and summer houses has exceeded 20 million units (see Table 2).

Table SE 2: Potential market for electric baseboard heating in Sweden.

Type	Number of baseboard heating systems	Annual heating consumption (TWh)
Detached houses	532,000	8.5
Offices	200,000	2.0
Summer houses	300,000	0.9

Hotels also represent a potential market for single-room heat pumps for heating and cooling. However, hotels in Sweden do not have electric heating systems and the need to cool is fairly limited, due to the maritime climate conditions. Consequently this is not a feasible market for single-room heat pumps.

Most of the ground-source and exhaust-air heat pumps marketed in Sweden are also manufactured there. There are around 30 small and medium-sized companies specialising in heat pump manufacture and import. Over the past 3-4 years total annual sales have been low, at approximately 10,000 units per year. However, due to a general upward trend in the national market, combined with government activities (information, heat pump competition), the market is now rapidly increasing. Table 4 illustrates the sales figures for 1994-97, with estimates for 1998.

Table SE 3: Heat pump sales in Sweden 1994-97 and 1998 (estimated).

Heat source	Sales (number of units)
1994	**10,300**
Outside air	3,800
Exhaust air	3,700
Liquid	2,800
1995	**9,000**
Outside air	3,100
Exhaust air	3,100
Liquid	2,800
1996	**14,200**
Outside air	3,000
Exhaust air	4,000
Liquid	7,200
1997	**20,000**
Outside air	4,000
Exhaust air	3,000
Liquid	13,000
1998	**25,000**
Outside air	4,000
Exhaust air	6,000
Liquid	15,000

Market conditions vary according to energy prices. There are approximately 230 electricity suppliers in Sweden working in a deregulated market with varying rates for both electricity and distribution. The tariff variations (combinations of fixed rates, rates per used kilowatt hour, and different kinds of tariffs) are so complex that it is not possible to tabulate and explain them all in this report. Two extreme rates and an average rate are presented in Table 4 to illustrate the electricity price for an average electric-heated house with an annual energy consumption of 20,000 kWh.

Table SE 4: Residential energy prices 1996: USD cents per kilowatt hour.

	Low	Average	High
Electricity	9	12.1	14.4
Oil	7.9	10.3	12.6
Energy price ratio: electricity to Oil	0.85	0.88	0.86

3 Regional, economic, and environmental considerations

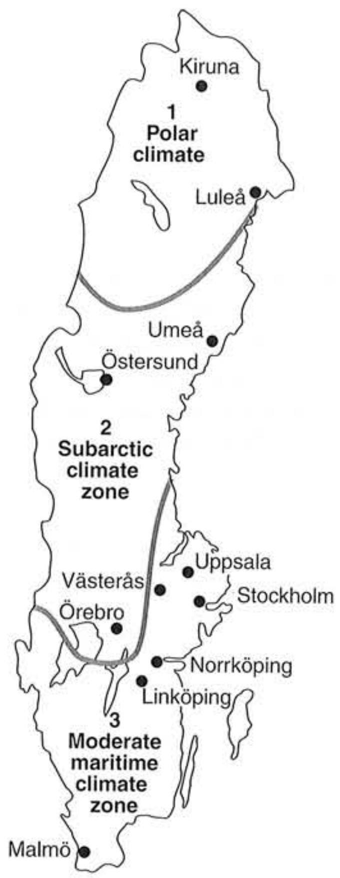
The expected simple payback period for a given alternative varies from region to region and from home to home. Both regional climate and fuel costs affect payback, as do installed costs. Installed costs and installation quality vary significantly from one installer to another, and vary regionally according to the availability and popularity of the heating option. The choice of heating options also involves national and environmental considerations that tend to have quite a strong influence on the market. The heat pump is an attractive option to customers looking for an environmentally friendly heating system using mostly renewable and locally produced energy.

3.1 Climate

Climatic conditions in Sweden can vary widely. Using these climatic regions, the country can be divided into three major zones:

1. **Polar climate**, in the northern parts of the country;
2. **Subarctic climate**, in the central regions;
3. **Moderate maritime climate**, in the southern areas.

The vast majority of the population lives in the subarctic and moderate maritime climate zones (see map).



The average temperatures in some of the major cities are shown in Table 5. Degree-days for each region are shown in Table 6.

Table SE 5: Average temperatures in major cities across Sweden.

City	Average temperature (°C)
Kiruna	-1.2
Östersund	2.7
Uppsala	5.7
Stockholm	6.6
Gothenburg	7.9
Malmö	8.0

Table SE 6: Heating degree-days by region.

	Southern regions	Central regions	Northern regions
Heating degree-days (20°C base)	3,750	5.833	7,083

3.2 Energy supply in Sweden

The total annual energy consumption in Sweden is approximately 430 TWh. Energy production is divided as follows:

- 44% fossil fuel;
- 18% hydronic power;
- 16% renewable fuel plants (wood etc.);
- 14% nuclear power;
- 6% coal plants;
- 2% gas.

The total energy consumed (production minus losses and export) is approximately 360 TWh per year. This end-use is split into:

- 39% fossil-fuel consumption;
- 32% electricity;
- 15% renewable fuels;
- 10% district heat;
- 4% coal.

Forty-one percent of the energy is used in the residential and service sectors, 36% in industry, and 23% for transport.

The electricity production mix is 41% nuclear power, 42% hydronic power, 11% fossil power plants and 6% biomass cogeneration.

3.3 Cost factors

One of the main barriers to selling a heat pump for heating-only purposes is the additional cost of the equipment. In Sweden, heat pump systems can cost 1.5 to 3 times as much as an oil burner of the same capacity, and the price difference with electric resistance heating is even greater.

In terms of energy value, the electricity consumed by a heat pump is typically about one-sixth to one-third of that used by fossil fuel equipment. The high oil price (due to high tax policy on fossil fuels, the electricity/oil ratios are between 0.7 to 1.8, in Sweden, 1998) combined with inexpensive electricity is favourable to the heat pump (see Table 6). On the other hand, the traditionally low cost of electricity in Sweden has also made resistance heating attractive, with its low investment cost compared with other heating systems. Electricity prices are still too low and the heat pump too expensive for heat pumps to financially outclass the resistance baseboard heater. At current investment costs and electricity prices a normal payback period for a heat pump in homes with baseboard heating is around 8-10 years.

3.4 Building factors

Heat distribution systems are another factor influencing heat pump markets. The traditional distribution system in Sweden is low-temperature hydronic (wet) heating systems, well-suited for heat pumps and district heat. Underfloor or forced-air heating systems together with heat pumps are currently common for new buildings.

3.5 Environmental factors

The heat pump is recognised as a key technology for reducing CO_2 emissions. The reduction of CO_2 depends mainly on the electricity mix, the efficiency of the heat pump and on the heating system the heat pump is replacing. When a heat pump is used instead of an oil burner, CO_2 emissions are reduced by nearly 100%.

A political decision in Sweden to phase out HCFCs (sales of equipment containing HCFCs, mainly R-22, are to be discontinued in 1998, and all sales of HCFCs are prohibited after the year 2002) has led to the use of non-chlorine refrigerants (e.g. R-407C, R-404C). This might even improve the status of the heat pump as an environmentally sound heating system and thus help the market to grow.

4 Technologies

Heat pump technologies for domestic heating can be divided into four main categories:

- ground-source heat pumps;
- outside air-to-air heat pumps;
- exhaust-air heat pumps;
- outside air to water heat pumps.

The air-to-air heat pump and the small ground-source heat pump are suitable for single-room applications.

4.1 Air-source room heat pump technology in Sweden

The air-to-air heat pumps marketed in Sweden are mainly imported from Japan and the Far East or from the USA. The air-source ductless heat pumps (DHP) are mostly minisplit aggregates for both cooling and heating with either a variable- or single-speed compressor. The advantages of the DHP technology is its easy installation, low price and (possibly) the cooling option. Prices, including installation, vary from USD 2,150 to USD 5,700. A low installed price, together with an energy saving of 35-40% of the heat demand, can often give the DHP a reasonable payback period. However, a number of disadvantages, namely poor cold weather performance, unreliable defrosting mechanism and poor durability, must also be recognised.

First developed for the Japanese market, ductless heat pumps have become more popular in recent years. Sweden has developed a market of over 90,000 units, which is increasing at around 3,000-4,000 units per year.

Characterised by quiet room-sized indoor fan-coil units with many control features, these systems are often mounted on the wall for zone heating and cooling. Indoor units are sized from 2.1 to 5.8 kW. The most common wall-mounted indoor units can be installed easily on an exterior wall, with wiring, piping and condensate lines passing through a small hole to the outside. Indoor units are also available in console-, vertical-, and ceiling-mounted versions. A single outdoor cabinet can handle one to five indoor units with either multiple compressors or a single variable-speed compressor.

Since most installations provide space conditioning to only the main living areas of a home, recent work has focused on the interzonal heating effects of DHPs. Researchers found that a correctly sized indoor unit could provide almost all the heat required for an adjoining zone, where the temperature was 2°C below the DHP zone setpoint.

Ductless heat pumps offer an electric space-heating option which provides a great deal of flexibility and a lack of disruption to the interior of the home. Advantages to the customer include zoning, cooling, air filtering, sophisticated setback and fan-speed controls, and other desirable amenities not found on even sophisticated central systems (electrostatic filters, cordless remote control). Ductless heat pumps would be very competitive for customers who require cooling, and where ducting would be difficult to install. They are most effective in homes with large open areas.

