International Energy Agency
Programme of Research and Development on Advanced Heat Pump Systems

Annex I:
Common Study on Advanced Heat Pump Systems

Final Report
Volume III: Market Study

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Contents

CHAPTER	PAGE	TITLE
		INTRODUCTION
CHAPTER 1		SUMMARY OF STUDY RESULTS AND CONCLUSIONS
	1.4	Summary of Results
	1.9	Conclusions
	1.10	Future Directions for Advanced Heat Pumps
CHAPTER 2		DEFINITIONS AND ASSUMPTIONS
CHAPTER 3		MARKET ESTIMATES BY AHP SYSTEM
	3.3	Systems with Greater Market Potential
	3.31	Systems with Limited Market Potential
CHAPTER 4		MARKETS FOR ADVANCED HEAT PUMP SYSTEMS IN PARTICIPATING COUNTRIES
	4.1	Austria
	4.12	Belgium
	4.22	Canada
	4.33	Denmark
	4.47	Germany
	4.63	Italy
	4.72	Japan
	4.83	The Netherlands
	4.93	Spain
	4.103	Sweden
	4.121	Switzerland
	4.131	United Kingdom
	4.142	United States
APPENDIX A		AHP Market Study Participants: Current Contact Persons
APPENDIX B		Technical Characteristics of AHP Systems
APPENDIX C		Technical Approach

INTRODUCTION

To reduce their dependence on imported oil, the 20 member countries of the International Energy Agency (IEA) are conducting a number of research and development (R&D) programs in energy-efficient technologies. Thirteen of these countries are members of the IEA Executive Committee on Advanced Heat Pumps.* Advanced heat pump (AHP) systems are relatively more energy-efficient than conventional heating and cooling equipment or conventional heat pumps; in addition, AHP systems are powered by solar, waste heat, oil, or gas instead of the expensive electricity used to drive conventional heat-pump systems.

The first project sponsored by this committee was a two-part Common Study of Advanced Heat Pump Systems:

1. A technical study to document the state-of-the-art in AHP technology and determine R&D needs

2. A market study to estimate the market potential of AHP systems in member countries for the period 1981-2000, and derive conclusions for R&D.

KFA Jülich, as representative of the Federal Republic of Germany, is the overall operating agent for the Common Study, assisted by Battelle-Institut e.V. Frankfurt. KFA Jülich also has primary responsibility for the technical study. The U.S. Department of Energy (DOE), assisted by Resource Planning Associates, Inc. (RPA), is responsible for the market study. National analysis teams were appointed in each participating country to conduct the technical and market analyses.

The results of the Common Study are reported in three volumes:

Volume 1: Summary

Volume 2: Results of the Technical Study

Volume 3: Results of Market Study (this report).

The key results and conclusions of the market study are summarized in Chapter 1 of this volume. Chapter 2 is an introduction to the market estimates, in which the definitions and key assumptions used by participating countries in the study are explained. Chapter 3 contains estimates of the markets for each AHP system. In Chapter 4, market estimates of AHP potential in each country are presented in more detail.

Organizations participating in the study are listed in Appendix A, technical descriptions (or "profiles") of each heat pump system are included in Appendix B, and the technical approach used to complete the market analysis in Appendix C.

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* The committee includes Austria, Belgium, Canada, Denmark, the Federal Republic of Germany, Italy, Japan, the Netherlands, Spain, Sweden, Switzerland, the United Kingdom, and the United States.

1 SUMMARY OF STUDY RESULTS AND CONCLUSIONS

The objective of the market study was to estimate the market for advanced heat pumps (AHPs) in residential buildings over the period 1981 to 2000, to identify systems with significant potential, to determine future research and development (R&D) needs, and to determine the barriers that constrain the market potential of other AHP technologies. Participating countries analyzed 16 heat pump systems (Exhibit 1.1). Although other systems were also initially selected for study, they were excluded from the market study because national teams expressed less interest in these systems at this time.

A complete analysis of the technical characteristics and R&D status of each AHP is contained in the final report of the technical study (Volume 2 of the results of the Common Study). For the market study, the cost and performance data for each system were defined in technical profiles derived from the technical study results and made available to the market study teams (see Appendix B).

National teams estimated the market for each profile using a technical approach developed by RPA (see Appendix C). The first step in developing market estimates for AHPs was to estimate the demand for heating and cooling installations in residential buildings. To fill this demand, AHPs will compete against conventional heating and cooling systems such as boilers and room air conditioners. In estimating the demand for heating and cooling installations, some countries ignored installations in which heat pumps initially did not seem to be competitive. For example, Germany did not consider the projected demand for room heating systems, such as stoves or electric resistance heaters; relatively few of these installations will be required in Germany, and AHP technologies, which have high first costs, will be unlikely to compete with conventional systems. Spain considered only demand for installations in new construction, assuming that AHPs would not be competitive in the replacement market in existing buildings. Only Japan and the United States considered the demand for AHPs with cooling capacity.

The 13 countries participating in the study predicted a total average annual residential demand of 9.5 million heating and cooling system installations between 1981 and 2000, as shown in Exhibit 1.2. Installations are characterized by type: single-family houses (SF market segment), individually heated apartments (MFI market segment), and centrally heated apartments (MFII market segment).

Installations in single-family houses represent 74 percent of the market, and installations in individually heated apartments 20 percent. Although installations in centrally heated apartment buildings ("building-central" installations) are only 6 percent of the total, they are much larger than single-family installations and offer more potential for energy savings per installation. District heating installations, which were analyzed in detail by Denmark, Sweden, and Switzerland, offer even larger savings. District heating installations require systems with heating capacity greater than 1 to 2 MW.

The United States represents the largest market for heating and cooling installations, accounting for half of the total market in the 13 countries. U.S. demand is largely for installations in single-family houses and accounts for 60 percent of total SF installations considered in the study. The second largest market in single-family houses is in the United Kingdom, which has 15 percent of the total. The primary demand for installations in individually heated apartments is in the United States, the United Kingdom, and Italy.

EXHIBIT 1.1
AHP SYSTEMS ANALYZED BY NATIONAL MARKET STUDY TEAMS

System	Cycle	Market Segment	Fuel
2a (H/C)	Absorption	SF, MFI	Oil or gas
2b (H)	Absorption	SF, MFI	Oil or gas
3 (H)	Two-stage absorption	MFII, District	Coke oven gas
4 (H)	Diesel-Rankine	SF, MFI	Oil
4a (H)	Diesel-Rankine	District	Oil
5 (H)	Diesel-Rankine	MFII	Oil
6 (H)	Diesel-Rankine	District	Heavy fuel oil
7 (H)	Otto-Rankine	MFII, District	Oil
8 (H)	Otto-Rankine	MFII	Gas
9 (H/C)	Stirling-Rankine	SF, MFI	Oil or gas
13 (H)	Electric-Rankine	SF, MFI, MFII	Electricity
14 (H/C)	Ammonia-absorption	SF, MFI	Gas
15/18 (H)	ORC-Rankine	SF, MFI, MFII	Oil or gas
16 (H/C)	Brayton-Rankine	MFII	Oil or gas
19 (H)	Absorption	District	Kerosene
20 (H)	Absorption-Rankine	District	Electricity

Exhibit 1.2

AVERAGE ANNUAL HEATING SYSTEM INSTALLATIONS, 1981-2000
(000 Housing Units)

	Single-Family	Individually Heated Apartments	Centrally Heated Apartment Buildings
Austria	38	2	65
Belgium	168	38	4
Canada	242	17	-[c]
Denmark	153	0	1
Germany	386	400	226
Italy	188	239	165
Japan	173	86	2
Netherlands	198	23	0.7[c]
Spain[a]	18	483	8
Sweden[b]	104	2	72
Switzerland	32	0	46
United Kingdom	1,100	353	-[c]
United States	4,201	642	29

a. New construction only.

b. See Swedish national analysis in Chapter 4.

c. Market segment not considered.

Austria, Denmark, Germany, Sweden, and Switzerland have little or no demand for such installations because apartment buildings in these countries are either gradually being fitted with central water systems or are already centrally heated. In contrast, Austria, Germany, and Sweden have a significant share of the market for building-central installations. The Spanish demand for heating system installations will be divided between individually heated apartments and building-central systems.

In Europe, the majority of the heating and cooling installations between 1981-2000 will use water distribution systems. In the United States, Canada, and Japan, most installations will use air distribution systems.

In addition to categorizing the demand for heating and cooling installations into SF, MFI, and MFII segments, countries distinguished between installations in new construction and those in existing buildings. In all countries except Spain (which considered only installations in new construction), more than half the projected installations will occur in existing buildings. Installations in existing buildings were further subdivided among three categories:

- Replacement. Heating system is worn out and must be replaced.
- Modernization. Housing unit is upgraded with a central heat distribution system to replace room heating units.
- Retrofit. Heating system is replaced before it is worn out to reduce operating costs.

National analysis teams then segmented their markets for heating and cooling installations to reflect the characteristics of their housing stock, the fuels available, and the criteria that purchasers in each market segment would use in choosing a new heating and cooling system (e.g., first cost, annual operating or energy cost, or life-cycle cost). Competing systems in each segment (both AHP and conventional) were ranked according to these decision criteria. To perform the ranking, it was necessary to calculate the capital and operating costs of the systems. National analysis teams developed their own estimates of conventional system costs; AHP costs were adopted, in some cases with modifications, from the AHP profiles. Operating costs were derived from energy consumption estimates, which in turn were based on weather data and the operating characteristics of the AHP and conventional systems.

Using the technical approach, most countries assumed that demand in a given market segment would be met by the system ranking first on the associated decision criterion. In allocating heating and cooling installations to AHPs and conventional systems, national analysis teams took into account any technical constraints (e.g., availability of natural gas) that would prevent a system from fully capturing market segments in which it ranked first. In these cases, remaining demand was filled with the second-ranking system.

SUMMARY OF RESULTS

The results, when summed over all the segments, gave the total economic potential for each competing heating and cooling system in each country. The economic potential is, broadly speaking, the market that a system would achieve if economic factors alone determined the decision maker's choice.

In the last step of the technical approach, national analysis teams adjusted the economic potential downward to reflect the effects of institutional barriers, the reluctance of consumers to try advanced heat pump systems, and production constraints. The result was the implementation potential, an estimate of the market that might be achieved in practice by the year 2000.

The estimated economic potential of AHP systems is summarized in Exhibit 1.3. The systems are grouped in three broad categories: small or single-family systems, including systems for single-family houses and for individually heated apartments, medium systems for building-central installations in apartment building, and large systems for district heating. The economic potential is given as an annual average number of installations and percentage of market for the period 1996-2000. Data for this period reflects the market after all advanced heat pumps have become available to the market and all transients (i.e., systems that lose market shares after new systems are introduced) have been eliminated. An entry of zero means that the associated system failed to compete for market against other systems in that country in that period; a blank means that the system was not analyzed.

The market share for AHPs is zero or small in Canada, Italy, the Netherlands, Spain, the United Kingdom, and the United States. Canada, the Netherlands, and the United Kingdom have abundant natural gas at low prices that makes conventional gas boilers formidable competitors for all other systems. In Italy and the United States, consumers base their heating system purchase decisions primarily on first cost, and AHP systems are too expensive to capture a significant portion of the market. In Spain, the conventional electric heat pump is far more economical than the AHPs and dominates the future market.

Advanced heat pumps demonstrate significant market shares in northern European countries with expensive imported fuels and long heating seasons: i.e., Austria, Belgium, Denmark, Germany, Sweden, and Switzerland. In addition, consumers in many of these countries tend to select heating systems based on annual cost or energy cost, criteria that favor AHPs. In these countries the AHP market shares in small systems range from 30 percent (Austria), to 57 percent (Germany), and in medium systems from 16 percent (Sweden and Switzerland) to 90 percent (Denmark). The market estimate for Japan is exceptional; Japan assumed a capital cost for AHP 9 that is below that for a conventional gas boiler and separate air conditioner. As a result, the predicted market share for AHP 9 is very high in market segments requiring both heating and cooling. Countries interested in district heating (Denmark, Sweden, and Switzerland) predict significant market shares for the large advanced heat pumps.

A number of AHP systems contribute to these overall percentages: AHPs 2, 4, 9, 13, 14, and 15/18* in single-family and individually heated apartments; AHPs 5, 14, and 15/18 in centrally heated apartments, and AHP 3, 4a, 5, 6, and 13 in block central and district heating applications. However, AHP systems compete against each other as well as against conventional systems, and most countries concluded that a maximum of two AHP systems would capture market share within a given segment. For example, in the market for small systems, AHP 2 severely limits the potential of AHPs 4 and 9. AHP 4 has market potential only in Switzerland and the United Kingdom, where analysts allocated a portion of the market to this system based on a qualitative judgment of its economic competitiveness. AHP 9 has market potential only in Japan, where analysts assumed a very low

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* The numbers refer to the systems listed in Exhibit 1.1 and described in Appendix B.

Exhibit 1.3

1996-2000 Economic Potential

(000 average annual installations/% of market segment*)

Profiles	Type of Building	Application	Countries: Austria	Belgium	Canada	Denmark	Germany	Italy	Japan	Netherlands	Spain	Sweden	Switzerland	United Kingdom	United States	Total
Small																
2a	SF	H/C							0						208 (4%)	208.0
	MF I	H/C							0							
2b	SF	H		0	28.8 (19%)		181 (45%)	0		0	1 (4%)	10 (24%)	7 (17%)		112 (2%)	364.9
	MF I	H		0	0.1 (2%)			0		0	25 (5%)					
1	SF	H	0	0			0						7 (17%)	15 (5%)	0	22.0
	MF I	H												2.4 (3%)	0	2.4
7	SF	H								0					0	0
	MF I	H													0	0
9	SF	H/C							167 (53%)	0					0	167.0
	MF I	H/C							83 (53%)						0	83.0
13	SF	H	0	0		25 (51%)	4 (1%)		37.5 (12%)		1 (4%)	5.8 (14%)			0(%)	73.3
	MF I	H		0					18.5 (12%)						0(%)	18.5
14	SF	H	12 (30%)							0				115.2 (11%)		127.2
	MF I	H												18.8 (5%)		18.8
15/18	SF	H		50.2 (32%)			48 (12%)		0	0				38.4 (4%)	0	136.6
	MF I	H		10.8 (32%)					0					6.3 (2%)	0	17.1
Medium																
4a	MF II	H										0				0
5	MF II	H	14 (21%)			0.3 (51%)		0							0.4 (1%)	14.7
7	MF II	H													0	0
8	MF II	H								0						0
13	MF II	H	20 (30%)			0.2 (39%)			0.5 (12%)		0	0.02 (16%)				20.7
15/18	MF II	H		1.8 (38%)			64 (26%)				0.8 (7%)		7.6 (16%)		0.3 (1%)	74.5
	MF II	H/C													1.1 (3%)	1.1
16	MF II	H													0	0
	MF II	H/C													0.1 (0.4%)	0.1
Large																
3	BC/DH	H											7.6 (16%)			7.6
4a	BC/DH	H				0.06 (4%)			0							0.6
5	BC/DH	H				0.85 (54%)						0.27 (54%)				0.85
6	BC/DH	H				0.28 (18%)										0.28
13	BC/DH	H				0.16 (10%)						0.1 (22%)				0.26
19	BC/DH	H							0							0
20	BC/DH	H							0							0

NOTE: Abbreviations are defined in the text and Appendix C.