There are, however, a number of barriers to increased use of DHPs in Sweden. The costs of DHPs are often higher per saved kWh than central heat pumps, partly due to the novelty of these systems. Increased competition from domestic manufacturers should help bring costs down. Some wall space is taken up by the indoor unit and care must be taken to locate the unit to minimise warm and cold air layers. Since an indoor unit could not be provided for every room in a house, not all the heating load could be displaced with these machines. Energy and demand savings may therefore not be as great as with central systems of comparable efficiency. Most DHPs provide only a limited amount of backup resistance heating. Electric baseboard heaters would provide backup heat, but should be upgraded with better thermostats to avoid conflicting with the DHP thermostat. Piping and wiring run along the outside walls of the house may be aesthetically unacceptable to some customers. Consideration must be given to noise reduction and adequate sealing of the window penetration.

The greatest barrier to DHPs in Sweden is their limited energy savings in cold weather (less than ducted units). Test results for a variety of DHPs show the coefficient of performance (COP) approaches unity at around -15°C. Today's ducted ASHPs have improved controls, larger outdoor coils, better compressors, and better cold weather performance. Different kinds of ground-source heat pumps (GSHPs), avoiding the cold weather limitations of ASHPs, are also available on the Swedish market. To date, only a limited amount of work has been done to improve the cold/warm weather performance of DHPs. The operation of many DHPs is restricted to temperatures above -10°C. As with central ASHPs, defrosting systems can defrost unnecessarily and be unreliable.

The Swedish government's decision to phase out HCFCs has led to a sudden drop in sales of DHPs using R-22. A number of alternative refrigerants are used to replace R-22, usually R-407C. New production lines for small units using R-410A were introduced early in 1998.

Research and development initiatives should focus on alternatives to HCFC refrigerants, reducing costs and improving cold/warm weather performance. Reduced costs will come through greater competition from domestic manufacturers. Cooperative efforts between various utilities and industry allies (e.g. Sweden, American utilities, Electric Power Research Institute (EPRI), and the IEA) could offer enough of a market incentive to ensure that manufacturers improve cold/warm weather performance and defrost control.

4.2 Small ground-source heat pumps

The use of fan-coil units commonly associated with DHPs presents opportunities for use with low-temperature heat sources such as hydronic heat pumps. For example, a single hydronic heat pump can be coupled to one or more fan coils via a piping loop. This system provides most of a home's heating, with backup heating provided by existing baseboard heaters. The indoor fan-coil units provide the same advantages as DHPs (e.g. quietness, controllability, ease of installation). This system requires only one single-speed heat pump unit, unlike multisplit DHPs, which require either a variable-speed compressor or a compressor for each indoor unit. A minisplit hydronic heat pump using fan coils has an installed cost which starts at around USD 5,150 (3.2 kW heating capacity) and requires no separate boiler for backup heating.

The advantages of the ground-source heat pump, compared with the DHP, are its superior cold weather performance and the larger energy savings (50-70% reduction of heating demand).

5 Research and development

5.1 Recent developments

A major part of the Swedish government- and power utility-funded research on heat pumps has been oriented toward applications using ground and water heat sources. Unlike air-source heat pumps, these heat pump applications give the possibility to diminish the peak power demand during cold periods. Practically no research has been done on single-room heat pump applications in Sweden.

In May 1995, two Swedish companies won competitions against competitors from Denmark, Finland, Norway, and Sweden. The heat pumps that won the competition were heating-only ground-coupled systems for residential applications. The 3.9 kW heating capacity heat pump unit, designed by IVT Energy AB (Tranås, Sweden), is a ground-source unit intended either for homes using oil or electric backup heating, or for homes without a heat distribution system using fan coils. The other winning design, by Eufor AB (Härnösand, Sweden), was a single-room unit with 3.4 kW heating capacity for use in homes without a heat distribution system, such as those using baseboard resistance heating. The unit is designed for use with direct-evaporation ground coupling and can be complemented by a small hydronic heat distribution system. Both units are for heating purposes only.

Since the competition Eufor has developed a smaller simplified version of the Markus heat pump concept (called Markus 2200) with a heating capacity of 2.2 kW and a somewhat shorter ground coil.

5.2 Current research

A three-year research programme involving industry and most technical universities in Sweden was initiated in 1994 by NUTEK, and focused on the development of new alternatives to CFCs and HCFCs.

A number of research projects are led by technical universities together with heat pump manufacturers, and involve the system design and development of heat pump components. An example of this is the successful collaboration between the University of Härnösand and Eufor.

Isolated studies have been carried out on problems of cold weather performance, and on frosting and defrosting issues.

The main universities and institutions for heat pump research are Chalmers Technological University in Gothenburg, The Royal University of Technology in Stockholm, The Swedish National Testing and Research Institute, and Lund Technological University.

6 Conclusions

The Swedish market for heat pumps for single-room applications has shown a steady growth since 1995. This trend will continue, as a large number of homeowners in electric baseboard-heated houses will be searching for possible ways to save energy as the energy price increases. The prerequisites for market growth are mainly economic, depending on energy prices and the investment cost of the heat pump, but other considerations such as environmental issues can also play an important role. To ensure continuous market growth, the price of heat pumps for single-room applications must be reduced. For DHPs, the problems of poor cold climate and defrosting performance should be solved.

Heat Pump Systems for Single-room Applications in Switzerland

Annex 23

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IEA
OECD
heat pump programme

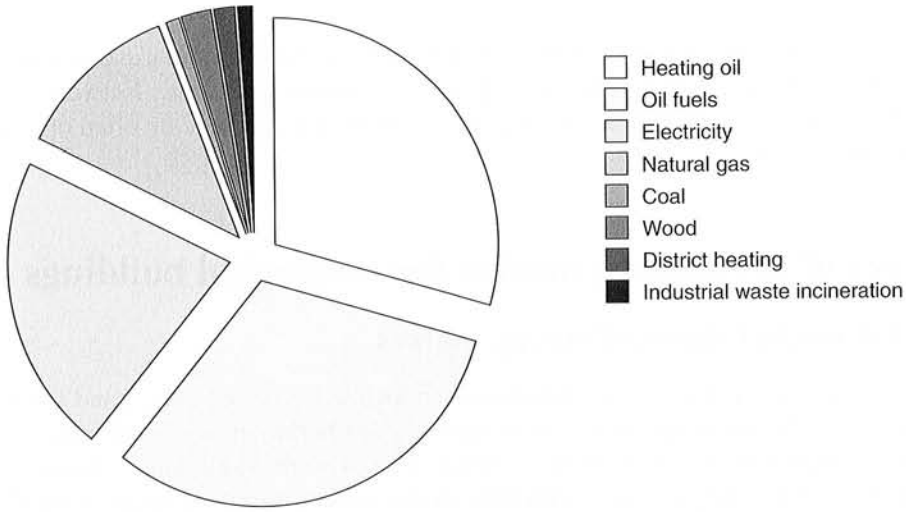
1 Introduction

This report presents the most important market factors for single-room heat pumps in Switzerland. Most of the fundamental data in this report was drawn from an extensive market survey carried out in 1992 and is based on the 1990 status unless otherwise indicated. Some of the information has been updated using information from a variety of sources wherever this has proved possible at reasonable cost. A survey of 22 electrical utilities was carried out to obtain additional information. An exchange rate of USD 1 = CHF 1.20 was used in indicating costs.

2 Energy supply in Switzerland

Energy consumption in Switzerland shows a clear bias towards oil products, which cover around 61% of the energy consumption (see Figure 1).

Figure CH 1: Structure of energy consumption in Switzerland.



Switzerland is organised on a small-scale federal basis, and energy supply is no exception. Around 1,100 electrical utilities exist, most of which are state owned. Their capacities range from an annual electricity output of 3,000,000 MWh down to small-scale rural electrical utilities with an output of 100 MWh [1]. Consequently, a strict comparison of energy costs does not permit a direct comparison of economic efficiency. To do this we must include the investment costs for the various heating systems. Since local competition determines the prices of energy sources, the respective economic efficiency rates must be estimated on a local basis.

In cities, various energy sources are often distributed by the same state-run structures. In Zürich, for example, this includes district heat from waste combustion, gas supplies, and electrical utilities. In some areas compulsory connections may apply, i. e. a specified energy source must be used.

3 Energy policy

In Switzerland, the use of energy resources for private households is regulated through the Energy Article, the Decree on Energy Use, and the Ordinance on Energy Use, plus the Energy 2000 Action Programme. The principal objectives of the Energy 2000 Action Programme are to:

- stabilise the overall consumption of fossil fuels, and thus CO_2 emissions, at 1990 levels in the year 2000, and to reduce these levels thereafter;
- slow down the increase in electricity consumption and stabilise it from the year 2000 onwards;
- promote renewable energies, so that they can contribute an additional 0.5% to electricity production and 3% to heat generation in the year 2000;
- increase the capacities of both hydro power plants (+5%) and existing nuclear power plants (+10%).

In order to secure the future energy supply as well as provide the optimum use of resources, energy planning is carried out at cantonal, regional, and municipal levels. Network-based energy sources (i. e. gas, district heat) and the use of environmental heat are often officially stipulated in these plans.