*As defined by each country.

initial cost for this system. AHP 2 also limits the potential of AHPs 13, 14, and 15/18, though to a lesser extent. The electric AHP 13 is also able to compete with the gas-powered AHP 2, partly because natural gas is not available to all installations. AHP 15/18 outranks AHP 2 in Belgium and divides the market with AHP 2 in Germany. AHP 14 gains market share in Austria and the United Kingdom; however, Austria did not consider AHP 2 as a competitor.

In the market for medium systems, most countries analyzed a single AHP system, or two systems operating on different fuels: AHP 13 (electric) and AHP 5 or 15/18 (oil and gas). Only in the United States were AHPs 5 and 15/18 allowed to compete, and the latter gained most of the market.

The market for district heating systems was analyzed in detail only by Denmark, Sweden, and Switzerland. Switzerland analyzed only one system (AHP 3). However, in Denmark and Sweden, several systems were allowed to compete, and AHP 5 gained the largest market share.

Overall, AHP 2, the small absorption heat pump, demonstrates the most economic potential with 208,000 annual installations for heating and cooling (all in the United States), and 365,000 installations for heating only (31 percent in the United States, 8 percent in Canada, and 61 percent in Europe). AHP 15/18, the organic Rankine heat pump, ranks second, with 154,000 installations in small systems (single-family houses and individually heated apartments) and 76,000 installations in medium systems, all in Europe. AHP 9 performs well in Japan, with a market of 250,000 units per year. AHP 14, the ammonia absorption heat pump, will be installed in 127,000 units a year in Austria and the United Kingdom. This estimate could be high because Austria did not analyze AHP 2.

For the electric heat pump, AHP 13, the predicted annual market is 117,000 units, spread over five European countries and Japan. It does particularly well in Scandinavia. AHP 4 will be installed in 24,000 units a year in the United Kingdom and Switzerland. AHP 5, a large Diesel Rankine design, will be installed in 14,700 centrally heated apartments in Austria, Denmark, and the United States annually, but only the United States calculated competition from AHP 15/18 in estimating the market for AHP 5. AHP 16 will have a small market in heating and cooling installation in the United States. AHPs 5 and 6 show potential for district heating; however, the most successful system in this market is AHP 3, the 2-stage absorption system that will have 7,600 installations in Switzerland alone. AHPs 7 and 8, the Otto-Rankine designs, show no economic market potential at all.

The implementation potential predicted by the national teams for AHP systems is given in Exhibit 1.4. The figures are cumulative installations over the period 1981-2000. The great majority of installations will be in small or single-family systems. AHP 2 will generate on the order of 3,896,000 installations; AHP 14,1,482,000 installations; and AHP 15/18,954,000 installations. AHP 13 will be installed in about 912,000 units, and AHP 9, 1,692,000 (again, all in Japan). The other AHP systems have smaller or zero penetration. Austria, Spain, and Switzerland did not calculate implementation potentials, which reduces the overall implementation potential for AHPs 2, 3, 4, 5, 13, 14, and 15/18.

Exhibit 1.4

Cumulative Implementation Potential, 1981-2000
(000 installations)

Profiles	Type of Building	Application	Countries												
			Austria*	Belgium	Canada	Denmark	Germany	Italy*	Japan	Netherlands*	Spain*	Sweden	Switzerland*	United Kingdom	United States
Small															
2a	SF	H/C													
	MF I	H/C													2,277
2b	SF	H			139.5*		230					23.6			
	MF I	H			0.5										1,225
4	SF	H					15							274.6	
	MF I	H												43.3	
7	SF	H													
	MF I	H													
9	SF	H/C							1,692.6						
	MF I	H/C							846.3						
13	SF	H				370	13.4		336.3			20.7			
	MF I	H							166.2						
14	SF	H												1,482.4	
	MF I	H												236.6	
15/18	SF	H		187			81.4							494.1	
	MF I	H		40										84.3	
Medium															
4a	MF II	H													
5	MF II	H				2.8									7.9
7	MF II	H													
8	MF II	H													
13	MF II	H				2.6			2.0			0.3			
15/18	MF II	H		7			41.5								4.3
	MF II	H/C													14.1
16	MF II	H													
	MF II	H/C													1.3
Large															
3	BC DH	H													
4a	BC DH	H				8.0									
5	BC/DH	H				10.6						0.4			
6	BC DH	H				4.1									
13	BC DH	H				2.2						0.3			
19	BC/DH	H													
20	BC DH	H													

NOTE: Abbreviations are defined in the text and Appendix C.

*Implementation potential not calculated.

CONCLUSIONS

Although 15 advanced heat pumps were analyzed in the market study, only AHPs 2, 4, 5, 9, 13, 14, and 15/18 have significant market potential in one or more countries. The conclusions of the market study for each system are discussed below.

AHP 2: Organic Absorption System

AHP 2, in its heating and cooling (2a) or heating (2b) versions, has the largest market potential of all the AHPs considered in the market study. This potential could be increased even more by R&D oriented toward the following objectives:

- Accelerate development to allow earlier commercialization (estimated in the analysis to occur in 1986).
- Reduce first cost. A cost reduction of 3,000 DM would open new markets for AHP 2b in Europe (e.g., Belgium, Italy, and the United Kingdom) and double its potential in Germany.

AHP 4: Diesel-Rankine System

AHP 4, the small Diesel system, does not achieve significant market penetration in any of the countries that studied it, except in the United Kingdom and Switzerland, where the market estimate was based on qualitative judgment. In fact, AHP 2, introduced later, has better economic performance than AHP 4, and would tend to drive it out of the market. However, other, larger Diesel systems (e.g., AHPs 4a and 5) show good prospects in other market segments, indicating that Diesel-driven systems benefit from economies of scale.

AHP 4 will benefit from any delay in the commercialization of AHP 2 to establish its market position and reduce its cost through longer production runs. Time is also needed for installers and customers to adapt themselves to its more complex heating system. It is uncertain whether single-family home owners will accept a motor-driven heating system. Reducing noise and improving reliability through R&D would make the system more acceptable.

AHP 5: Diesel-Rankine System

Despite its large size, which limits it to certain applications and countries, AHP 5 is the most successful of the Diesel systems studied. Except for Italy, the system performs well in all the countries that studied it. The Swedish analysis showed that the system performed relatively better in large installations (10 MW). No major R&D conclusions can be drawn from the results of the study.

AHP 9: Stirling-Rankine System

AHP 9, the Stirling engine-driven heat pump, is applicable only in Japan, the United Kingdom, and the United States, because of its air distribution system.

The system penetrates the market only in Japan, outranking AHPs 2 and 15. This estimate is partly due to the fact that Japanese analysts assumed a lower first cost than that assumed by other countries. To achieve market share in the United States, R&D should be directed to significant first cost reductions.

AHP 13: Electric-Rankine System

The market share for AHP 13, the ground-source electric heat pump, is large, especially in colder countries where decision makers are sensitive to energy costs. In many of these markets, AHP 13 holds a similar position as the conventional electric compression heat pump, which it resembles. Although economical, the market potential for AHP 13 is limited by the ground area needed to install and operate the soil heat source for the horizontal system, or by the geological conditions required by the vertical system. R&D should be directed to improving heat source designs and installation methods. Such research, of course, would also benefit absorption heat pump technologies.

AHP 14: Absorption System

The AHP 14 absorption system should be very competitive, particularly if its first cost is as low as assumed in this study. However, its use of ammonia fluid and natural gas could prevent it from entering many markets. If R&D on AHP 14 changes the working fluid to another fluid that is more widely acceptable at a reasonable cost, the system could have a greatly expanded market potential.

AHP 15/18: ORC System

AHP 15/18, the organic Rankine/Rankine cycle (ORC) heat pump, is one of the few AHP systems that have potential in both small and medium systems. Among AHPs, AHP 2 is its major competitor, often ranking ahead of AHP 15/18 on life-cycle cost and payback period. R&D efforts should be directed toward lowering the cost and bringing the system on the market sooner. If AHP 15/18 were available significantly earlier than AHP 2, it might be able to consolidate a market position and reduce its cost fast enough to remain in market segments where AHP 2 is now dominant.

In single-family applications, AHP 15/18 could suffer from some of the same consumer reluctance that plagues AHP 4. Demonstrations and field tests may be necessary to increase consumer acceptance.

FUTURE DIRECTIONS FOR ADVANCED HEAT PUMPS

The economic potential for all AHP systems, although significant, is limited by strong competition from conventional systems, especially natural gas boilers and conventional electric heat pumps. Strong competition among AHPs limits the market for each of them separately.

The overall conclusion of the market study for R&D policy in participating countries is relatively clear. To expand the market share for advanced heat pumps as a group, R&D efforts should be focused on AHPs most likely to generate

market potential by 2000: the absorption, ORC-Rankine, and Diesel/Rankine systems. Countries contemplating R&D investment in other technologies with limited or zero markets in the present study should carry out a more complete analysis and consider all the systems that will compete for the heating and cooling market. Many systems may show initial promise, but over time, each market segment is likely to be dominated by one or two technologies.

Additional market for AHPs can probably be achieved more easily by attempting to change consumers' purchasing decision processes than by R&D programs to improve AHP technical performance. Government subsidies and tax credit programs can lower the first cost of the system and, like education, encourage the consumer to take a longer run view of investment decisions. If initial production runs can be stimulated by programs such as those in Sweden or Germany, then accumulated experience will lower AHP unit cost and improve system reliability more effectively than government R&D. Such experience has already reduced the cost and improved the reliability of conventional heat pumps and should be extended to AHP technologies.

To avoid producing government-dependent markets, any subsidy program should cover only the period immediately after commercialization and be phased out over time. Such subsidies should be limited to energy-efficient technologies such as AHP systems that meet broad energy and political objectives. As subsidies are phased out, normal competitive forces will determine which systems will dominate in each market.

2 DEFINITIONS AND ASSUMPTIONS

Although most of the countries participating in the AHP market study followed the same technical approach, they analyzed different AHP systems in different markets and made divergent assumptions as required by specific conditions in each country. The definitions and assumptions that were used in developing the market estimates presented in Chapters 3 and 4 are explained in this chapter; the similarities and contrasts help illuminate the wide differences in the market potential for AHP systems in the countries covered in the study.

National teams estimated markets for heating and cooling installations in three types of buildings:

- Single-family (SF): individual houses
- Multifamily I (MFI): apartment buildings with individually heated or cooled apartments
- Multifamily II (MFII): apartment buildings with a single (building central) heating/cooling plant.

Heating distribution systems installed in existing or new buildings were limited to four types:

- Central air: central heating and cooling system serving any of the three types of buildings with forced hot and cold air distribution; the most common system in the United States and Canada.
- Central water: central heating plant with heat distribution by hot water; used in all three building types; the most common system in Europe.
- Space I: electric baseboard (or other electric heating systems built into the building structure) and ductless furnaces; used only in SF and MFI buildings
- Space II: stoves or other room heating units (i.e., not built into the building structure); common in Japan and in older buildings in Europe; used only in SF and in MFI buildings.

Most AHP systems will be installed in central heating systems. (Japan was perhaps the only country that considered room or space II installations.) Denmark, Japan, Sweden, and Switzerland also assessed the market potential for large AHPs installed in block central heating systems suppling several buildings or in district heating systems supplying urban districts.

In addition to the housing stock and types of heating and cooling installations, the potential for AHPs is conditioned by the price and availability of fuels. Each country made its own assumptions about future energy prices and their escalation rates over the period covered by the study (see Exhibit 2.1).

Fuel prices vary considerably among countries. Canada and the United States have the lowest oil prices, Denmark, Austria, and Switzerland the highest (the latter three countries all show substantial heat pump markets). Natural gas

Exhibit 2.1

ENERGY PRICE ASSUMPTIONS

Energy Prices (0.01 DM/kWh)	Austria	Belgium	Canada	Denmark	Italy	Germany	Japan	Netherlands	Spain	Sweden	Switzerland	United Kingdom	United States
Oil price (1979)	6.5	5.5	2.2	7.0[a]	5.0	5.0	4.5		5.0	4.7[b]	6.2	3.7[c]	2.6
Projected escalation rate (%)	4.5	3.0	3.2	8.0	3.0	5.0	8.0		4.0	2, 4[d]	2.5-3.5		2.0-3.0
Gas price (1979)	6.1	5.5	1.3-1.6		3.0	3.7	8.9	4.3	6.0		5.5	3.24	1.4-3.1
Projected escalation rate (%)	4.0	3.0	3.2		2.0	5.0	7.0	3.5	3.0		2.0-3.0	4.2	1.5-4.5
Electricity price, end 1979	15.0	15.0	4.0-5.6	14.0		9.0[e]	14.1	17.0	10-13.2	7.2	5.0-15.0	10.7	5.5-12.9
Projected escalation rate (%)	2.5	0	1.4	3.0		2.5	7.0	1.8	3.0	1, 2[d]		<1.0	0-2.0

a. Heavy oil.
b. 4.5 single-family, 4 multifamily, 5 Diesel oil.
c. Estimate for 1990.
d. Three scenarios: 4% oil, 2% electricity; 2% oil, 2% electricity; 2% oil, 1% electricity.
e. Price for operating heat pump only, excludes taxes.

prices are lower, in general, than oil prices for the same energy equivalent of fuel, reflecting perhaps the inertia of regulated gas prices and the desire of some governments to limit oil usage through expanded sales of gas. The Netherlands and the United Kingdom, bordering the North Sea, predicted very low gas prices, one factor that limits AHP market potential in these countries. Electricity prices are highest in the Netherlands, Austria, Japan, and Denmark and, lowest in Sweden (where AHPs have a considerable market share) and Canada.

Because gas prices are often lower than oil prices, and gas boilers are less expensive than most other heating systems, the market share for AHP systems using gas depends more on the availability of gas than on its price. Thus, the extent of the natural gas network is a key assumption in many countries. Several countries, including the United States, Canada, Spain, and Switzerland have entire regions that lack natural gas pipelines. Sweden has little or no gas distribution system.

Participating countries selected the AHP systems and market segments that they would analyze in the study. Their selections are listed in Exhibit 2.2. This choice amounted to a prejudgment of the systems most likely to succeed in the market, but limited resources forced some participants to consider less than the full number of systems that could in fact compete in their markets. AHPs 2, 13, and 15/18 were selected for analysis by the most countries, and these systems also demonstrate the most significant market potential.

All countries participating in the market study agreed on the estimated technical performance of the AHP systems analyzed in the study (see the technical profiles in Appendix B), but there was some divergence on the capital costs. The capital costs assumptions made by individual countries are included in the country-by-country AHP market analyses in Chapter 4.

A number of technical constraints limit the market penetration of specific systems, including:

- Space limitations in buildings, especially in replacement/retrofit applications
- Space limitations between buildings, which limit the use of groundwater or soil-source heat pumps; particularly in urban areas
- Difficulty of sizing the unit for both heating and cooling loads
- The high temperature (90/70°C) often required by existing hot water distribution systems
- Climate conditions (cold air temperatures, icing) that render air-source heat pumps unattractive
- High noise-level problems.

In addition, several institutional barriers limit the technical applicability of AHPs, such as environmental restrictions on the use of groundwater as a heat source or safety restrictions on the use of ammonia as a working fluid. Countries considered these constraints in deciding which AHP systems would be able to compete for each market segment. In some cases, the technical constraints represented only partial limitations on the AHP, and they were applied later in the analyses when calculating implementation potentials.

Exhibit 2.2

AHP Profiles Analyzed by National Market Study Teams: Technical and Market Characteristics

AHP Profile	Year of Introduction	Heat Pump Cycle	Drive		Heat Source	Thermal Output (kW)	Market Segment*
			Type	Fuel			
2a	1985-1986	Absorption	Direct	Oil, gas	Ambient air	3-20	SF, MF I
2b	1985-1986	Absorption	Direct	Oil, gas	Ambient air		SF, MF I
3	1981	Absorption	Steam boiler	Oil, gas	Wastewater	>2,000	MF II, district
4	1982	Rankine	Diesel	Oil	Ambient air	10-20	SF, MF I
4a	1980	Rankine	Diesel	Oil	Soil	>400	MF II
5	Before 1985	Rankine	Diesel	Oil	Ambient air	100-6,000	MF II, district
6	1981	Rankine	Diesel	Oil	Sewage	>2,000	MF II
7	1980	Rankine	Otto	Gas	Ambient air	10-400	SF, MF II
8	1981	Rankine	Otto	Gas	Air/ground/ surface water	400	MF II
9	1983	Rankine	Stirling	Oil, gas	Air/ground/ surface water	3-20	SF, MF I
13	1980	Rankine	Motor	Electricity	Ground	3-1,000	SF, MF I, MF II
14	1985	Absorption	Direct	Gas	Ambient air	10-20	SF, MF I
15/18	1985	Rankine	Rankine	Oil, gas	Ambient air	10-400	SF, MF I, MF II
16	1985	Rankine	Brayton	Oil, gas	Ambient air	50	MF II
19	1982	Absorption	Direct	Kerosene	Wastewater	>2,000	District
20	1982	Absorption/ Rankine	Motor	Electricity	Wastewater	>2,000	District

*SF = Single-family houses
MF = Individually heated apartment units
MF II - Apartment units in centrally heated buildings
District = District heating

Because AHP systems are almost always more expensive to buy and install than conventional competitors, including electric heat pumps, their economic attractiveness depends largely on achieving low operating costs. Low operating costs in turn require a low energy consumption or high energy efficiency, in addition to reasonable maintenance costs.

The energy efficiency of a heat pump is measured by the seasonal performance factor (SPF), the ratio of energy delivered (or extracted in the case of cooling) to energy consumed over the heating or cooling season (either fossil or electricity) by the entire heat pump system, including the back-up system, if any. Because the instantaneous efficiency (the coefficient of performance or COP) varies with climate for many heat sources (e.g., outside air, soil), calculating SPF can be complex. The approach that most countries used to calculate the SPFs used in the study is outlined in Appendix C. The SPF values for heating are shown in Exhibit 2.3. The countries with the colder, more extreme climates (e.g., Canada, Sweden, United States), show lower SPFs than those with moderate climates (e.g., United Kingdom, Belgium). The Netherlands used COP estimates from revised case studies, instead of cost profiles, used by Austria and the United Kingdom. Therefore, their calculated SPFs are low, which may partly explain why AHPs have no market in that country. The SPFs of AHP 13 (the electric heat pump) are higher than SPFs of systems burning fossil fuels, because they do not reflect electricity generating efficiency.

To calculate measures of economic attractiveness for each AHP system and for each conventional competing system, countries selected measures that reflect the criteria used to select new heating and cooling systems in each market segment. The most common criteria were:

- Initial or first cost: capital cost of the system plus installation cost; the cost of the heat or cold air distribution system was included where the system was not the same for all competing systems. Most countries adjusted costs to reflect government subsidies, if any. Rather than trying to achieve accuracy in total installation cost estimates, which was often impossible because of the very large uncertainty affecting AHP cost estimates, national teams made a special effort to impose consistency on installations cost in each market segment and from one technology to another.

- Life-cycle cost: the capital cost plus the "present value" of the total energy and maintenance costs to be expected over the lifetime of the system.

Countries judged the relative importance of these criteria to decision makers, as shown in Exhibit 2.4. The importance of first cost has been calculated separately from the importance of all other criteria (i.e., life-cycle costs, annual energy costs, and payback period), a key distinction for the market estimates. The technical approach assumes that the demand for heating and cooling installations in a given market segment will be met by the technically feasible conventional or AHP system ranking first on the associated decision criterion. Very often, conventional systems rank first on first cost but behind one or more AHP systems on other, longer-run, criteria. Broadly speaking, those countries with the least preoccupation with first cost (e.g., Denmark, Switzerland, Germany, Sweden) demonstrate good market penetration by heat pumps. Those most interested in first cost (e.g., Italy, the Netherlands, the United States) show smaller markets, at least in terms of market share.

Exhibit 2.1

REPRESENTATIVE HEATING SEASON PERFORMANCE FACTORS (SPF) OF ADVANCED HEAT PUMPS

	Small							Medium						Large			
Country	2	4	7	9	13	14	15/18	4a	5	7	8	13	15/18	16	3	5	6
Austria		1.3			2.9	1.3			1.2			3.1					
Belgium	1.25	1.25			3.37		1.29						1.29				
Canada	1.00																
Denmark					2.1			1.59	1.2			2.52					1.9
Germany	1.38	1.39			3.74		1.18						1.18				
Italy	1.3								1.2								
Japan	1.27			1.33	2.14		1.18	1.84				2.14					
Netherlands	1.19		1.35	1.3		0.87	1.01				1.33						
Spain	1.32				3.34							3.36	1.17				
Sweden	1.1				2.76							3.36				0.85	
Switzerland	1.158	1.183					1.11								1.42		
United Kingdom	1.32	1.35	0.86	1.15	3.25	1.48	1.25										
United States	1.02	1.232	0.807	1.108	2.381		1.081		1.282				1.084	0.994			

NOTE: These SPFs may not be consistent with those in Appendix B because of later regulating.

Exhibit 2.4

IMPORTANCE OF DECISION CRITERIA IN NEW CONSTRUCTION MARKET[a] (%)

Country	Single Family		Multifamily I		Multifamily II	
	Initial Cost	Life-cycle Cost, Annual Energy Cost, and/or Payback Period	Initial Cost	Life-cycle Cost, Annual Energy Cost, and/or Payback Period	Initial Cost	Life-cycle Cost, Annual Energy Cost, and/or Payback Period
Austria	50	50	50	50	30	70
Belgium	75	25	67	33	20	80
Canada	25	75	40	60	NA	NA
Denmark[b]	0	100	10	90	10	90
Germany	40	60	NA	NA	70	30
Italy	60	40	60	40	0	100
Japan	75	25	75	25	75	25
Netherlands	40	60	50	50	50	50
Spain[c]	25	75	45	55	35	65
Sweden[b]	45	55	45	55	30	70
Switzerland	0	100	0	100	0	100
United Kingdom	50	50	75	25	NA	NA
United States	80	20	60	40	50	50

a. Same criteria weightings apply in retrofit market, except in Austria, Belgium, Germany, Sweden, and the United States.

b. Criteria weightings also estimated for block central and district heating.

c. 1996-2000.

The allocation of heating and cooling installations to conventional and AHP systems according to economic performance and decision criteria gives the economic potential for AHPs, the market that AHP systems would have if these factors alone determined the choice of system. In practice almost all the countries reduced these estimates to take account of other factors that are difficult to capture in the technical limitations or the economic calculations. Such factors included:

- The reluctance of consumers to purchase AHP systems until the technology has become familiar, and experienced supply/installation and service networks are established.
- The reluctance of consumers to take the extra time to install an AHP system for replacement applications. He will be strongly tempted to install another conventional system and return heat to the building as soon as possible.
- Institutional or economic constraints that cannot fully be incorporated in earlier steps of the analysis. Detailed discussion of these is contained in Chapter 4.
- Supply constraints on the availability of new AHP systems.

In practice, many of the countries used diffusion or market penetration curves to simulate these effects. The result of applying these additional factors was the implementation potential, the most likely estimate of AHP potential.

3 MARKET ESTIMATES BY AHP SYSTEM

Twenty-one AHP systems were initially selected for analysis in the market study, based on the interests of the participating countries and on a general awareness of current research developments. Because not enough of the data needed for both the technical and market studies were available for all 21 systems, the number of systems analyzed was reduced to 15 (see Exhibit 3.1). The following systems were eliminated from the market study:

- Ground-source absorption (AHP 1)
- Solar-powered absorption (AHP 10)
- Gas-powered absorption with solar assist (AHP 11)
- Solar-driven organic Rankine cycle (ORC) (AHP 12)
- Steam-turbine-driven heat pump, with air-heat source (AHP 17)
- Organic Rankine cycle, with seawater heat source (AHP 18).

To ensure consistency between the market study and technical survey, RPA and Battelle agreed on detailed cost and performance data for the remaining systems. Profiles of each system were compiled and distributed to the participants. Excerpts from each profile are included in Appendix B. In some cases the technical performance and cost data in these initial profiles were later updated. The updated values are included in the profiles of individual systems in Appendix B.

Each country then selected system profiles for analysis, matching profiles against its energy situation, available fuels, building stock, and climate. This selection amounted to a preassessment of the system most likely to succeed in each market. However, limited study resources forced some participants to consider less than the full number of systems that could in fact compete in the markets in those countries.

Seven systems appear to have the greatest market potential, and seven have limited or insignificant market shares. In the first part of this chapter, we describe AHP systems 2, 4, 5, 9, 13, 14, and 15/18 in detail. These systems, selected for analysis by more than one country, demonstrate the most market potential. In the remainder of this chapter, we describe we briefly explain why AHP systems 3, 4a, 6, 7, 8, 16, 19, and 20 have no significant market potential.

Exhibit 3.1

AHP Profiles Analyzed by National Market Study Teams: Technical and Market Characteristics

AHP Profile	Year of Introduction	Heat Pump Cycle	Drive		Heat Source	Thermal Output (kW)	Market Segment*
			Type	Fuel			
1		Absorption	Direct	Oil, gas	Ground	3-4	SF, MF I
2a	1985-1986	Absorption	Direct	Oil, gas	Ambient air	3-20	SF, MF I
2b	1985-1986	Absorption	Direct	Oil, gas	Ambient air		SF, MF I
3	1981	Absorption	Steam boiler	Oil, gas	Wastewater	>2,000	MF II, district
4	1982	Rankine	Diesel	Oil	Ambient air	10-20	SF, MF I
4a	1980	Rankine	Diesel	Oil	Soil	>400	MF II
5	Before 1985	Rankine	Diesel	Oil	Ambient air	100-6,000	MF II, district
6	1981	Rankine	Diesel	Oil	Sewage	>2,000	MF II
7	1980	Rankine	Otto	Gas	Ambient air	10-400	SF, MF II
8	1981	Rankine	Otto	Gas	Air/ground/ surface water	400	MF II
9	1983	Rankine	Stirling	Oil, gas	Air/ground/ surface water	3-20	SF, MF I
10		Absorption	– Solar –		Solar	15-20	
11		Absorption	Solar	Gas	Room air	3-4	
12		Rankine	Rankine	Solar	Room air	3-4	
13	1980	Rankine	Motor	Electricity	Ground	3-1,000	SF, MF I, MF II
14	1985	Absorption	Direct	Gas	Ambient air	10-20	SF, MF I
15/18	1985	Rankine	Rankine	Oil, gas	Ambient air	10-400	SF, MF I, MF II
16	1985	Rankine	Brayton	Oil, gas	Ambient air	50	MF II
17		Rankine	Rankine	Oil, gas	Ambient air	>50	MF II
18		Rankine	Rankine	Oil, gas	Sea water	400	
19	1982	Absorption	Direct	Kerosene	Wastewater	>2,000	District
20	1982	Absorption/ Rankine	Motor	Electricity	Wastewater	>2,000	District

*SF = Single-family houses
MF I = Individually heated apartment units
MF II = Apartment units in centrally heated buildings
District = District heating

SYSTEMS WITH GREATER
MARKET POTENTIAL

AHP 2: Absorption System

Technical Potential

AHP 2, which will be introduced in 1985-1986, is an absorption unit. Version 2a offers heating and cooling; version 2b offers heating only. The impact of the system's technical characteristics on its technical potential market is shown in Exhibit 3.2. The system is technically applicable in all countries and was analyzed by more countries than any other system.

Economic Potential

Different cost and performance data sets were prepared for both versions of AHP 2. The price of version 2a, a heating and cooling system, was estimated by the manufacturers to be rather low (e.g., 5,000 DM for 20-kW output), compared to the estimated cost of version 2b, a heating-only unit (8,000 DM for the same heat output).