4 Survey of the heating market for residential buildings

4.1 Current market shares of energy sources

In 1990 there were approximately 3,160,000 homes in Switzerland (see Figure 2 and Table 1). In 1994, 46,326 new buildings were constructed, 5,686 buildings were renovated, and 16,598 new residential homes were built, of which 10,714 were single-family houses. Oil was clearly the leading energy source with 68% of the market, followed by gas with 11%. In 1990, heat pumps heated only around 1.2% of Swiss homes. Wood and coal were still fairly widely used for heating residences, especially for holiday apartments and in rural areas. Although the use of coal has constantly declined, state programmes are promoting wood as a local and renewable energy source, and this has become more popular over the past few years. On the other hand, cleaner combustion technologies have significantly reduced emission levels (Table 2) [2–6].

Figure CH 2: Regional distribution of dwelling densities of all types of dwellings per square kilometre in Switzerland. (Status 1990, Swiss average: 77 dwellings per km²)

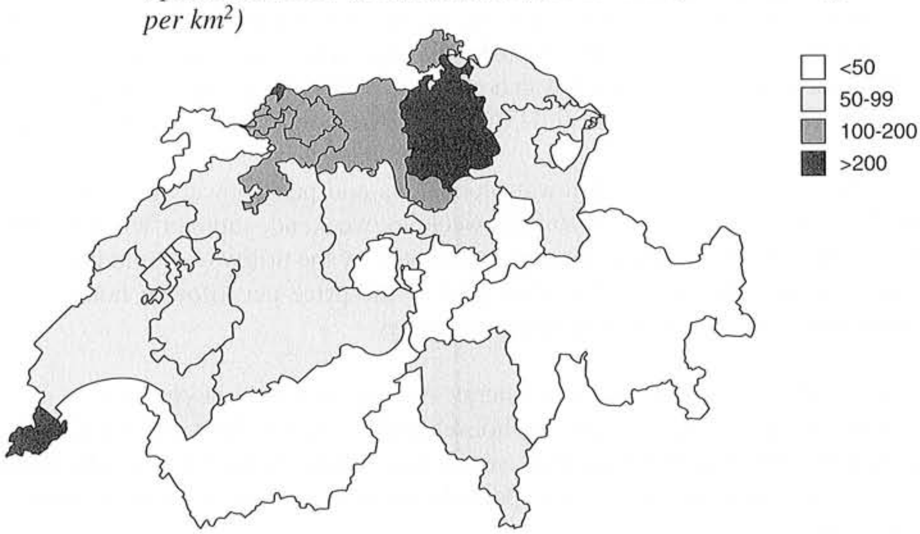


Table CH 1: Building statistics (1990) [2].

	Number n = 2,247,000	Energy reference area (million m²)[1]	Energy reference area (%)
Single-family houses	635,000	115	21
Apartment buildings	327,000	158	29
Mixed residential buildings	120,000	66	12
Service buildings	131,000	100	19
Industrial buildings	107,000	62	12
Agricultural buildings	546,000	34	6
Secondary buildings	381,000	2	0

1 Total in 1990 = 537, updated 1992 total = 555.

Table CH 2: Energy for space and hot water heating.

	Energy (GWh)	Energy reference area (million m²)[1]	Energy reference area (%)
Heating oil	67,000	396.4	74
Gas	19,500	36.4	7
Wood/Coal	7,400	61.8	12
Electricity	3,200	36.3	7
Others	1,800	5.3	1
Total	98,900	536.2	100

4.1.1 Price structure

Prices are mainly specified at a political level by the municipalities and cantons. Each electricity company has its own tariff structure. Average prices are therefore only a rough guide. In 1994 approximate costs per kilowatt hour of the main energy sources in the residential buildings sector were USD 0.027 for oil, USD 0.04 for gas, and USD 0.153 for electricity.

Tariffs are divided into categories: kilowatt hour rates and peak power rates. The former involves peak and off-peak tariffs (day/night, weekday/weekend, summer/winter) with the possibility that the electricity supply may be interrupted by the utility (e.g. midday), as well as certain special room-heating tariffs. The latter is the price per kilowatt hour for peak power consumption, such as electric resistance heating.

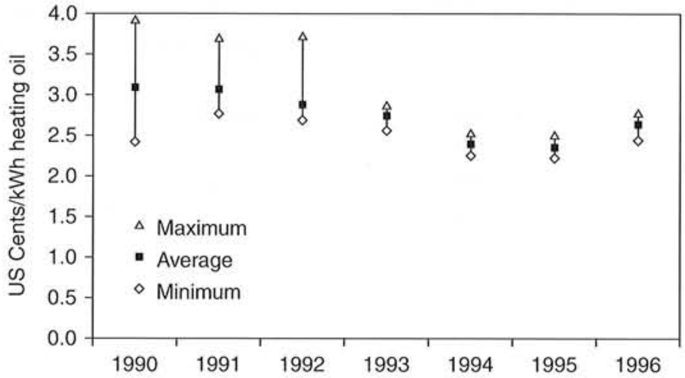
A comparison made by the International Energy Agency based on buying power showed that, compared to other countries, private households in Switzerland pay relatively low electricity charges, whereas the industrial sector pay relatively high rates. The planned liberalisation of the electricity market is expected to lead to increased electricity prices for private households [1, 7, 8].

The Swiss Oil Association publishes average monthly prices for extra light heating oil in the Zürich area. Figure 3 shows the trend in oil prices since 1990. Details of regional variations are not known. Rebates are fairly standard, though they vary considerably from one supplier to another [9]. The Swiss natural gas network is limited mainly to the central plateau region; in the mountain areas links to the network are very isolated.

A survey of the gas tariff structure (for heating purposes) carried out in 1995 included 11 gas utilities with 35% of the overall market. Tariff distribution includes:

- a one-off connection charge (very seldom);
- basic charges: on average, USD 63 per year (minimum: USD 0, maximum USD 163 per year);
- a supply rate (normally if no basic charge applies) in USD/kW; and
- a kilowatt hour rate (USD/kWh): average price, approximately USD 0.038/kWh (minimum: USD 0.031/kWh, maximum USD 0.052/kWh) for a supply of 2,500 kWh per month.

Figure CH 3: Monthly average prices for deliveries of 3,000 to 6,000 litres of heating oil in the Zurich area.



For a supply of 2,500 kWh per month, the total price is around USD 0.04/kWh. According to information provided by the gas industry, the heating oil price for the previous reference period is used as a reference when setting the new gas price [7].

4.2 Future trends and tendencies

Consumption forecasts produced as part of the assessment of Swiss energy perspectives indicate the following trends for private households [2].

1. The overall end-use energy consumption for single-room heating will remain more or less constant over the next few years, although the number of residences is increasing.

2. Market shares for oil and coal will decrease.

3. The market shares for gas will increase substantially, though electricity will increase only slightly, due to wide distribution of heat pumps. The market share for wood will increase.

A similar perspective was indicated by 22 electrical utilities which were asked about the heating market in their individual areas. They made the following conclusions.

1. Oil will continue to dominate, though its market share will tend to decline.

2. Gas will gain importance, except in the mountainous regions. The reasons given for this are its clean ecological image, powerful marketing, and low investment costs for owners of gas heating systems.

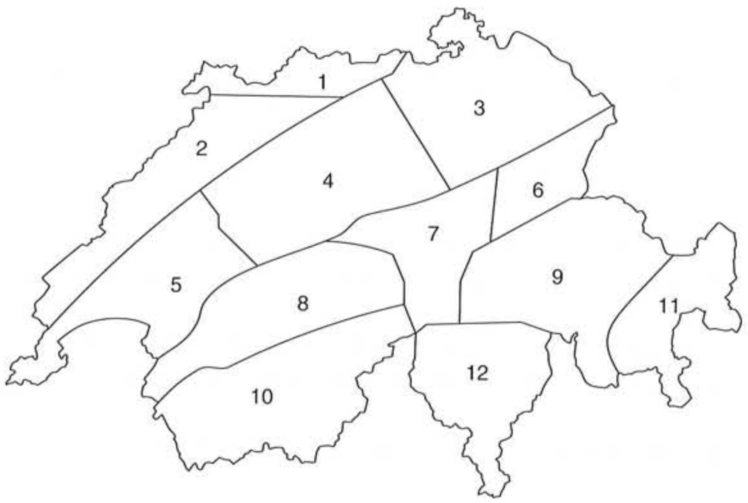
3. District heat is also gaining ground, since it is being promoted by the public authorities as a form of waste heat utilisation.

4. Central heat pumps are unanimously regarded as important heating systems. The reasons here include a positive ecological image, potential for combining with other energy sources (e.g. wood), and intensive promotion by the public authorities (e.g. the Energy 2000 Action Programme).

5 Climate

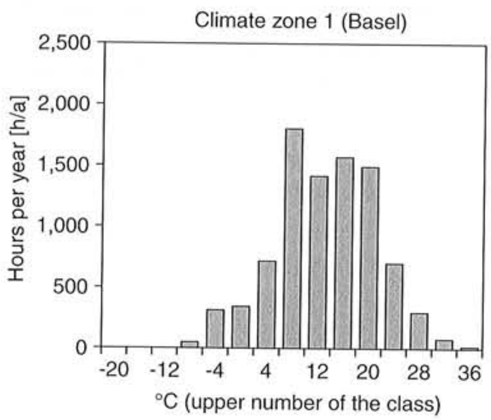
The Swiss Meteorological Office divides Switzerland into 12 climate zones, as shown in Figure 4.