The heating and cooling version (2a) was evaluated in the U.S. and Japanese markets only. The heating-only version (2b) was also evaluated by the U.S. team, which reduced the estimated cost of version 2b to approximately 4,500 DM (for 20-kW output) to make it more consistent with national conditions. Economic potential is summarized in Exhibit 3.3.

Although AHP 2 requires no backup boiler, its high initial cost generally limits its economic potential. Initial cost is often the major criterion used by potential purchasers. Both conventional heating technologies, including electric heat pumps, and several advanced technologies (e.g., advanced boilers or furnaces, AHPs 9, 14, 15/18) have a lower initial cost.

This system has a high potential in countries such as Germany and Sweden, where the cost of conventional systems (e.g., oil boilers) is relatively high. It also penetrates the market in the United States, but only in that part of the market that uses life-cycle cost as a decision criterion.

Twelve countries evaluated the potential of AHP 2. In Belgium, the initial cost of the system is too high (by 3,000 DM) to allow a penetration of the market. Alternatively, its seasonal performance factor (SPF) should be increased to 1.5 and more.

In Canada, AHP 2 captures 42 percent of the market in the period 1986-1995, with major installations occurring in new construction. However, competition with advanced gas furances was not considered, which would reduce this share. In the 1996-2000 period, relatively low electricity tariffs will make the conventional electric heat pump very competitive, thus reducing AHP 2's share to 18 percent.

Exhibit 3.2
TECHNICAL CHARACTERISTICS OF AHP 2

Technical Characteristic	Impact
Working fluid: organic	No impact
Fuel: natural gas or oil	No impact
Heat source: air	No impact
Distribution system: water or air	No impact
Thermal output: 10-20 kW	Limits application to single-family and multifamily I market segments

Exhibit 3.3
ECONOMIC POTENTIAL OF AHP 2
AVERAGE ANNUAL INSTALLATION (000) AND MARKET SHARE (%)

Country/ System	Market Segment	1986-1990 (Market Share)	1996-2000 (Market Share)
AHP 2a (H/C)			
Japan	SF, MFI	-	-
United States	SF, MFI	180 (3.4%)	208 (4.1%)
AHP 2b (H)			
Austria	SF	Not evaluated; potential will be lower than AHP 14.	
Belgium	SF	-	-
Canada	SF	73 (42%)	29 (18%)
Denmark	SF	Not evaluated; potential could be large.	
Germany	SF	174 (44%)	191 (48%)
Italy	SF	-	-
Netherlands	SF	-	-
Spain	SF, MFI	-	-
Sweden	SF	11 (23%)	10 (24%)
Switzerland	SF	1 (1%)	7 (8%)
United Kingdom	SF	-	-
United States	SF, MFI	84 (1.6%)	112 (2.2%)
TOTAL		523	557

In Denmark, AHP 2 could perform well in the single-family market, as it does in Germany and Sweden, unless advanced gas boilers appear to be economically superior on energy cost or payback-period criteria.

In Germany, AHP 2 could represent half of all heating and cooling installations from 1986, on economic factors alone. With a cost reduction of 3,000 DM, the market potential could be 100 percent. In the first period after introduction, one-fifth of all AHP 2 installations would be gas units; this proportion becomes one-third in 1996-2000, as the gas network is extended. In Germany, 62 percent of all AHP 2 installations will be made in existing buildings, a large proportion of which will be replacements of conventional heat generators in centrally heated single-family houses.

In Italy, Japan, the Netherlands, and the United Kingdom, AHP 2 is not competitive with other systems and has no chance to enter the market. Cost reductions achieved through R&D efforts or subsidies would increase its market share.

In Spain, restrictions on the use of oil and the national team's assumption of rising electricity prices allow AHP 2 to enter the market in the period 1991-1995, although it is more expensive than competing systems. The Spanish market share held by AHP 2 in the period 1996-2000, however, is only 6 percent.

In Sweden, AHP 2 takes a large part of the market in single-family houses heated by individual central water systems. The economic potential stays around 10,000 units during the 1986-2000 period (25 percent of the market).

In Switzerland, it was estimated that AHP 2 has an economic potential of approximately 1,000 units in the period 1986-1990. This potential will increase to 7,000 units by the 1996-2000 period.

In the United States, heating-only and heating and cooling installations of AHP 2 will capture 5 percent of the total single-family and multifamily I markets in 1986-1990. AHP 2 systems will account for 84,000 heating-only installations and 180,000 installations of heating and cooling units. This potential is strongly limited by the minor importance of life-cycle cost in the decision process used by purchasers. From 1986-2000, AHP 2 will have an economic potential of 351,000 units (6 percent of the market).

Implementation Potential

The implementation potential of AHP 2 was analyzed in Canada, Germany, Sweden, and the United States, the four major countries with significant economic market potential for this system.

In Sweden, AHP 2 must be produced domestically to meet climatic conditions and Swedish standards. Manufacturers' capacity will therefore limit market penetration of AHP 2 for the first 5 years after its introduction (1986-1990). Other possible constraints, such as lack of consumer acceptance or limited numbers of installers and maintenance companies, will not affect its diffusion during this period. AHP 13, introduced earlier on the market, will be affected by these factors.

In Germany, Canada, and the United States, diffusion rates were derived from those observed for similar heating technologies in the past. The implementation potentials for AHP 2 in these four countries are compared in Exhibit 3.4.

AHP 4: Diesel Rankine System

Technical Potential

AHP 4, introduced in 1982, is a Diesel Rankine unit used for heating only. The impact of the system's technical characteristics on its technical potential market is summarized in Exhibit 3.5.

This system was analyzed by Austria, Belgium, Germany, Switzerland, the United Kingdom, and the United States. Although it is technically applicable in most other countries, it was not analyzed for various reasons. For example, low natural gas prices in Canada and the Netherlands prevent it from being economically competitive.

Economic Potential

The installed cost of AHP 4 is 7,000 DM for 10- to 12-kW output and 9,000 DM for 15- to 20-kW output, which is relatively higher than competing AHP systems 2, 9, 13, 14, and 15/18. In addition, AHP 4 requires a gas- or oil-fired boiler as a backup system. Larger Diesel-driven heat pumps (e.g., AHPs 4a and 5) are relatively less expensive, indicating that Diesel-driven heat pumps generally benefit from economies of scale.

The system captures market share over the period 1982-2000 only in the United Kingdom and Switzerland. In both countries it is more expensive than competing conventional systems and does not rank first on a life-cycle cost basis. Even so, the United Kingdom assumed that AHP 4 could capture 10 percent of the portion of the single-family and multifamily I segments where gas is not available and life-cycle cost is used as a decision criterion. In Switzerland, where life-cycle cost is the only decision criterion used, experts assumed that AHP systems would gain some market share.

In Belgium, Germany, and the United States, AHP 4 penetrates the market for the first few years after its introduction, but disappears after AHPs 2 and 15/18 are introduced. It does not penetrate the market at all in Austria, where its initial cost differential over competing conventional and AHP systems is too high to be compensated by energy savings. As a result, AHP 4 is economically competitive only on the basis of life-cycle cost or payback period. The economic potential market of AHP 4 in the United Kingdom and Switzerland is summarized in Exhibit 3.6.

Implementation Potential

The implementation potential of AHP 4 was estimated by the United Kingdom, assuming 6 years for full consumer acceptance of such a new technology (see Exhibit 3.7).

Exhibit 3.4
IMPLEMENTATION POTENTIAL OF AHP 2:
AVERAGE ANNUAL INSTALLATION (000) AND MARKET SHARE (%)

Country/ System	Market Segment	1981-1985 (Market Share)	1986-1990 (Market Share)	1991-1995 (Market Share)	1996-2000 (Market Share)	Cumul-ative Sales 2000
AHP 2a (H/C)						
United States	SF, MFI	0	80.0 (1.5%)	191.0 (3.3%)	208.0 (4.1%)	479
AHP 2b (H)						
Canada	SF	0	3.5 (5%)	8.8 (12%)	15.7 (21%)	28
Germany	SF	0	5.8 (3%)	13.6 (6%)	26.2 (13%)	230
Sweden	SF	0	3.5 (8%)	10.2 (24%)	10.0 (24%)	24
United States	SF, MFI	0	37.0 (0.7%)	72.0 (1.2%)	112.0 (2.2%)	221
TOTAL			153.0	350.0	479.0	982

Exhibit 3.5
TECHNICAL CHARACTERISTICS OF AHP 4

Technical Characteristic	Impact
Working fluid: R12	No impact
Fuel: oil	No impact
Heat source: air	No impact
Distribution system: water	Prevents retrofit application where existing system is air
Thermal output: 10-20 kW	Limits application to single family and multifamily I segments

Exhibit 3.6
ECONOMIC POTENTIAL OF AHP 4:
AVERAGE ANNUAL INSTALLATIONS (000) AND MARKET SHARE (%)

Country	Market Segment/Use	1986-1990 (% Market Share)	1996-2000 (% Market Share)
United Kingdom	SF, MFI where gas is not available/heating	20.2 (4%)	17.4 (4%)
Switzerland	SF/heating	2.2 (6%)	7.0 (17%)
TOTAL		22.4	24.4

Exhibit 3.7
IMPLEMENTATION POTENTIAL OF AHP 4:
AVERAGE ANNUAL INSTALLATIONS (000)

Country	Market 1981-1985	1986-1990	1991-1995	1996-2000	Total Cumulative Sales 1981-2000
United Kingdom	8.6	20.2	17.4	17.4	317.9

AHP 5: Diesel-Rankine System

Technical Potential

AHP 5, introduced by 1985 or possibly earlier, is a Diesel Rankine unit. It is used for heating only, but could be designed for cooling. The impact of the system's technical characteristics on its technical potential market is summarized in Exhibit 3.8.

The technical potential for AHP 5 was analyzed by national teams in Austria, Denmark, Italy, Sweden, and the United States. It is too large to be applicable in most other countries, although Switzerland uses large systems for district heating. However, AHP 5 was not considered by Switzerland because of its low water-delivery temperature.

Economic Potential

The unit cost of AHP 5 with an output of 800 kW is approximately 200,000 DM. An existing fossil fuel-fired boiler is required as a backup system. The economic potential market for AHP 5 is shown in Exhibit 3.9.

AHP 5 has significant economic potential in Austria, Sweden, and Denmark. In the Austrian market for medium-sized systems, it ranks below AHP 13 on life-cycle cost and payback period criteria, but captures that portion of the market where AHP 13 is not technically applicable. Over the period 1981-2000, AHP 5 captures approximately 42 percent of the multifamily II new construction market and 10 percent of the retrofit market. In Sweden, the 1-MW AHP 5 captures 50-55 percent of the block central heating market, as a result of its good ranking on life-cycle cost and payback period criteria. The 10-MW AHP 5 captures approximately 87 percent of the small-size district heating system market; on the average, however, this share corresponds to only 2 percent of the capacity installed in district heating systems each year.

The system does not have significant economic potential in the United States and Italy. Because it is used for heating alone, it captures only a small portion of the market in the United States, which has a large demand for both heating and cooling. In addition, the system ranks first only on the criterion of life-cycle cost, which is not considered by most American consumers. AHP 5 captures no market share in Italy, where its initial cost is relatively high and its high maintenance costs offset energy savings over the system's life.

In Denmark, the medium-size AHP 5 captures approximately half of the multifamily II market, and the large version half of the district heating system market in the period 1996-2000. AHP 5 as a whole capture 80-90 percent of the total market for medium and large systems in Denmark. AHP 5 is not as economically competitive as other AHP systems; however, its widespread technical applicability allows it to capture some market share.

Implementation Potential

The implementation potential of AHP 5, analyzed by Denmark, Sweden, and the United States, is shown in Exhibit 3.10. By the year 2000, about 10,700 medium-size units will be installed in Denmark and the United States, and about 10,960 large units in Denmark and Sweden.

Exhibit 3.8
TECHNICAL CHARACTERISTICS OF AHP 5

Technical Characteristic	Impact
Working fluid: R12	No impact
Fuel: Diesel oil	No impact
Heat source: air	No impact
Distribution system: water	Prevents retrofit application where existing system is air
Thermal output: 200 kW to several MW	Limits application to multifamily II segment and block centrals, district heating

Exhibit 3.9
ECONOMIC POTENTIAL OF AHP 5:
AVERAGE ANNUAL INSTALLATIONS (000) AND MARKET SHARE (%)

Country	Market Segment	1986-1990 (Market Share)		1996-2000 (Market Share)	
Austria	MFII	12.0	(18%)	14.0	(21%)
Denmark	MFII	0.11	(18%)	0.3	(51%)
	BC, DH	0.83	(55%)	0.85	(54%)
Italy	MFII	0		0	
Sweden	BC	0.213	(55%)	0.287	(53%)
	DH	0.005	(87%)	0.005	(87%)
United States	MFII	0.5	(1.6%)	0.4	(1%)
TOTAL		13.68		15.83	

Exhibit 3.10
IMPLEMENTATION POTENTIAL FOR AHP 5:
AVERAGE ANNUAL INSTALLATIONS (000)

Country/System	1986-1990	1991-1995	1996-2000
Medium system:			
Denmark	0.55	0.205	0.3
United States	0.48	0.42	0.41
Large system:			
Denmark	0.42	0.84	0.85
Sweden	0.028	0.09	0.242

AHP 9: Stirling-Rankine System

Technical Potential

AHP 9, introduced in 1983, is a Stirling/Rankine unit used for both heating and heating/cooling. The impact of the system's technical characteristics on its technical potential market is illustrated in Exhibit 3.11.

AHP 9 was analyzed only by national teams in Japan, the Netherlands, the United Kingdom, and the United States; even though the system is applicable in other countries, including Sweden. AHP 9 uses an air distribution system, whereas existing distribution systems are primarily water. As a result, AHP 9 has limited technical applicability in the retrofit market. In addition, Canada felt the system was not economically competitive and that low natural gas prices would decrease the likelihood of its use.

Economic Potential

The installed cost of AHP 9 with an output of 15-20 kW is 5,000 DM. In addition, a natural gas or oil boiler is required as a backup system. The economic potential market of AHP 9 in Japan and the United States is shown in Exhibit 3.12.

AHP 9 captures significant market share only in Japan, where an oil-fired configuration was analyzed. It ranks first above competing conventional systems and AHPs 2 and 15/18 on the basis of initial cost and payback period, capturing 100 percent of the single-family and multifamily market segment where heating and cooling is required (over half of the total single-family, multifamily I market segments). However, since Japan assumed an unusally low initial cost, market potential for AHP 9 may have been overestimated.

In the United States, where a gas-fired configuration was analyzed, the system captures a small portion of the market in the first few years after its introduction, but disappears from the market after AHPs 2 and 15/18 are introduced.

In both the Netherlands and the United Kingdom where gas-fired configurations were analyzed, AHP has no significant economic penetrations. In the Netherlands, it ranks below conventional systems but above other advanced systems (AHPs 2, 14, and 15/18) competing in the single-family market segment. In the United Kingdom, AHP 9 ranks below competing conventional systems as well as AHPs 14 and 15/18, which do capture market share.

Implementation Potential

Japan analyzed the implementation potential of AHP 9, assuming it would be a percentage of economic potential, as shown in Exhibit 3.13. Using this market penetration rate, approximately 2.5 million units will be installed in Japan (by 2000). Exhibit 3.14 shows average annual installations over the period 1986-2000.

Exhibit 3.11
TECHNICAL CHARACTERISTICS OF AHP 9

Technical Characteristic	Impact
Working fluid: R22	No impact
Fuel: natural gas or oil	No impact
Heat source: air	No impact
Distribution system: air	Prevents retrofit application where existing system is water
Thermal output: 10-20 kW	Limits application to single-family and multifamily I segments

Exhibit 3.12
ECONOMIC POTENTIAL OF AHP 9:
AVERAGE ANNUAL INSTALLATIONS (000) AND MARKET SHARE (%)

Country	Market Segment/Use	1986-1990 (Market Share)	1996-2000 (Market Share)
Japan	SF, MFI/H & C	83.3 (46%)	250.1
United States	SF, MFI/H & C	1.3 (0.02%)	0
TOTAL		84.6	250.1

Exhibit 3.13

Implementation Potential of AHP 9 as a Percentage of Economic Potential

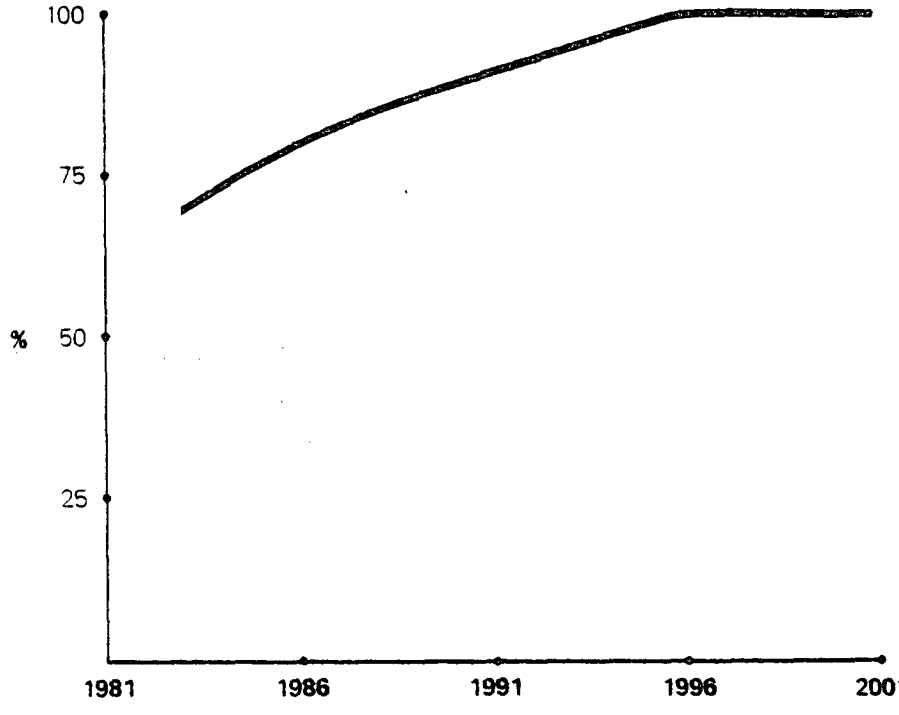

Exhibit 3.14
IMPLEMENTATION POTENTIAL OF AHP 9:
AVERAGE ANNUAL INSTALLATIONS (000) AND MARKET SHARE (%)

Country	1986-1990	1991-1995	1996-2000
Japan	66.6 (37%)	140.6 (45%)	250.1 (53%)

AHP 13: Electric Rankine System

Technical Potential

AHP 13 is an electric motor/Rankine unit used for heating only. One version of this system, which will be introduced between 1982 and 1985, uses vertical ground coils as a heat source. The other version, introduced in 1980, uses horizontal ground coils. The impact of the system's technical characteristics on its technical potential market is summarized in Exhibit 3.15.

AHP 13 was analyzed in the majority of countries, including Austria, Belgium, Denmark, Germany, Japan, Spain, Sweden, the United Kindgom, and the United States. Although, it is technically applicable in Italy and Switzerland, it was not analyzed in these countries. In Canada and the Netherlands, the system was not analyzed because electricity prices are relatively higher than those of natural gas.

Economic Potential

The installed cost of AHP 13 with 10- to 12-kW output is approximately 13,000 DM, relatively higher than that of competing AHP systems (e.g., small AHPs 2, 4, 9, 14, and 15/18; medium AHPs 5 and 15/18). In addition, an electric resistance backup system is required.

The small AHP 13 (used in individually heated housing units) was analyzed in all countries, but gains significant market share only in Japan, Sweden, and Denmark. In Japan, it ranks first on payback period and captures the portion (25 percent) of the market in heating-only regions that uses payback period as a decision criterion. The competing conventional oil boiler ranks first on initial cost, and captures the remaining 75 percent of that market.

In Sweden, AHP 13 captures approximately 13-14 percent of the single-family market. It loses market share to AHP 2 on the basis of payback period, but ranks well on the criterion of life-cycle cost. Limitations on its technical applicability further reduce its economic potential market.

In Denmark, AHP 13 captures 38-50 percent of the single-family market, because heating-systems purchasers are highly sensitive to energy costs and payback period and electricity is relatively less expensive than oil. As in Sweden, AHP 13's potential in Denmark is somewhat constrained by its limited technical applicability.

In the remaining countries, the small version of AHP 13 does not capture significant market share. In Germany, it captures only 1 percent of the single-family market, primarily because of its high initial cost and consumer reluctance to install electric heating systems.

In Belgium, AHP 13 captures market share in the first few years after its introduction, but loses share when AHP 15 is introduced. In Austria, Spain, the United Kingdom, and the United States, the system is too expensive and seems to have no market potential.

Exhibit 3.15
TECHNICAL CHARACTERISTICS OF AHP 13

Technical Characteristic	Impact
Working fluid: R22	No impact
Fuel: electricity	No impact
Heat source: ground	Prevents application where adequate ground area is not available; important barrier for version using horizontal ground coils, as an area of approximately 200 m^2 is required for a single-family system; vertical-coil system can be used only where ground is clay
Distribution system: water or air	No impact
Thermal output: 3-100 kW	No impact; application in all market segments

The medium AHP 13 system (used in centrally heated buildings) was analyzed in Austria, Denmark, Japan, Spain, and Sweden, and gains market share in all of these countries except Spain. In Austria, it captures about 15 percent of the multifamily new construction market and 25 percent of the multifamily retrofit market over the period 1986-2000. It ranks first on life-cycle cost and payback period, but requires a large ground area, which limits its technical, and thus economic, potential markets.

In Denmark, AHP 13 captures 25 percent of the multifamily II market over the period 1981-2000. The percentage is somewhat lower in the early years (approximately 13 percent) and higher in the later years (40 percent), because it ranks well on the criterion of life-cycle cost by 1981, and well on the basis of both life-cycle cost and payback period by 1991. Limitations on its technical applicability reduce its economic potential market.

In Japan, like the small version of AHP 13, the medium-sized version ranks first on payback period and captures 25 percent of the multifamily II market segment in heating-only regions. Again, the competing conventional oil boiler captures the remaining 75 percent of the market that uses initial cost as a decision criterion.

In Sweden, AHP 13 captures approximately 15 percent of the multifamily market, but its economic potential is constrained by its limited technical applicability. In Spain, both sizes of AHP 13 are too expensive and have no economic potential.

A large version of AHP 13 (used in block central and district heating) was analyzed by Sweden and Denmark. In Sweden, this version gains only a small portion of the block-central market, because AHP 5 ranks above it on life-cycle cost and payback period, the decision criteria used in this segment. In Denmark, it gains only 10 percent of the district heating market, due to severe limitations on its technical applicability. Economically, the system ranks first on life-cycle cost, the only decision criterion used in this segment.

The economic potential market for AHP 13 is summarized in Exhibit 3.16.

Implementation Potential

The implementation potential of AHP 13 was analyzed by Germany, Japan, and Sweden. The results are shown in Exhibit 3.17. By 2000, approximately 537,000 small systems, 2,300 medium systems, and 286 large systems will be installed.

AHP 14: Absorption System

Technical Potential

AHP 14, introduced in 1985, is an absorption unit used for both heating and cooling. The impact of the system's technical characteristics on its technical potential market is summarized in Exhibit 3.18.

AHP 14 was analyzed by national teams in Austria, the Netherlands, and the United Kingdom. It is also technically applicable in Canada, Italy, and Switzerland, but was not analyzed in these counties. AHP 14 is not technically

Exhibit 3.16
ECONOMIC POTENTIAL OF AHP 13:
AVERAGE ANNUAL INSTALLATIONS (000) AND MARKET SHARE (%)

Country/ System	Market Segment/Use	1986-1990 (Market Share)	1996-2000 (Market Share)
Small system:			
Austria	SF/heating	0	0
Belgium	SF, MFI/heating	0	0
Denmark	SF/heating	30 (41%)	25 (51%)
Germany	SF/heating	4 (1%)	4 (1%)
Japan	SF, MFI/heating	24 (13%)	56 (12%)
Spain	SF/heating	-	-
Sweden	SF/heating	5.5 (13%)	5.8 (14%)
United Kingdom	SF, MFI/heating	0	0
United States	SF, MFI/heating	0	0
TOTAL		63.5	90.8
Medium system:			
Austria	MF/heating	20 (30%)	20 (30%)
Denmark	MFII/heating	0.08 (13%)	0.23(40%)
Japan	MFII/heating	0.2 (13%)	0.5 (12%)
Spain	MFII/heating	-	-
Sweden	MF/heating	0.1 (14%)	0.02(16%)
TOTAL		20.38	20.75
Large system:			
Denmark		0.15 (10%)	0.16(10%)
Sweden	Block central/ heating	0.09 (22%)	0.1 (22%)
TOTAL		0.24	0.26

Exhibit 3.17
IMPLEMENTATION POTENTIAL OF AHP 13
AVERAGE ANNUAL INSTALLATIONS (000)

Country/System	1986-1990	1991-1995	1996-2000
Small system:			
Germany*	0.5	0.8	1.2
Japan	16.7	31.5	50.4
Sweden	5.5	5.9	5.8
Medium system:			
Japan	0.17	0.32	0.46
Sweden	0.11	0.07	0.02
Large system:			
Sweden	0.06	0.09	0.11

* Slow penetration rate.

Exhibit 3.18
TECHNICAL CHARACTERISTICS OF AHP 14

Technical Characteristic	Impact
Working fluid: ammonia/water	Prevents application in countries where the use of ammonia is restricted
Fuel: natural gas	Limits application to the portions of a country where natural gas connections are available
Heat source: air	No impact
Distribution system: water or air	No impact
Thermal output: 10-20 kW	Limits application to single-family and multifamily I market segments

applicable in the remaining market study countries, which restrict the use of ammonia as a working fluid and prefer AHP 2, a similar system using an organic working fluid.

Economic Potential

The initial cost of AHP 14 is relatively lower than that of competing AHP systems 2, 4, 9, 13, and 15/18, although still higher than competing conventional systems. The cost of a unit with 10- to 12-kW output is approximately 4,000 DM; a unit with 15- to 20-kW output costs approximately 7,000 DM. No backup system is required. The cost estimates as given in Appendix B may be too optimized.

The system performs well in Austria, where the initial cost of competing conventional systems is relatively high. It ranks first on payback period and, over the period 1986-2000, captures 50 percent of the single-family new construction market and approximately 20 percent of the single-family retrofit market. It gains no market share in the Netherlands, however, because of the relatively lower initial cost of competing conventional and advanced conventional boilers.

In the United Kingdom, where competing conventional systems are also initially less expensive, the national team assumed that AHP 14 could capture approximately 30 percent of the portion of the SF and MFI market segments where natural gas is available and that use life-cycle cost as a decision criterion. The economic potential market for AHP 14 in Austria and the United Kingdom is shown in Exhibit 3.19.

Implementation Potential

The implementation potential of AHP 14 was analyzed only by the United Kingdom, which assumed that it would take 6 years after introduction for full consumer acceptance of a new technology. During this period, its implementation potential as a percentage of economic potential would be as follows: 10 percent in year 1, 20 percent in year 2, 30 percent in year 3, 50 percent in year 4, 75 percent in year 5, and 90 percent in year 6. Starting in year 7, implementation potential would be 100 percent of economic potential. By the year 2000, approximately 1.5 million units will be installed in the United Kingdom.

AHP 15/18: ORC System

Technical Potential

AHP 15/18, introduced in 1985, is an organic Rankine/Rankine unit used for both heating and heating/cooling. The impact of the system's technical characteristics on its technical potential market are summarized in Exhibit 3.20. The system is technically applicable in all countries. It was analyzed by national teams in Belgium, Germany, Japan, the Netherlands, Switzerland, the United Kingdom, and the United States.

Exhibit 3.19
ECONOMIC POTENTIAL OF AHP 14
Average Annual Installations (000) And Market Share (%)

Country/ System	Market Segment/Use	1986-1990 (Market Share)	1996-2000 (Market Share)
Austria	SF/heating	9 (24%)	12 (30%)
United Kingdom	SF, MFI where gas is available/heating	142 (12%)	134 (13%)
Total		151	146

Exhibit 3.20
TECHNICAL CHARACTERISTICS OF AHP 15/18

Technical Characteristic	Impact
Working fluid: various	No impact
Fuel: natural gas or oil	No impact
Heat source: air	No impact
Distribution system: water or air	No impact
Thermal output: 10 kW and up	No impact; applicable in all market segments

Economic Potential

The target installed cost of a small AHP 15/18 with output of 10-12 kW is approximately 5,700 DM. Medium and large versions with 20 kW output or more cost approximately 500 DM/kW. In addition, an auxiliary boiler is required as a backup system.