Figure CH 4: Climate zones in Switzerland.

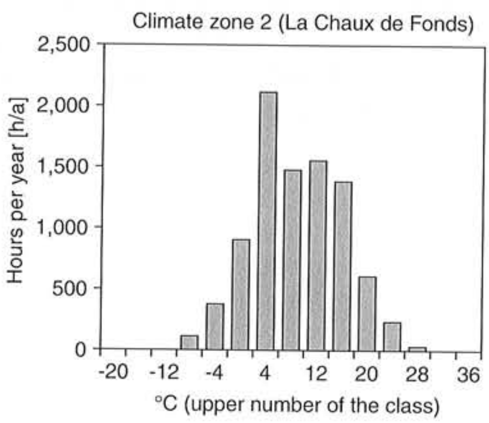


The graphs below show the frequency of the temperature averages in hours per year and the number of heating degree-days (12°C/20°C), as well as the corresponding height above sea level (a. s. l.), in metres.

Jura (climate zones 1 and 2)

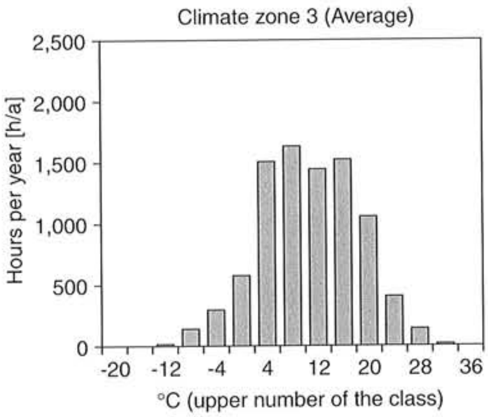


Heating degree-days: 2,778
Height a. s. l.: 270 m

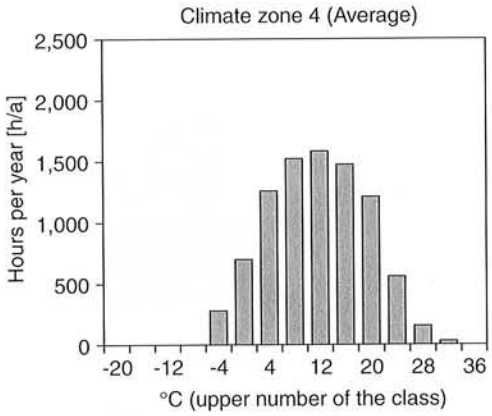


Heating degree-days: 4,332
Height a. s. l.: 994 m

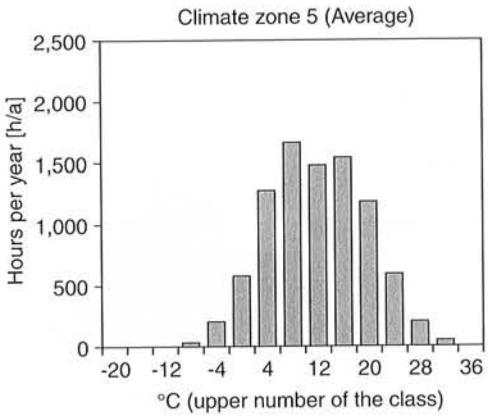
Central plateau (climate zones 3, 4, and 5)



Heating degree-days: 3,603
Height a. s. l.: 542 m

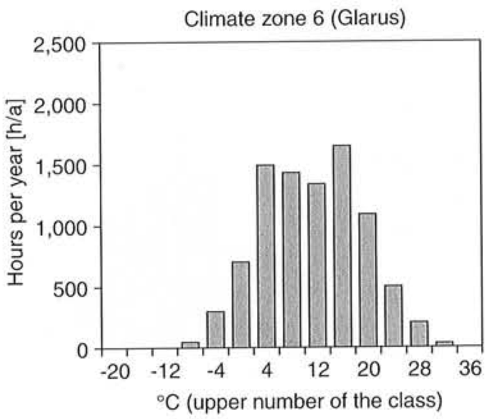


Heating degree-days: 3,300
Height a. s. l.: 488 m

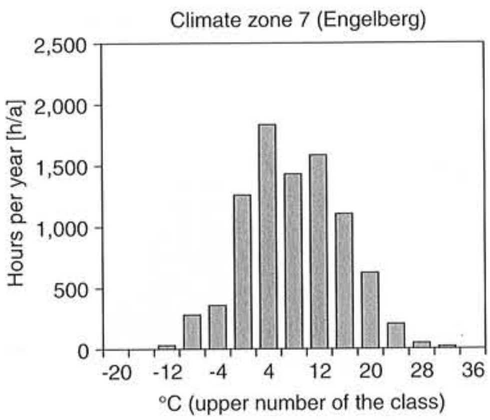


Heating degree-days: 3,212
Height a. s. l.: 424 m

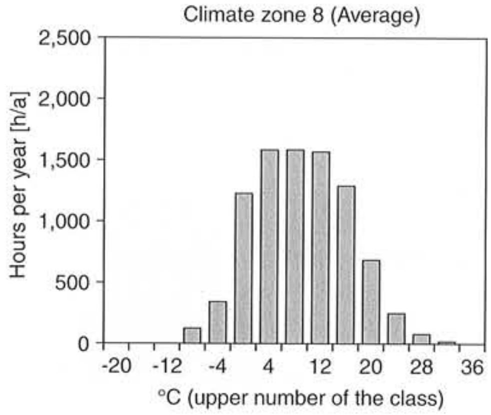
Alps 1: north side (climate zones 6, 7, and 8)



Heating degree-days: 3,410
Height a. s. l.: 478 m

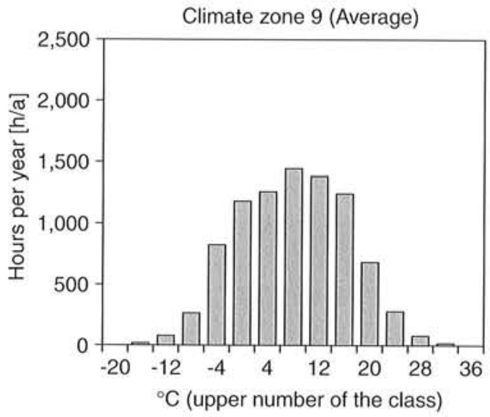


Heating degree-days: 4,625
Height a. s. l.: 1,020 m

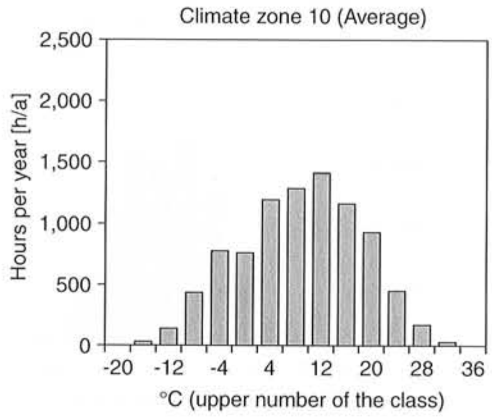


Heating degree-days: 4,281
Height a. s. l.: 960 m

Alps 2: northern and eastern Grisons, Valais (climate zones 9 and 10)

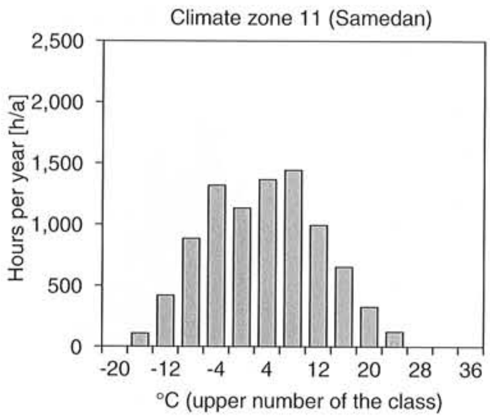


Heating degree-days: 4,680
Height a. s. l.: 1,073 m

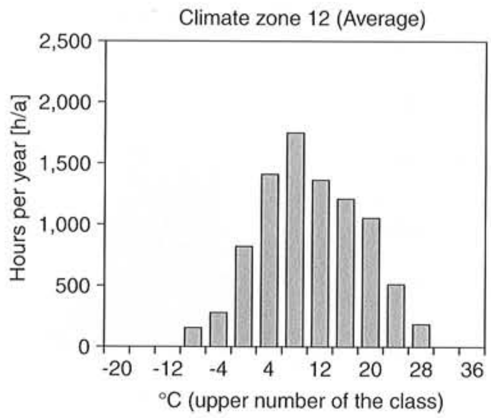


Heating degree-days: 4,387
Height a. s. l.: 932 m

Engadine (upper Alpine plateau) and southern Alps (climate zones 11 and 12)



Heating degree-days: 6,499
Height a. s. l.: 1,725 m



Heating degree-days: 3,749
Height a. s. l.: 724 m

6 The heat pump market in Switzerland

At the end of 1994, approximately 35,000 electric heat pumps with a capacity of more than 5 kW were installed in Switzerland. Of these, 91% were in private households, 5% in the agricultural sector, and 4% in the service sector. The average connection capacity for households is 6 kW, and the mean annual electricity consumption is 11.1 MWh. Thirty-one percent more heat pumps were sold in 1994 than in 1993. In the retrofitting sector, sales rose by as much as 68% in a year. In 1994, the number of heat pumps installed in private households rose by 4,000. This is linked to the fact that the utilisation of environmental heat using heat pumps is regarded as a renewable energy source in the government's Energy 2000 Action Programme.