The small system (used in individually heated housing units) was analyzed by a number of market study countries. It has significant economic potential only in Belgium, Germany, and the United Kingdom. In Belgium, the oil-fired configuration ranks above competing conventional and oil boilers and AHPs 2, 4, and 13 on payback period, allowing it to capture 30 percent of the market for small systems by 1996-2000.

In Germany, the oil-fired configuration ranks first on the basis of initial cost for new and modernization applications, allowing it to capture 12 percent of the small-systems market by 1996-2000. However, it is outranked by the competing conventional oil boiler on the basis of initial cost for replacement applications and by AHP 2 on the basis of energy cost (the only other decision criterion used in Germany) for all applications. The gas-fired configuration gains a small market share over the period 1985-1990, ranking well on the basis of energy cost. However, after 1990, AHP 15/18 has no market potential in Germany, losing to the competing AHP 2.

In the United Kingdom, the gas-fired configuration captures 4 percent of the market where natural gas is available by 1996-2000. It ranks relatively well on life-cycle costs, and the British study team assumed it could capture 10 percent of the portion of the market using life-cycle cost as a decision criterion.

The system does not attain significant economic potential in other countries. In the United States, the oil-fired configuration gains only a small portion (less than 1 percent) of the market for small systems over the period 1985-1990. After 1990, it gains no market share, losing to AHP 2. In Japan and the Netherlands, AHP 15/18 has no economic potential market because of its poor performance and high initial cost.

The medium system (used in centrally heated buildings) was analyzed in Belgium, Germany, Switzerland, and the United States, and captures market share in each. In Belgium, the oil-fired configuration ranks first on the basis of payback period, allowing it to capture 38 percent of the multifamily II market by 1996-2000.

In Germany, AHP 15/18 wins the portion of the multifamily market that uses energy cost as a decision criterion, capturing 15 percent (oil-fired) and 11 percent (gas-fired) by 1996-2000. Competing conventional oil and gas systems rank first on initial cost.

In Switzerland, the AHP 15/18 systems rank relatively well on life-cycle cost, the only decision criterion used, and capture 16 percent of the multifamily II market by 1996-2000.

The system also ranks well on life-cycle cost in the United States, which uses primarily the gas-fired configuration, and it captures 4-5 percent of the total multifamily II market during 1986-2000. In the multifamily II market requiring heating/cooling systems, it achieves 10-percent market share over the same period. The economic potential markets for both small and medium AHP 15/18 configurations in the seven market study countries that analyzed it are listed in Exhibit 3.21.

Implementation Potential

The implementation potential of AHP 15/18, analyzed by Belgium, Germany, the United Kingdom, and the United States, is shown in Exhibit 3.22.

SYSTEMS WITH LIMITED MARKET POTENTIAL

AHP 3: Absorption System

AHP 3 is a large absorption system for district heating applications. It is powered by a steam boiler and uses wastewater as a heat source. Switzerland, the only country to analyze this system, predicted a 16-percent share for it in district heating applications.

AHP 3 uses ammonia as a working fluid, which constrains the system's potential market in countries that prohibit use of ammonia. A change to an organic working fluid would remove this barrier. The system could then compete with AHP 6 and 19 for district heating applications. In addition, a reduction of minimum size (now 2 MW) could make AHP 3 applicable in multifamily II buildings.

AHP 4a: Diesel System

AHP 4a is a large Diesel-driven heat pump with soil heat source for multifamily and district heating applications. For district heating, AHP 4a was analyzed only in Denmark, where it compares poorly to AHP 5 (the Diesel heat pump with air source) on economic grounds, and in Japan, where it loses to AHP 13. AHP 4a was analyzed in Sweden for multifamily II applications and loses all its potential market share to AHP 13, the electric soil-source heat pump. AHP 4a appears to have too high a first cost and too low an efficiency to compete with other AHP systems.

AHP 6: Diesel System

AHP 6 is a large Diesel-driven heat pump, using wastewater as a heat source and intended for district heating applications. This system was studied only in Denmark, where competition with other large AHPs (AHPs 5 and 13) and rather limited technical applications (the AHP 6 requires connection to a wastewater stream) reduce its potential. It is likely that the same results would occur in other countries interested in district heating applications.

Exhibit 3.21
ECONOMIC POTENTIAL OF AHP 15/18:
AVERAGE ANNUAL INSTALLATIONS (000) AND MARKET SHARE (%)

Country/ System	Market Segment/Use		1986-1990 (Market Share)		1996-2000 (Market Share)
Small system:					
Belgium	Heating		58.6 (28%)		61 (32%)
Japan	Heating & cooling		0		0
Germany	Heating	oil	25 (6%)	oil	48 (12%)
		gas	20.4 (5%)	gas	0
Netherlands	Heating		0		0
United States	Heating,		0.8		0
	Heating & cooling		1.8 (0.05%)		0
United Kingdom	Heating		47.3 (4%)		44.7 (4%)
Total			153.9		153.7
Medium system:					
Belgium	Heating		1.8 (44%)		1.8 (38%)
Germany	Heating	oil	36 (16%)	oil	36 (15%)
		gas	25 (11%)	gas	28 (11%)
Switzerland	Heating		2.4 (5%)		7.6 (16%)
United States	Heating,		0.4 (1%)		0.3 (1%)
	Heating & cooling		1.3 (4%)		1.1 (3%)
Total			66.9		74.8

Exhibit 3.22
IMPLEMENTATION POTENTIAL OF AHP 15/18:
AVERAGE ANNUAL INSTALLATIONS (000) AND MARKET SHARE (%)

Country/ System	1986-1990	1991-1995	1996-2000	Cumulative Total 1981-2000
Small system:				
Belgium	5.24 (3%)	14.74 (7%)	25.41 (13%)	227
Germany*	2.8 (1%)	3.4 (1.6%)	10 (5%)	81.4
United Kingdom	25.3 (2%)	44.8 (4%)	44.7 (4%)	578.4
United States	2.6 (0.05%)	1.2 (0.02%)	0	19
Medium system:				
Belgium	0.16 (3%)	0.46 (7%)	0.79 (13%)	7
Germany	0.26 (0.25%)	3.4 (3.6%)	4.6 (5.1%)	41.5
United States	0.67 (2%)	1.6 (4.5%)	1.4 (4%)	18.4

* Slow penetration rate.

AHPs 7 and 8: Otto-Cycle System

AHPs 7 and 8 are Otto-engine-driven heat pumps using ambient air or groundwater as a heat source and intended for application in single-family homes and multifamily II buildings. These systems were analyzed only in the Netherlands where, like all other AHP systems, they failed to gain any market share against conventional technologies. Generally, their costs seem too high to allow them to capture market share, even in countries with more favorable conditions.

AHP 16: Brayton-Cycle System

AHP 16 is a Brayton-cycle-driven heat pump of approximately 50-MW capacity, designed for multifamily II buildings and using an air heat source. Although applicable in many countries, this system was studied only in the United States. Due to high first cost, it generates a market only in the South, which has both heating and cooling demand. But even there, conventional systems predominate. In other regions, AHP 16 is less attractive than AHP 15/18.

AHPs 19 and 20: District Heat Absorption Systems

AHPs 19 and 20 are large absorption systems used for district heating applications. They were analyzed only by Japan, which considered AHPs 19 and 20 in competition for heating and cooling applications with other small systems (AHPs 2, 9, and 15/18) in the single-family and multifamily I market segments. In effect, the analysis by the Japanese market study team addresses the question of installing district heating or relying on small systems. The decision maker must chose between large and small systems, a choice not considered by other countries.

AHPs 19 and 20 lose market share to AHP 9 for heating and cooling applications. In a more complete analysis, it would be interesting to compare the competitive position of AHPs 19 and 20 with other district heating systems, because it seems unlikely that small AHPs will compete directly with large systems.

4 MARKETS FOR ADVANCED HEAT PUMP SYSTEMS IN PARTICIPATING COUNTRIES

Thirteen national teams, listed with their key personnel in Appendix A, analyzed the market potential for heat pumps using a technical approach developed by RPA. This technical approach, outlined in Appendix C, consisted of a set of analysis tables and instructions for completing them. The use of standardized tables ensured that the results of the analysis in one country would be comparable to those in another, while allowing for appropriate, country-specific divergence on key assumptions.

For example, each country was free to select the HP systems and market segments appropriate for analysis, depending on that country's heating requirement, current fuel mix, and building stock (see Exhibit 4.1).*

The market estimates for AHP systems made by the individual countries are presented in detail below.

AUSTRIA

National Energy Demand and Residential Consumption

In 1978, Austria's total energy consumption was 25 Mtoe, about the same as Switzerland's; final end-use was 19 Mtoe.** By fuel, oil consumption accounted for 11 Mtoe of total demand, coal about 4 Mtoe, and natural gas about 4 Mtoe. Hydroelectric power met the balance of Austria's energy requirements (about 6 Mtoe if the thermal equivalent is taken).

Austria depends on imports for 58 percent of its energy, including 54 percent of its gas, 70 percent of its coal, and 83 percent of its oil. By 1990, import dependency is expected to increase to 69 percent as domestic energy production declines and oil and gas imports double. In contrast to many other countries, nuclear energy is expected to supply a small portion of Austrian energy demand through 1990, but hydroelectric power, however, will be significantly expanded.

Residential energy consumption represents about 40 percent of end-use demand and is expected to rise to 45 percent by 1990. Because space heating accounts for at least 80 percent of residential consumption, heat pumps could potentially offer a very significant reduction in Austrian energy consumption.

Housing Stock and Current Heating Systems

In 1975, 48 percent of the 2.5 million housing units in Austria were in single- and two-family houses (grouped as single-family housing for convenience),

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* Percentages of fuel consumption were calculated from IEA Balance Sheets (February 1980) to allow easier comparison.

** Million tons oil equivalent.

Exhibit 4.1

Advanced Heat Pump Market Study
AHP Systems and Market Segments Analyzed

Profile/System		Austria	Belgium	Canada	Denmark	Germany	Italy	Japan	Netherlands	Spain	Sweden	Switzerland	United Kingdom	United States
Single-family systems	2a							●						●
	2b		●	●		●	●		●	●	●	●		●
	4	●	●			●						●	●	●
	7								●					●
	9							●	●					●
	13	●	●		●	●		●		●	●			●
	14	●							●				●	
	15/18		●			●		●	●				●	●
Apartment building, building-central	4a										●			
	5	●			●		●							●
	7													●
	8								●					
	13	●			●			●		●	●			●
	15/18		●			●				●		●		●
	16													●
District heating, block-central	3											●		
	4a				●			●						
	5				●						●			
	6				●									
	13				●						●			
	19							●						
	20							●						

41 percent in individually heated apartments, and only 11 percent in centrally heated apartments. This distribution contrasts markedly with Switzerland, where over 80 percent of the entire stock is in centrally heated apartments, and with Germany, where only 25 percent of the units are in single-family houses and 75 percent in apartments. The distribution of heating systems and fuels is categorized by building stock in Exhibit 4.2.

Although the relative distribution of fuels used for heating is expected to remain the same through 2000, the types of heating systems used in Austria are projected to change significantly. Existing housing stock in Austria is now heated by a very high proportion of stoves (in both single-family and multi-family structures) that consume a great diversity of fuels. By 1990, stoves will decline in importance, to 20 percent of the single- and multifamily market. In new construction, 70-80 percent of the market will be captured by central water systems.

Projected Heating and Cooling Installations Through 2000

The annual demand for heating installations will average about 37,000 units per year in single-family houses and 67,000 units per year in multifamily buildings. Installations are categorized by 5-year periods and by fuels for the replacement/modernization/retrofit and new applications in Exhibit 4.3. Replacements will exceed installations in new construction.

Heat Pump Systems and Markets

Although heat pumps have only recently been installed in Austria, Austrian analysts expect the heat pump market to develop rapidly in 2 or 3 years and penetrate 15 percent of the housing market by 2000. Many of the companies marketing this equipment in Germany and Switzerland also have operations in Austria. There is considerable interest in motor-driven and solar-assisted heat pumps. The largest manufacturer of combustion motor-drives for heat pumps in Europe is an Austrian company.

The Austrian market study team evaluated the heat pump systems and markets listed in Exhibit 4.4. Initial costs of AHP systems and competitive conventional systems are estimated in Exhibit 4.5.

Factors Affecting Market Penetration

Recent government legislation provides generous homeowner subsidies (including initial investment plus interest) to encourage the installation of heat pumps for space heating and solar systems, among other energy-saving systems. Like Germany, Austria used the decision criteria listed in Exhibit 4.6 in allocating installations to competing systems.

Market Estimates

The Austrian AHP market potential is summarizes in Exhibit 4.7. In new single-family houses, during the period 1986-2000, AHP 14 has a potential market share

Exhibit 4.2
AUSTRIAN HEATING SYSTEMS AND FUEL TYPES
(% Housing Units)

	SF	MFI	MFII
Heating Systems			
Central air			
Central water	30		100
Space I: electric baseboard heating and ductless furnaces	10	7	
Space II: stoves, room heating units	60	93	
Fuel Type			
Electric	4	13	3
Gas	4	18	4
Oil	26	23	47
District heating			30
Coal, coke	30	37	2
Other (wood)	36	9	14

Exhibit 4.3
PROJECTED AVERAGE ANNUAL HEATING
INSTALLATIONS IN AUSTRIA, 1981-2000 (000)

	1981-1985		1986-1990		1991-1995		1996-2000	
New construction:								
Single-family	10		10		10		10	
Multifamily, individually heated	2		2		2		2	
Multifamily, centrally heated	43		42		42		41	
Replacement, Modernization, and Retrofit:	(SF)	(MF)	(SF)	(MF)	(SF)	(MF)	(SF)	(MF)
Oil	6	5	7	5	7	5	7	5
Gas	2	4	4	5	5	6	7	7
Coal/wood	15	8	15	8	13	8	12	7
Electricity	2	2	2	2	3	3	3	3
District		2		2		2		3
TOTAL	25	21	28	22	28	24	29	25

Exhibit 4.4
COMPETITIVE HEATING SYSTEMS IN
EACH AUSTRIAN MARKET SEGMENT

Market Segment	AHP System	Competing Conventional System
Single-family, new construction	4 (Diesel/Rankine) 13 (electric/Rankine) 14 (ammonia absorption)	Oil and solid fuel, central water, electric resistance
Single-family, existing	4 (Diesel/Rankine) 13 (electric/Rankine) 14 (ammonia absorption)	Oil, solid fuel, central water, electric resistance
Multifamily, new construction	5 (Diesel/Rankine) 13 (electric/soil)	Oil, gas, central water, district heating
Multifamily, existing	5 (Diesel/Rankine) 13 (electric/soil)	Oil, solid fuel, central water, district heating, electric heating

Exhibit 4.5
INITIAL COST OF AHPS AND COMPETING CONVENTIONAL
AND ADVANCED CONVENTIONAL SYSTEMS IN AUSTRIA

Small	Cost (1980 DM)
Small	
AHP 4	25,500
AHP 13	25,500
AHP 14	15,500
Conventional oil (12 kW)	15,200
Medium	
AHP 5	164,000
AHP 13	180,500
Conventional oil (170 kW)	112,000

Exhibit 4.6
AUSTRIAN DECISION CRITERIA (%)

Application	Life-Cycle	Payback Period & Energy Costs	First Cost
Single-family			
New	0	50	50
Existing	0	60	40
Multifamily I			
New	0	50	50
Existing	0	60	40
Multifamily II			
New	30	30	40
Existing	20	30	50

Exhibit 4.7
ECONOMIC POTENTIAL OF HEATING SYSTEMS IN AUSTRIA
(000 Installations/Year)

	1981-1985		1986-1990		1991-1995		1996-2000	
	New	Existing	New	Existing	New	Existing	New	Existing
Single-Family Homes								
Oil boiler	10	8	5	7	5	7	5	7
AHP 14	0	0	5	4	5	5	5	7
AHP 13	0	0	0	0	0	0	0	0
AHP 4	0	0	0	0	0	0	0	0
Electric heating	0	2	0	2	0	3	0	3
Coal/wood	0	15	0	15	0	13	0	13
TOTAL	10	25	10	28	10	28	10	29
Multifamily Buildings								
Oil boiler	14	8	11	5	11	5	10	5
AHP 13	19	2	18	2	18	2	18	2
AHP 5*	3	1	7	5	7	6	7	7
Electric heating	1	0	1	0	1	0	1	0
Coal/wood	0	8	0	8	0	8	0	7
District heating	6	2	6	1	6	2	6	3
TOTAL	43	21	43	22	42	24	41	25

* Introduced in 1984. Total estimated installations (000): 7 in new construction and 4 in existing buildings.

Exhibit 4.8

Economic and Implementation Potential of AHP 14 in Austria
(SF market)

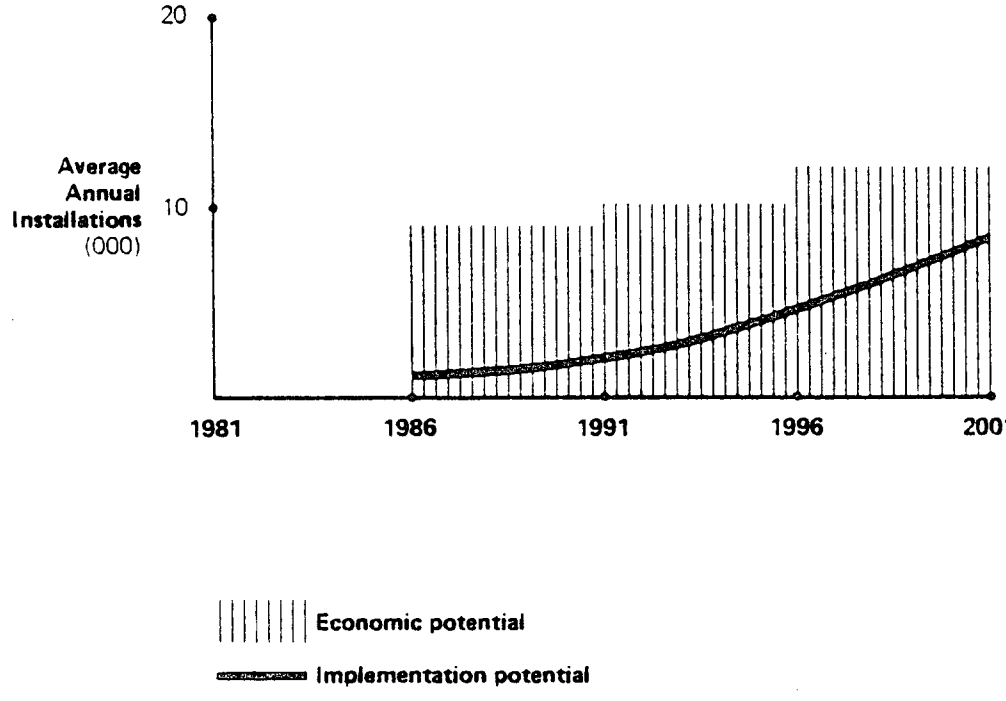
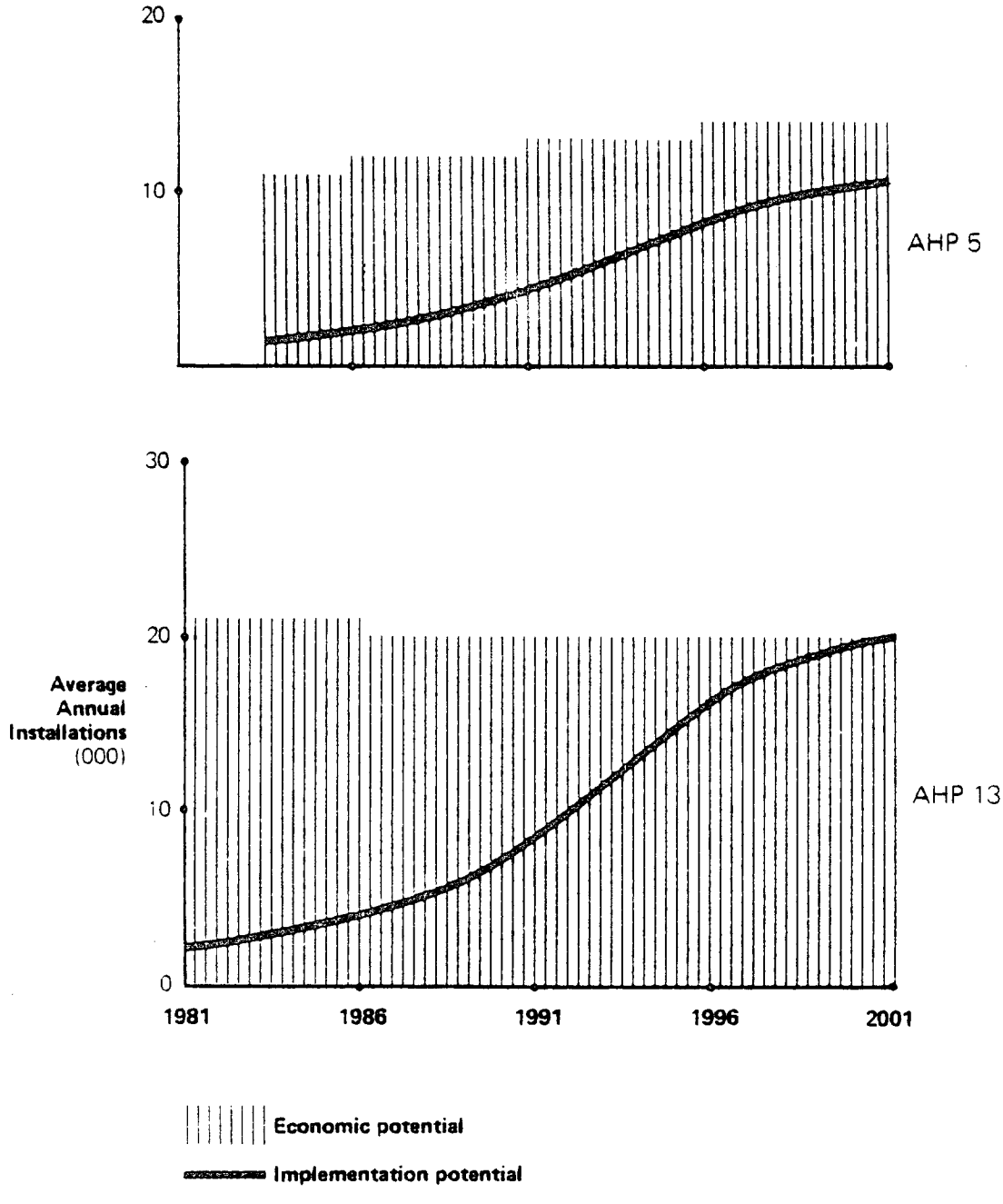


Exhibit 4.9

Economic and Implementation Potential of AHPs 5 and 13 in Austria
(MF market)



of 50 percent, because it ranks above oil boilers to consumers using the payback criterion. In existing single-family houses, the market share for AHP 14 increases from 14 percent to 23 percent during the same period. However, these results must be viewed cautiously. Cost and performance figures were drawn from cost profiles in Appendix B, which may be considered optimistic.

The initial cost of AHP 13 and AHP 4 is more than 10,000 DM in excess of the cost of a conventional system. This difference cannot be compensated by energy savings in less than 7 years for AHP 13, which is not considered acceptable by the Austrian single-family homeowner.

In multifamily buildings, both AHP 13 and AHP 5 penetrate the market. AHP 13 ranks first when life-cycle cost and payback period are used as decision criteria, but this system is not applicable in 100 percent of the market because its heat collector requires ground area. Using the same decision criteria, AHP 5 ranks second and is competitive when AHP 13 is not applicable. The market share of AHP 13 will be 42 percent in new construction and 10 percent in existing buildings during the 1981-2000 period. AHP 5 may be commercialized in 1984 and its market share is estimated at 15 percent in new construction and 23 percent to 29 percent in existing buildings from 1986 to 2000.

Austria did not calculate an implementation potential for AHP systems because of technical and cost limitations. On the basis of a 1978 study by the Technische Universitat Graz, the installation rates of advanced heat pumps could increase by approximately 15 percent per year from 1985 to 2000. Implementation potentials based on this analysis are compared to economic potentials in Exhibits 4.8 and 4.9.

BELGIUM

National Energy Demand and Residential Consumption

In 1978, Belgium's total energy consumption was 45 Mtoe. Final end-use consumption was 36 Mtoe, with 27 percent consumed in the residential sector. Coal is Belgium's only domestic energy resource, making Belgium 85-percent dependent on imported energy resources. Oil imports supply over 55 percent of energy demand, natural gas imports approximately 20 percent, and coal imports approximately 10 percent. Import dependency is predicted to decrease by 5 percent in 1990, as a result of increased use of nuclear energy.

Housing Stock and Current Heating Systems

The 9.9 million residents of Belgium live in 3.3 million housing units, of which approximately 70 percent are single-family houses. Of the remaining units, 17 percent are individually heated apartments and 14 percent are apartments in centrally heated buildings. A breakdown of the building stock by heating systems and fuels is estimated in Exhibit 4.10.

Almost 40 percent of the Belgian housing stock is heated by coal, and an unusually large number of space II systems (stoves and room heating units)

Exhibit 4.10
BELGIAN HEATING SYSTEMS AND FUEL TYPES
(% Housing Units)

	SF	MFI	MFII
Heating Systems			
Space II: stoves, room heating units	68	59	0
Central water	28	38	95
Central air	2	2	5
Space I: electric baseboard heating and ductless furnaces	2	1	0
Fuel Type			
Coal, coke	54	55	2
Oil	33	33	92
Gas	9	9	4
Electricity	3	2	1
Other	1	1	1

are used to heat in single-family houses and apartment units. Almost all centrally-heated buildings have water distribution systems.

By 2000, space II systems in single-family and individually heated apartment units are projected to be replaced by central air and central water systems. Correspondingly, coal use will decrease while oil, natural gas, and solar use will increase. Water-based systems will continue to be used in most centrally heated buildings, with a slight increase in the use of natural gas.

Projected Heating and Cooling Installations

In Belgium an average of 210,000 heating systems will be installed per year over the period 1981-2000. Reflecting the current building stock, an estimated 98 percent of these systems will be installed in single-family houses and individually heated apartments. Replacement and retrofit/modernization of existing systems will account for approximately 80 percent of this demand. (See Exhibit 4.11.)

Replacement of space II systems alone represents 58 percent of all installations through 2000. Most installations will be central systems, but the allocation between air and water distribution is unclear. Since central air distribution is a recent development in Belgium, it can be assumed that central water will continue to dominate.

Heat Pump Systems and Markets

As of 1978, Belgians purchased approximately 1,000 heat pumps for heating residential dwellings, 30 heat pumps for heating and cooling commercial buildings, and 50 heat pumps for swimming-pool heating. All existing systems are of the vapor-compression type, and the large majority are electric. Currently, five Belgian companies assemble heat pumps from imported components. In addition, a large number of engineering firms sell heat pumps imported as ready-to-use packages.

Short-term heat pump market projections are not available; however, given the Belgian energy situation the prospects for heat pumps will depend on both the price of gas and how fast oil and natural gas replace coal. In the residential sector, heat pumps will be applicable for heating only, whereas in the commercial sector they will be applicable for both heating and cooling.

Heat pumps using soil as a heat source appear to have a promising future in Belgium, because soil temperatures are moderate and do not fluctuate extensively. However, to heat a single-family house, these systems require an estimated 250 square meters (m^2) of ground area to provide adequate heat-source capacity. Use of a soil heat exchanger with vertical tubes could alleviate this problem.

The potential for electric heat pumps could be enhanced by the fact that in Belgium electricity is available at a substantially lower price during off-peak hours. To benefit from this rate, consumers may not draw power during peak hours, but must store energy. In addition, power companies do not impose any size limitations on residential electric heating systems. However, in the residential sector, the electric-driven heat pump must achieve an average coefficient of performance (COP) of about 1.9 to save more primary energy than conventional oil-heating systems. Current systems do not seem to be able to achieve this and still cover significant proportions of the heating load.

Exhibit 4.11
PROJECTED AVERAGE ANNUAL HEATING SYSTEM INSTALLATIONS IN BELGIUM, 1981-2000
(000 Units)

	Central Air	Central Water	Unallocated	Total
Single-Family:				
New construction	7	33	-	40
Replacement - central system	3	21	-	24
Replacement - space I	-	-	2	2
Replacement - space II	-	-	100	100
Retrofit/modernization	0	0	4	4
TOTAL	10	54	106	170
Multifamily:				
New construction	1	3	-	4
Replacement - central system	1	11	-	12
Replacement - space I	-	-	1	1
Replacement - space II	-	-	22	22
Retrofit/modernization	-	-	1	1
TOTAL	2	14	24	40

The advanced heat pump systems in Exhibit 4.12 were considered by Belgium within the context of the market study. The costs of AHPs and competing conventional systems are estimated in Exhibit 4.13.