An Association for the Promotion of Heat Pumps in Switzerland was also established within the framework of the Energy 2000 programme. This organisation includes representatives from the Federal Office of Energy, Energy 2000, the electricity industry, the cantons, heat pump manufacturers, and the installation industry. Its objective is to promote the distribution of heat pumps. A variety of measures carried out to date, such as "open house" events at the premises of heat pump owners, or the construction of an official heat pump testing centre, and award-of-quality seals for heat pumps, have led to an increase in sales [10,11].

7 Electric resistance heating in Switzerland

Table 3 shows the data for electric resistance heating in Switzerland in 1990.

Table CH 3: Resistance heating in Switzerland, 1990.

Connected capacity >5 kW		
Number of fixed electric heaters	229,400	
Total connected capacity	3,350	MW
Total electricity consumption	2,950	GWh/yr
Supplied energy reference area	36,300,000	m^2
Full load hours	875	h/yr
Average connected capacity	15	kW/system
Average electricity consumption	13	MWh/yr/system
Average supplied area	160	m^2/system
Average energy indicator	81	kWh/m^2/yr
Proportion of total national consumption	6%	
Connected capacity <5 kW		
Number of small heaters	1,370,000	
Total electricity consumption	260	GWh/yr
Average energy consumption	190	kWh/yr/system
Proportion of total national consumption	0.5%	

An analysis of the economic trend between 1974 and 1988 carried out by the Federal Institute of Technology in Zürich indicated that there is a significant correlation between the price of oil and the distribution of electric resistance heaters. In contrast, the price of electricity, ascertained from a survey of all electrical utilities, has no influence and was more or less constant during the period. Although the price of electricity is the most important influencing factor for an individual electricity company, for individual consumers it is not so much the price of electricity that is the deciding factor, but the difference between electricity and oil prices [5, 12-16].

7.1 Electric heating systems and building types

7.1.1 Heating systems

Electric heating systems used in Switzerland include the following types.

Central systems, which include 8% of all electric heating systems and utilise central water or magnesite storage units that are heated during off-peak periods. The heat is subsequently distributed to a heating unit located in the home.

Decentral systems, which are single-room heaters located in the rooms to be heated.

Storage heaters, which are loaded during off-peak periods wherever possible (mainly at night), to provide heat during the day. According to the Swiss Association of Electrical Utilities, at least 90% of the electricity consumption must take place during off-peak periods, primarily during the night.

Direct heaters, which are operated independent of peak and off-peak tariffs, i. e. the electricity is used at the time the heating is required.

Storage heaters with direct heating facilities, which combine the characteristics of both peak and off-peak heating systems. This includes floor heating.

The distribution of these heating systems is shown in Table 4.

Table CH 4: Distribution of electrical heating systems by type (1990).

Type of electric heating	Number of systems			
	Single-family houses	Apartment buildings	Other buildings	Total (%)
Central storage heaters	11,800	4,200	1,700	17,700 (8)
Decentral room storage heaters	21,600	12,700	3,600	37,900 (16)
Decentral storage heaters with ~20% direct heating	62,800	42,400	11,100	116,300 (51)
Decentral direct heaters[1]	15,700	8,500	2,600	26,800 (12)
Floor heaters[2]	23,600	4,200	2,900	30,700 (13)
Total, 1990	135,500	72,000	21,900	229,400 -100
Trend, 1990-95 [17]	+10%	-3%	-10%	+4%

1 Heating walls, convectors, etc.

2 Underfloor elements.

Electric storage heaters were promoted (particularly in the German-speaking area of Switzerland) to utilise the night-time surplus of electricity. Currently, however, the degree of night-time off-peak electricity consumption is sufficient for most electrical utilities, and most distribution networks are fully utilised on cold winter days. The promotion of electric resistance heaters by the electricity industry is therefore no longer necessary. From an energy policy point of view, electric heaters are disapproved of, which is why a permit is required for their installation. In the meantime electricity tariffs have risen so sharply that the operating costs of electric heaters are now up to five times higher than those of gas heaters.

Approximately 25% of all buildings heated with electricity are also equipped with wood heaters; in most cases, fireplaces, tiled stoves, and iron stoves. These provide extra heat when outside temperatures are very low or during seasonal transition periods [13, 17, 18].

7.1.2 Building types

The number of partially occupied or unoccupied houses amount to around 360,000, or (11%) of the approximately 3,160,000 homes in Switzerland. These are holiday apartments, secondary residences and otherwise unoccupied homes. Around 165,000 (46%) of the partially occupied homes are located in three cantons (Valais, Ticino, Grisons). Six percent of the permanently occupied residences and 15% of the partially occupied homes are heated with electricity, without heat pumps. This situation is similar for coal and wood.

This indicates that electricity and coal or wood are more commonly used as an energy source in partially occupied homes. Therefore, a considerable proportion of the replacement potential is likely to be found here. This needs to be taken into consideration when assessing the market [2].

7.1.3 Annual electricity consumption by type of heating system and region

The type of electric heating system installed depends largely on the procurement situation of the electricity companies, their network structure, and the resulting operational policy. In a 1993 study, four regions were formed based on the electrical utilities structure:

- conglomerates;
- mountain regions;
- remainder of the French-speaking area;
- remainder of the German-speaking area.

Annual consumption figures were indicated for these four regions as a percentage of the electric heater types. As no precise figures were available, it was not possible to produce details regarding definite consumption per region. The electricity consumption of combined heaters was divided into a proportion of direct energy and indirect storage energy (Figure 5).

Region 1: Conglomerates. Electrical utilities in cities frequently supply district heat and gas in addition to electricity. Electric resistance heaters have not been promoted.

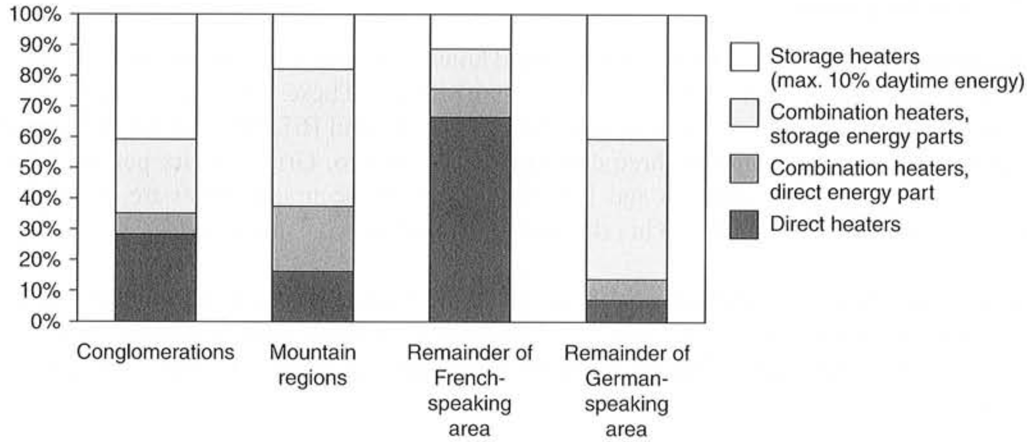
Region 2: Mountain regions. Electricity has a special significance in these areas because it is produced here, is plentiful, and is generated using hydropower (for ecological reasons). Gas and district heat play a subordinate role, owing to the topography of the area and low density of population. The proportion of holiday apartments and houses is above average for

Switzerland. Owing to the low investment costs, electric heaters offer an economic advantage for short periods of use.

Region 3: Remainder of the French-speaking area. Here the cultural and commercial influences from France play a major role. Electric heaters are not just stopgaps for surplus energy during the night, they are also a popular heating system for everyone. In the French-speaking region direct heating has been promoted, emphasising the low investments involved, and this has resulted in the rapid growth of these installations.

Region 4: Remainder of the German-speaking region. Here the development and significance roughly correspond to the national average [2,16,17].

Figure CH 5: Percentages of electricity consumption of electric heaters by type and region



7.1.4 Chronological development of sales

The sales figures for electric resistance heaters from 1970 to 1990 show some interesting trends. Since 1982, sales of electric heaters have been declining. Sales of single-room direct heaters have been falling far less rapidly, which is why they have increased proportionally in comparison to storage heaters. The reason for this is the high connection capacities of storage heaters. Many electrical utilities had to lower the power consumption of storage heaters in order to avoid night-time peaks in the network [16].

8 Factors that influence the market potential of single-room heat pumps

8.1 Factors relating to buildings and comfort

In 1990 the Decree on Energy Use was issued, which called for the efficient use of energy and the promotion of renewable resources. Among other things, a licence system was introduced for fixed resistance heaters, which may be approved only under certain rather restrictive conditions. This is not a prohibition as such, but together with higher tariffs it has led to a considerable drop in sales of electric resistance heaters. Most electric resistance heaters that have reached the end of their service life are replaced by other heating systems. The subsequent installation of hydronic distribution systems in such buildings would severely reduce the economic efficiency of oil, gas, or central heat pump systems. This represents a major opportunity for single-room heat pumps to improve their market share.

In general, single-room heat pumps only have a chance in situations where no hydronic heat distribution systems are installed or planned. In Switzerland, this is currently limited to the retrofitting of buildings with decentral electric heating systems (direct or storage heaters), and to those with single furnaces heated by wood or coal.

8.2 Compulsory secondary regulations

Standard SIA 181, "Noise Abatement in Buildings", specifies various threshold values for noise. (See specifications, section 7.4.)

In the amendment to the "Decree on Pollutants", dated 14 August 1991, fully halogenated hydrocarbons (fluorocarbons) were prohibited for new systems as of 1 January 1994.

8.3 Market requirements

A survey of 22 electrical utilities resulted in the following list of decisive factors for the distribution of single-room heat pumps.

1. Low investment costs.

2. Low noise levels in the room.

3. High degree of reliability.

4. Low operating costs.

When assessing the economic market potential of single-room heat pumps, investment costs appear to be more important than operating costs. Another consideration is that lower tariffs apply if the power supply to the heat pump or electric resistance heater can be interrupted by the electricity company. Other factors (in descending order of importance) include simple installation, user-friendliness and convenience, less space requirements, thermal storage up to 2 hours, and external control by the electricity company.

8.4 Specifications for the development of single-room heat pumps in Switzerland

Until recently there were no products capable of meeting the specifications for a replacement system for electric resistance heaters. The Federal Office of Energy therefore decided to implement the development of a single-room heat pump and promote it up to the point of introduction onto the market. The following specifications form the basis for the development of a single-room heat pump in Switzerland. This list is based on extensive studies that encompassed both the potential market and the possible manufacturers and products, plus the relevant technical and legal requirements in Switzerland.

Heating capacity per radiator module	The heating capacity of the modules must correspond to that of the single-room resistance heater.
(Condenser)	Module 1: 600 W thermal capacity (outside air -10°C/room temperature 22°C); heating area: approx.12 m^2 Module 2: 900 W thermal capacity (outside air -10°C/room temperature 22°C); heating area: approx.18 m^2
Module dimensions	The heater should have roughly the same dimensions as the existing electric resistance heaters. Module 1: Depth: <30 cm Height: ~60 cm Length: ~95 cm Module 2: Depth: <30 cm Height: ~60 cm Length: ~128 cm
Voltage of heat pump	230 V/50 Hz
Power consumption P_{el} of compressor at 230 V	<1 kW power consumption according to module.
Power connection	Ready to plug in: plug type 12 (Ready to plug in: for series production, SEV test required).
Heat source	Outside air (possibly heat recovery from exhaust air).
Arrangement of heat pumps	The following operating and application restrictions apply for heat pumps: Operating limits (lowest possible surrounding air temperature at which the heat pump still functions without incurring damage): T_L (min): -20°C Application limits (minimum mean intended temperature): T_L (min): -15°C The condensation temperature may be constant or variable.
Performance rate and annual heat pump loads	Performance rate: Coefficient of Performance (COP) COP = 1.5 (outside air -15°C/room temperature 22°C) COP = 2.5 (outside air +5°C /room temperature 22°C) Average annual COP = 2 (climate in Kloten, climate zone 3).
Refrigerant	The refrigerant must have zero ozone depletion potential

and must be non-toxic, since heat pumps are located in populated areas. The service life of the refrigerant and the global warming potential must be low.
Wherever possible, propane should be used as the refrigerant (filling weight <1 kg).

Compressor	Low-noise compressors with a high performance rate (possibly with adjustable capacity) should be used (e.g. piston or rotating piston).
Radiator (condenser)	Verification is required that heat emission can be achieved through natural convection and radiation. The condensation temperature should be kept as low as possible.
Air channels	Air channels to the evaporator should be insulated or sealed so that no thermal bridges or damage to the building can occur.
Defrosting device for evaporator	Since outside air is to be used as the heat source, the evaporators must be equipped with a defrosting device so that the system remains functional even at low outside temperatures.
Control and adjustment of heat pump module	The system must be operated using an on/off switch. The single-room heat pump is adjusted using a room thermostat or temperature sensor in the unit.
Weatherproofing of evaporator (protection against snow, rain, etc.)	Weatherproofing is required to ensure that the function of evaporator is not impaired.
Noise regulations	Rooms intended for working and living in are subject to SIA standard 181, "Noise Abatement in Buildings", under the category "Medium Noise Sensitivity". This means that continuous noise generated by the radiators may not exceed 35 dB(A) ($L_{r,H}$) during the day, and 30 dB(A) ($L_{r,H}$) at night. However, the levels stipulated under "More Stringent Requirements" are recommended. These call for a maximum of 30 dB(A) ($L_{r,H}$) during the day and 25 dB(A) (Lr,H) at night.
Structure noise	All elements for the elimination of structure-related noise must be integrated into the standard package.
Aesthetic requirements	The radiators (condensers) should fulfil at least the same aesthetic requirements as the existing electric resistance heaters. The air intake and outlet apertures should be carefully integrated into the facade.

Ecological aspects	Ecological criteria, such as choice of materials, product declarations, recycling, waste disposal, etc. must be taken into account.
Installation	For installation purposes, complete sets should be supplied (mountings, junction channels, insulation material, seals, etc.). The necessary special tools (drilling templates for breaking through walls, etc.) must also be provided.
Guarantee period	At least 2 years from start-up date.
Maintenance and repair	The service life of such systems is very important in helping to increase the degree of acceptance. Therefore guaranteed maintenance and service contracts must be offered (e.g. parts replacement contract).
Costs	For these systems to have a realistic chance in the marketplace, the following price ranges should be targeted (according to capacity): Installed system: USD 2,500 to USD 3,300.

8.5 Current status of single-room heat pump development

Three modules with heating capacities of 600, 900, and 1,200 W have been developed and are about to go into mass production. They have undergone intensive tests, to ensure that no shortcomings can prematurely damage their reputation. The tests were carried out at a facility specially designed for testing single-room heat pumps, and the results will be published with the Annex 23 workshop proceedings.

8.5.1 Initial findings and results

It was only possible to reduce the noise to the required lower level of 30 dB by taking repeated noise measurements and optimisation measures.

A COP of 1.7 (-10°C) and 2.4 (5°C) have now been achieved; therefore, an average annual COP of 2 in the central plateau region is possible. Using propane as a refrigerant it is possible to increase the COP by approximately 15%.

Provisional investment costs for the end-user are shown in Table 5.

Table CH 5: Investment costs of single-room heat pumps.

	600 Watt (USD)	900 Watt (USD)	1,200 Watt (USD)
Device	1,850	2,000	2,150
Drilling and assembly	330	330	330
Electrical installation	250-400	250-400	250-400
Total (approx.)	2,500	2,650	2,800

9 Research, development and promotion

In Switzerland, the research and development of heat pumps are traditionally the responsibility of manufacturers or the public authorities. The electrical utilities themselves are not in a position to carry out these activities, as they are too small and lack the necessary funds and staff. The Association for the Promotion of Heat Pumps in Switzerland plays an important role by bringing together all the major players. Electrical utilities also carry out certain promotional activities, e.g. special tariffs for interruptible heating loads, information and advisory services, sale of heat pumps, exhibitions, visits to heat pump installations, and support at conferences and exhibitions where heat pumps may be included.

The only research and development work on single-room heat pumps is currently being carried out within the framework of the Federal Office of Energy project. (See sections 7.4 and 7.5.)

10 Conclusions and key criteria for the use of heat pumps in Switzerland

Renewable energy resources are promoted as part of the official energy policy. The Association for the Promotion of Heat Pumps in Switzerland, in which government bodies, electricity companies, heat pump manufacturers, and the installation industry are all represented, is an important organisation for improving the distribution of heat pumps. The electricity companies generally regard heat pumps in a positive light and believe there is a good chance of achieving widespread distribution of these systems.

In 1990, a licence system was introduced for fixed electric resistance heaters, and these may be approved only under certain, fairly restrictive conditions. Electric resistance heaters that have reached the end of their service life are usually replaced by other heating systems.

Generally, single-room heat pumps only have a chance in situations in which no hydronic heat distribution systems are already installed or planned. In Switzerland, this is currently limited to the retrofitting of buildings with decentral electric heaters (direct or storage heaters). In 1990, around 212,000 electric heaters were installed in Switzerland.

For the electricity companies, the most important factors for the distribution of single-room heat pumps are low investment costs, low noise levels in the rooms, good reliability, and low operating costs. When assessing the market opportunities for single-room heat pumps, investment costs are more important than operating costs. In addition, lower tariffs apply if the supply of electricity to the heat pump or electric resistance heater can be interrupted by the electricity company.

Other factors mentioned include (in descending order of importance): simple installation, user-friendliness and comfort, low space requirements, thermal storage up to 2 hours, and external control by the electricity company.

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Heat Pump Systems for Single-room Applications in the United States of America

Annex 23

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1 Introduction

According to statistical data from the early 1990s, buildings were responsible for about 35% of the total annual energy used by the USA – around 32-34 x 10^{18} J (30-32 quadrillion Btu (quads)) annually. Space heating accounts for around 27% of this total.

In 1990, electricity use for residential space heating accounted for around 1.1 x 10^{18} J of energy consumption. By 1993, this had increased to 1.4 x 10^{18} joules.[1] An ADL study estimated that built-in or portable single-room electric resistance heaters account for about half of this energy use [4].

Heat pumps for single-room applications could provide an energy- and cost-saving alternative to built-in or portable electric resistance heating in the residential market and for commercial buildings (offices, hotels/motels, etc.). They could also be an effective retrofit solution for adding air-conditioning to homes or offices where no ductwork for an air distribution system exists. Space heating costs and total national energy use could be reduced considerably by displacing existing single-room electric resistance heating equipment with appropriate heat pump technology.

Among the primary barriers to the wider use of single-room ductless heat pumps (DHPs) are their relatively high cost (e.g. compared to window air conditioners) and a lack of customer awareness of this product and its advantages. In addition, the most common single-room air-conditioning equipment in the USA (window air conditioners and packaged terminal air conditioners and heat pumps), have a reputation for being noisy. Most homeowners would not be willing to install multiple numbers of noisy units to provide the comfort of air conditioning for the home. (A typical US single-family residence may have 10 or more individual rooms that would require heating or cooling for some portion of the year.) Lack of familiarity with the product on the part of dealers and installers, as well as poor efficiencies at low outdoor temperatures, are also problems. The relatively high cost of electricity (compared to gas and oil) is also a barrier.

2 Energy costs

Residential energy prices (average and range) in the USA for 1995 are given in Table 1. Prices to commercial customers are typically around 10-15% lower than those for residences.

The average electricity-to-gas and electricity-to-oil price ratios for delivered energy are 3.1 to 1 and 2.9 to 1, respectively.

Average 1995 prices for selected states are listed in Table 2.

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1 Table 31 (EIA, 1993) and Table 5.14 (EIA, October 1995) give values for residential electricity consumption of 0.32 and 0.43 x 10^{18} J for 1990 and 1993, respectively [1, 2]. Using an average efficiency for generation, transmission, and distribution of electricity of 31% (EIA, January 1996) gives total energy consumption of 1.1 and 1.4 x 10^{18} J (1.0 and 1.3 quads) for 1990 and 1993, respectively, to produce this electric energy consumed at the residence [3].

Table US 1: US residential energy prices (1995).

	Low	High	Average	Cost/10^9 J delivered (USD)
Electricity (USD/kWh)	0.050	0.139	0.084	23.31[1]
Oil (USD/l)	0.21	0.27	0.23	7.92[2]
Natural gas (USD/m^3)	0.16[3]	0.35[3]	0.21	7.37[2]

From Energy Information Administration (EIA): averages and oil range [5]; natural gas range [6]; electricity range [7].

1 delivered energy cost for electric resistance room-heating units;

2 delivered energy cost for hydronic systems assuming 75% boiler/distribution efficiency;

3 excludes Alaska (USD 0.13/m^3) and Hawaii (USD 0.62/m^3).

Table US 2: US residential average energy prices for selected states (1995).

State	Electricity (USD/kWh)	Oil (USD/l)	Natural Gas (USD/m^3)
Arizona	0.091	–	0.28
California	0.116	–	0.23
Florida	0.078	–	0.35
Georgia	0.078	–	0.22
Massachusetts	0.112	0.223	0.32
Minnesota	0.072	0.212	0.17
New York	0.139	0.252	0.30
Texas	0.077	–	0.21
Virginia	0.078	0.223	0.25
Washington	0.050	0.254	0.21

3 Climate

Climatic conditions vary widely across the USA. The country is divided into five major climate zones based on heating and cooling degree-days (base 18.3°C) (Figure 1). About two-thirds of residential and commercial buildings are located in zones 3 to 5.

Winter outdoor ambient design temperatures, average winter temperatures, and average heating degree-days (base 18.3°C) are presented in Table 3 for selected cities. The design temperatures are tabulated by the American Society of Heating, Refrigeration, and Air Conditioning Engineers, Inc. (ASHRAE) and indicate that, on average, the outdoor temperature is at or above that level for 99% of the winter hours [8].

Figure US 1: US climate zones.

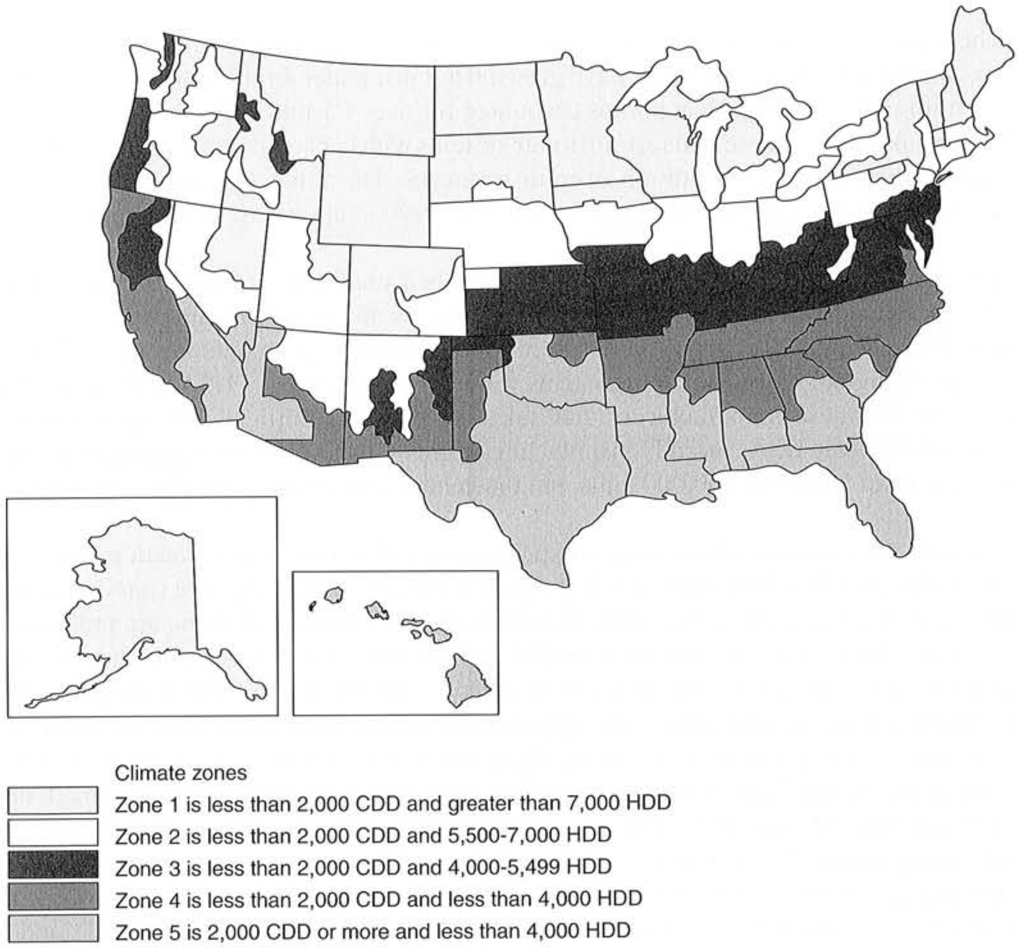


Table US 3: Winter climate data for selected US cities.

City	99% Outdoor design temperature (°C)	Average winter outdoor heating temperature (°C)	Average annual degree-days (base 18.3°C)
Albany, New York	-21.1	1.4	3,819
Atlanta, Georgia	-8.3	10.9	1,645
Seattle, Washington	-6.1	6.8	2,858
Washington, DC	-10.0	7.6	2,347
Phoenix, Arizona	-0.6	14.7	981
Minneapolis, Minnesota	-26.7	-2.1	4,657
San Diego, California	5.6	15.3	810
Boston, Massachusetts	-14.4	4.4	3,130

4 The market

The heat pump and air conditioner market in the USA is strong and growing. Total shipments of air conditioners and heat pumps have grown from just under 4 million in the early 1990s to 5.7 million in 1996 [9]. Heat pumps accounted for over 1.1 million of these shipments in 1996. The majority of these units are air-to-air systems with capacities ranging from 7-17 kW, intended to heat and/or air condition an entire residence. The number of heat pumps installed in US residences has risen from about 7 million in 1990 to almost 10 million in 1996.

Single-room heat pump products currently have only a small share of the US market. There are two principal system types in this category: ductless minisplit heat pumps and packaged terminal heat pumps (PTHPs). The minisplit system consists of an outdoor unit and one or more remote indoor units. Minisplit systems were introduced into the USA in the mid-1980s by several Japanese manufacturers, but sales were disappointing [10]. Approximately 10 companies in the USA currently manufacture or import these products. Estimates of annual sales vary from 50,000 to 100,000 units, but the general consensus is 60,000 to 80,000 [10].

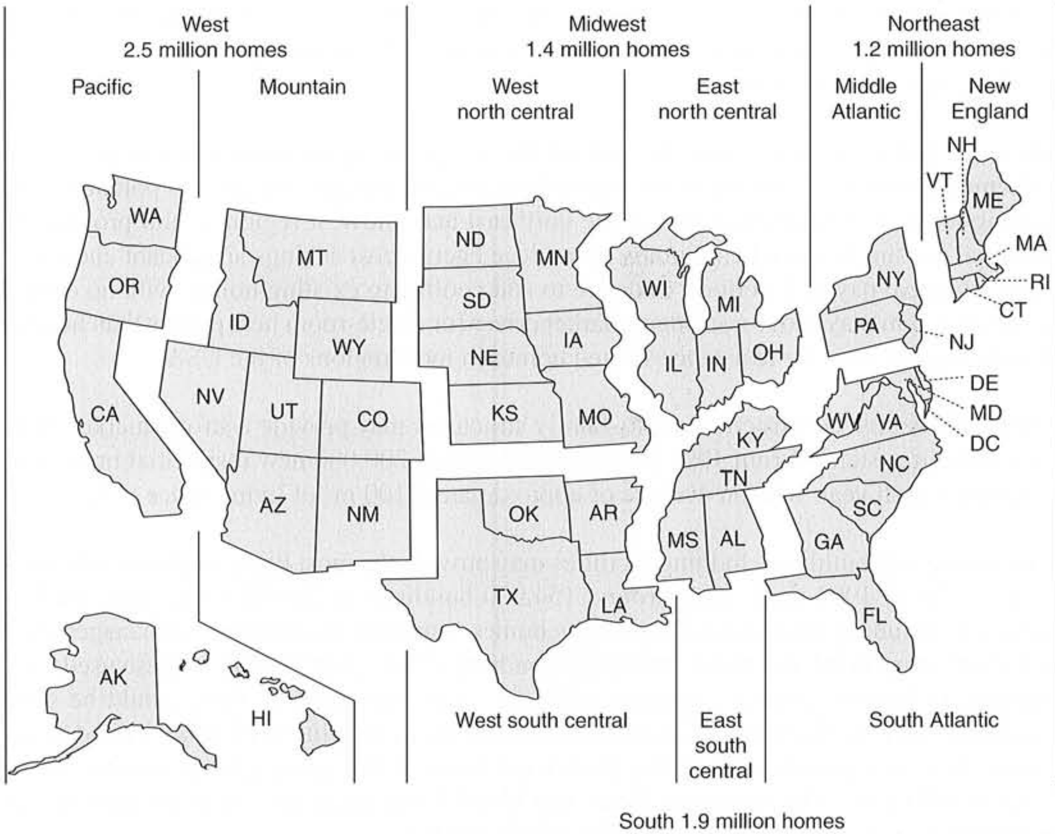
The market for minisplit heat pumps is experiencing a slow but steady growth pattern [10]. Most of this growth is believed to be in the light commercial building area (nursing homes, hotels/motels, offices, etc.). One manufacturer notes that ductless systems are preferred in new commercial constructions over traditional rooftop systems because they are less expensive, more efficient for the application, and pose no problems of roof leakage. Another manufacturer indicates that most sales appear to be concentrated along the east coast area. Multi-family housing, retrofits of hydronically heated homes, and add-on construction (adding a room to an existing house) are also providing markets for minisplit products. Small, non-ducted commercial structures, such as automatic bank teller machine terminals, are also using minisplit units. These products are required to meet the same energy efficiency standards as the larger central heat pumps and air conditioners sold in the USA. For cooling, the minimum seasonal coefficient of performance (COP) is 2.93 (SEER=10.0 Btu/Wh), and for heating, the minimum seasonal COP is 1.99 (HSPF= 6.8 Btu/Wh) (K. Epping, US Department of Energy. Personal communication.).

Packaged terminal heat pumps are single-package products designed to be installed in a sleeve in the exterior walls of a building. Installation is simple and relatively inexpensive. Mounting sleeves are placed in the exterior walls at the time of building construction, and the heating/cooling contractor then simply slides the PTHP units into the sleeves. Around 100,000 of these products were shipped in 1994 [11]. Another 75,000 cooling-only units (packaged terminal air conditioners (PTACs)) were also shipped in 1994. These figures are about 30% higher than those for 1993 [11]. The majority of these systems are used to heat and/or cool individual offices or motel rooms or for other light commercial applications. They are not popular choices for private homes, owing in part to their noise levels. Mandated minimum cooling COPs for these products range from 2.23 to 2.58 as rated at 35°C (95°F) depending on their capacity. Mandated minimum heating COP ranges from 2.52 to 2.71, rated at 8.3°C (47°F). (K. Epping, US Department of Energy. Personal communication.).

A large potential market exists for minisplit-type systems as a retrofit measure in residences. As of 1993 there were about 7 million homes that relied on built-in electric resistance heaters as the primary heating system [12]. Geographically, these were spread around the country as follows:

- 17% in the northeast;
- 20% in the midwest;
- 27% in the south; and
- 36% in the west (Figure 2).

Figure US 2: US census regions and divisions with number of homes using built-in electric resistance units as the primary heating system.



Of these 7 million homes, around 69% were located in areas with 4,000 or more heating degree-days (HDDs): 9% in climate zone 1, 30% in zone 2 and 30% in zone 3 (see Figure 1). Approximately another 14 million homes used built-in or portable resistance heaters for part of their heating needs (about 55% in areas with over 4,000 HDDs). In addition, there were some 5 million homes that used oil-fired hydronic heating systems, primarily in the northeast region (states of Maine, New Hampshire, Vermont, Rhode Island, Connecticut, New York, Pennsylvania, and New Jersey). If all US homes which use oil-fired hydronic heat or electric resistance units as the primary heating are considered, then a total of around 12 million homes could be retrofitted with minisplit systems, using 5-10 units per home, potentially between 60 million and 120 million heat pumps.

To achieve energy savings over oil-hydronic systems, single-room heat pumps would have to have a seasonal heating COP of about 2.9 or more. The desire for air conditioning or other factors rather than heating-season cost savings are likely to drive single-room heat pump penetration into the existing oil-hydronic home market in the northeast. The built-in resistance-heated home market is probably a more likely short-term candidate market for increased use of single-room heat pumps. However, the feasible single-room heat pump sales potential, even in this subset of the market, may be smaller than the above statistics would suggest. About 2.2 million built-in resistance-heated homes are located in the Pacific coastal area of the USA (V. Moorehead, EIA, personal communication). Washington and Oregon are characterised by fairly long, moderate winters but low electricity costs. The California coastal area has higher electricity costs but much lower heating loads. These conditions tend to reduce the potential energy cost savings from heat pumps relative to resistance heating, making them less economically attractive. Another 1.9 million built-in resistance-heated homes were located in the southern regions.

Those located in the states along the Gulf of Mexico generally experience low heating loads and enjoy moderate electricity costs, thus minimising the energy cost savings potential. The heating loads and electricity costs in the northeast and midwest regions could provide the potential for single-room heat pumps to produce energy cost savings significant enough to yield attractive payback periods. A desire to add cooling to existing homes with no central air-duct system may prove a stronger market driver for single-room heat pumps than heating energy savings even for resistance-heated homes in most regions of the USA.

In new residential construction, multi-family structures may provide a strong market niche for minisplit systems. From 1991 through 1994 almost 200,000 new residential units were completed each year, with an average of approximately 100 m^2 of living space [13].

For commercial buildings, lodging facilities may provide the most likely market for ductless systems. As of 1992 there were around 154,000 buildings in the USA that were used as lodgings, including both long-term (nursing homes, convents, dormitories, orphanages, etc.) and short-term (hotel and motel) residential buildings [14]. Over 50,000 of these used free-standing or built-in electric resistance units for space heating and, thus, would be good candidates for retrofitting with single-room heat pumps (minisplits or PTHPs). United States Census Bureau statistics indicate that there were about 33,000 nursing home facilities in the USA in 1991 [15]. The American Hotel and Motel Association has compiled statistics on hotel/motel rooms and buildings for 1995 (Table 4) [16].

Table US 4: Hotel and motel characteristics of the USA (1996).

Size	Number of buildings	Number of rooms
Less than 75 rooms	31,300	921,600
75-149 rooms	10,295	1,116,000
150-299 rooms	3,995	802,800
300-500 rooms	990	367,200
More than 500 rooms	420	392,400
All buildings	47,000	3,600,000

5 Residential market barriers

One of the biggest barriers to sales of ductless single-room minisplit units to US homeowners is their relatively high price. Homeowners who wish to add cooling to their home can choose between a ductless heat pump or a window air conditioner. The ductless unit is quieter and less obtrusive than the window air conditioners but costs 2-3 times more to purchase (around USD 1,200) [10]. Adding to the problem is the fact that contractors charge around USD 2,000 to install a minisplit unit.

American manufacturers and importers of these products acknowledge that dealers and contractors lack awareness of the advantages of minisplits and the installation requirements, which is a big problem. This leads directly to high installation charges (due to the "uncertainty" or "novelty" factor). Furthermore, they do not promote the product to their customers, the ultimate consumers.

Another potential problem for minisplit heat pumps is their limited efficiency and power demand reduction capability at low outdoor temperatures (below -8.3°C (17°F)). Central air-source heat pumps popular in the USA have benefited from technological improvements that have raised their cold-weather performance levels (e.g. larger outdoor heat exchangers, improved compressors and controls). As noted previously, ductless minisplits meet the same minimum seasonal heating efficiencies as central units, but they have not enjoyed the same degree of technology development and improvement directed at their low-temperature performance. The minisplit technology was originally developed in Japan, and the primary emphasis was on quiet operation and cooling efficiency.

Due to the higher cost of delivered space heat from electricity relative to oil-hydronic systems, ductless heat pump seasonal COPs would have to exceed about 2.9 in order to give equivalent annual heating costs.

6 Recommendations

Two general recommendations are offered for increasing the market penetration of single-room ductless heat pumps in the USA.

1. Increase marketing, advertising and educational activities to raise dealer, contractor, and consumer awareness levels about ductless products and their advantages.

2. Implement technology development activities to improve the cold-weather heating capacity and efficiency and to reduce unit costs.

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