Factors Affecting Market Penetration

The decision criteria estimated to be important in the selection of new heating systems and their estimated relative importance in Belgium are summarized in Exhibit 4.14. The initial cost of a new heating system is the most important criterion for owners of newly constructed single-family houses and individually heated apartments. The payback period is also used, although to a lesser extent, and life-cycle cost is not considered at all. For owners of single-family and individually heated apartments, initial cost, payback period, and market inertia play a role in system selection. For apartments in centrally heated buildings (both new and existing), life-cycle cost and payback period are usually considered, with initial cost also being used to a lesser extent as a decision criterion.

Several institutional regulations represent barriers to the use of heat pump systems. For example, the large-scale indiscriminant use of groundwater as a heat source is prohibited. In addition, regulations governing the use of primary fuels, particularly heating oil, will restrict the use of oil-fired heat pumps.

Belgium's energy policy focuses primarily on energy supply, with far less emphasis being placed on conservation. As such, energy conservation policy in the residential sector consists largely of an information campaign. No subsidies or tax cuts currently encourage homeowners to invest in energy-saving equipment.

Market Estimates

The economic potential market estimated by Belgium for competing systems in residential applications is summarized in Exhibit 4.15. Systems installed in apartments in centrally-heated apartment buildings, which account for only 2 percent of the total installations, are not included in this exhibit.

After its introduction in 1986, AHP 15/18 is the only system projected to gain market share. In the period 1986-2000, it will capture approximately 30 percent of the total new construction and replacement market because it ranks first with decision makers who use the payback period criterion in purchasing a heating system. During the same period, gas boilers will capture 46 percent of the total market, oil boilers 13 percent, coal stoves 6 percent, and direct electric or electric heaters 5 percent.

The implementation potential for AHP 15/18 was estimated assuming a high penetration rate from analogy with diffusion of innovative technologies in the past. The results are summarized in Exhibit 4.16.

Exhibit 4.12
COMPETITIVE HEATING SYSTEMS IN
EACH BELGIAN MARKET SEGMENT

Market Segment	AHP System	Competing Conventional System
Single-family, new construction	2 4 13 15	Oil, central water Gas, central water electric resistance
Single-family, existing stock	2 4 13 15	Oil, central water Gas, central water
Multifamily, individually	2 13 15	Oil, central water Gas, central water
Multifamily, individually	2 13 15	Oil, central water Gas, central water
Multifamily, centrally heated, new	15	Oil, central water Gas, central water
Multifamily, centrally heated, existing	15	Oil, central water Gas, central water

Exhibit 4.13
INITIAL COST OF AHPs AND COMPETING CONVENTIONAL AND ADVANCED CONVENTIONAL SYSTEMS IN BELGIUM

System	Cost (1980 DM)
Small:	
AHP 2 (gas)	14,500
AHP 4	14,500
AHP 13	18,500
AHP 15/18	12,700
Conventional oil	10,000
Conventional gas	10,000
Medium:	
AHP 15	70,000
Conventional oil	20,000
Conventional gas	20,000

Exhibit 4.14
BELGIAN DECISION CRITERIA (%)

Market Segment	Initial Cost	Payback Period	Life-cycle Cost	Market Inertia
Single-family, new construction	75	25	0	0
Single-family, existing stock	35	35	0	30
Multifamily, new construction -- individually heated	67	33	0	0
Multifamily, existing -- individually heated	33	33	0	34
Multifamily, new construction -- centrally heated	20	40	40	0
Multifamily, existing -- centrally heated	20	40	40	0

Exhibit 4.15
ECONOMIC POTENTIAL OF HEATING SYSTEMS
IN BELGIUM (000 Installations/Year)

	1981-1985		1986-1990		1991-1995		1996-2000	
System	New	Ret	New	Ret	New	Ret	New	Ret
AHP 2	0	0	0	0	0	0	0	0
AHP 4	0.7	2.7	0	0	0	0	0	0
AHP 13	8.7	38.0	0	0	0	0	0	0
AHP 15	0	0	10.1	48.3	10.1	50.5	11.0	51.8
Gas boiler	26.9	69.2	27.7	65.3	27.5	68.9	26.3	68.1
Oil boiler	9.5	18.3	9.5	18.3	7.7	17.9	7.6	17.7
Coal stoves	0	36.0	0	23.0	0	11.5	0	0
Electric heaters or direct electric[a]	0	6.6	0	8.0	0	11.5	0	14
Total	45.8	170.8	47.3	162.9	45.3	160.3	44.9	151.6

a. Direct electric refers to single-family houses; electric heaters refer to individually heated multifamily buildings.

Exhibit 4.16
BELGIAN IMPLEMENTATION POTENTIAL FOR AHP 15/18

	1986-1990	1991-1995	1996-2000
Economic Potential:			
Installations/year (000)	58.4	60.6	62.8
Total market (%)	28	29	31
Implementation potential			
Installations/year (000)	5.4	15.2	26.2
Total market (%)	2.5	7.3	12.5
Percentage of economic potential	9	25	43

CANADA

National Energy Demand and Residential Consumption

In 1978, Canada's total energy consumption was 219 Mtoe. By energy source, oil accounted for 40 percent of this total; nuclear and hydroelectric, 30 percent; gas, 20 percent; and coal, 10 percent. Final end-use consumption was 142 Mtoe.

In 1978, Canada imported only 7.5 percent of its energy requirements, including 15 percent of its oil and 13 percent of its coal needs. Although oil imports have since jumped to 25 percent, Canada is still less import-dependent than any other IEA country. Total imports are projected to reach 11 percent by 1990, mainly as a result of a further increase in oil consumption. Future natural gas production is expected to rise 12 percent between 1977 and 1985 (as a result of the gas "bubble") before falling again through 2000. Oil production will remain at current levels because of the exploitation of such unconventional resources as Western tar sands. Coal production is expected to more than double by 1990, making Canada a major exporter of coal.

About 19 percent of final consumption was in the residential sector in 1978, and this share is expected to decrease gradually through the rest of this century. Commercial usage represented another 14 percent of final demand. Although space heating represents more than half of total residential/commercial demand, the residential/commercial potential for heat pumps is equivalent to only 20 percent of Canada's energy use. In many European countries this percentage is near 50 percent.

Canada projects very little demand for residential air conditioning in Canada, and any cooling requirements will be concentrated in the Central region. At present, about 3.5 percent of the demand for heating and cooling installations in the Central region is for combined heating/cooling systems, and this small market share is not expected to increase significantly in the near future. As a result, demand for cooling was ignored in the Canadian analysis.

Housing Stock and Current Heating Systems

Canada's 23.2 million inhabitants live in 7.1 million housing units (1976 figures). The size and heating characteristics of the housing stock vary considerably across regions, making it difficult to assess meanings from averages. Housing units are categorized by building type and region in Exhibit 4.17.

Almost two-thirds of the entire building stock is concentrated in the Central region, i.e., Ontario and Quebec, the two most populous provinces. Seventy percent of the stock is in single-family houses and almost 20 percent in centrally heated apartments. Heating systems and fuel types also vary considerably by region (Exhibit 4.18).

Exhibit 4.17
CANADIAN HOUSING STOCK BY BUILDING TYPE AND REGION (000)

Region	SF	MFI	MFII	Total	Percentage of Total Units
Maritimes	488	20	69	577	8
Central	3,238	344	928	4,510	63
Prairies	963	15	202	1,180	17
British Columbia	661	26	176	863	12
Total	5,350	405	1,375	7,130	
Percentage of Total Units	75	6	19	100	

Exhibit 4.18
CANADIAN HEATING SYSTEMS AND FUEL TYPES (% Housing Units)

	Maritimes			Central			Prairies			British Columbia		
	SF	MFI	MFII	SF	MFI	MFII	SF	MFI	MFII	SF	MFI	MFII
Heating System												
Central air	51		28	72		30	88		43	78		30
Central water	21		72	12		70	4		57	6		69
Electrical heating (space I)	8	39		9	47		2	95		9	92	
Stoves, room heating units (space II)	20	61		7	53		6	5		7	8	
Fuel Type												
Electricity	8	39	4	9	47	6	2	95	2	9	92	5
Gas				29	12	26	78	3	81	49	2	44
Oil	85	47	93	60	33	67	19	2	14	42	5	50
Coal, coke	1	2	2		1		1		1			
Other	6	12	1	2	7	1			2	1	1	

The share of gas used to fuel heating systems increases in western regions because most of Canada's gas reserves are located in Alberta in the Prairies region. In contrast, most single-family houses and centrally heated buildings in the Maritimes and parts of the Central regions are heated by oil. Individually heated apartments, although they represent only 6 percent of Canada's total housing stock, are heated mainly by electricity.

The national team projects a general trend toward more electric and gas installations and fewer oil installations. The Central region will rely more on electric heating and gas than oil. The Prairies and British Columbia will shift even more heavily toward gas. Only housing stock in the Maritimes region will move toward oil-fired water distribution systems (unless, of course, a natural gas pipeline is built to link the Maritimes with gas reserves in western Canada).

Projected Heating Installations

On the average, 260,000 heating installations per year are projected in Canada for the period 1980-2000; the great majority will be installed in single-family houses and individually heated apartments. The breakdown by region and type of installation is given in Exhibit 4.19.

The Central region dominates system installation figures, as it does the building stock, with 56 percent of the total. Ninety-three percent of all systems will be installed in single-family houses, mostly central air or electric furnace or baseboard (space I).

Assumptions about available fuel types play a key role in allocating these installations to competing systems. The Canadian analysis assumed that the energy source for replacement, modernization, and retrofit installations would be the same as used in the original heating system. Although historical evidence justifies this assumption, recent Canadian energy policy encourages the substitution of other energy sources for oil. The impact of this policy is not reflected in the retrofit portion of the AHP market study.

When projecting installations in new construction, the national team considered only systems using electricity, natural gas, and oil. The team assumed that natural gas will be unavailable in the Maritimes and will continue to be used in the same (national average) proportion in all other regions. Oil and electricity are assumed to be available everywhere.

Heat Pump Systems and Markets

At present, over 3,000 heat pumps have been installed in Canada, almost all in Ontario, all of which are air-air electric-compression heat pumps. Canada has no measurable market for heat pumps at the present, unlike the United States where the need for cooling and heating in the same building has already produced a substantial market.

Much of current R&D is focused on solar-assisted and groundwater-source heat pumps. Such systems will have a future market in the Prairies and most of the Central region, where extreme climate makes air an unattractive heat source. More temperate coastal climates, however, could offer more promising

Exhibit 4.19
AVERAGE ANNUAL NUMBER OF CANADIAN HEATING SYSTEM INSTALLATIONS, 1981-2000 (000 units)

	SF		MFI			
Region	New	R/M/R	New	R/M/R	Total	Percentage of Total
Maritimes	12.0	18.2	0.51	0.72	31.43	12
Central	63.2	67.6	6.4	7.5	144.70	56
Prairies	30.9	20.1	0.32	0.51	51.83	20
British Columbia	19.1	11.3	0.81	0.60	31.81	12
Total	125.2	117.2	8.04	9.33	259.77	100
Percentage of Total	48	45	3	4		

market[s] for air-source heat pumps, particularly in British Columbia, which also has available supplies of natural gas. The Maritimes, with an equitable climate and no natural gas, could provide a future market for combustion-drive heat pumps, but only if small, single family-size units become available.

Canada investigated the market for the absorption heat pump (AHP 2). Although AHPs 2, 4, 7, 9, 13, 14, and 15/18 all have technical potential in Canada, low gas prices will keep all but AHPs 2 and 7 from finding a market. The systems assumed to compete for the installation market in each region are listed in Exhibit 4.20.

The choice of competing technologies was basically the same in the new construction and replacement/modernization/retrofit markets; in the retrofit market, "add-on" electric heat pumps were allowed to compete with AHP 2. Air distribution systems were assumed in costing the furnace systems.

The gas furnace system was assumed to be conventional, with a seasonal efficiency of 65 percent. But it is expected that new gas-furnace efficiencies will approach 90 percent by the mid-1980s with the introduction of new combustion technologies (e.g., pulse combustion). Because it was difficult to vary performance parameters for the conventional systems in the market study technical approach, the Canadian analysis did not take this development into account.

Factors Affecting Market Penetration

In the Canadian market study, annual operating costs were assumed to be the major decision factor in selecting among competing heating systems (Exhibit 4.21). Initial costs of AHP and competitive conventional systems are estimated in Exhibit 4.22.

Unlike purchasers' criteria in the United States, Canadian purchasers tend to emphasize annual operating costs over first costs. However, selecting only two criteria (i.e., first cost and annual operating cost) is a drastic simplification. Homeowners actually combine many rather subjective value judgments to arrive at a decision. Although the assumed percentages for the decision criteria may be realistic average estimates for the 20-year time period, it is recognized that a rigorous application of these criteria in 1979 would produce estimates of economic potential far different from actual 1979 sales.

In Canada, climate is the major factor inhibiting market penetration by both conventional and advanced heat pumps. The Canadian climate is so cold that much of the time the winter temperature is below the balance point of any air-source heat pump. Relatively cool summer temperatures remove the need for cooling and require homeowners to amortize their heat pumps over the winter season alone.

Another factor that will limit heat pump sales is the government's policy to limit oil imports by encouraging fuel switching to natural gas. The gas price will be controlled at substantially less than the energy equivalent of the oil price, which will make gas furnaces formidable competitors for all heat pumps in Canada.

Exhibit 4.20
COMPETITIVE HEATING SYSTEMS IN EACH CANADIAN REGION

System	Maritimes	Central	Prairies	British Columbia
Gas furnace		●	●	●
Oil furnace	●			
7 kW air-air electric HP and electric furnace	●	●	●	●
7 kW HP and oil furnace	●			
7 kW HP and gas furnace		●	●	●
9 kW HP and oil furnace	●			
9 kW HP and gas furnace		●	●	●
AHP 2		●	●	●
Electric furnace or baseboard (space I)	●	●	●	●

Exhibit 4.21
CANADIAN DECISION CRITERIA (%)

Market Segment	Initial Cost	Annual Operating Costs
Single-family, new construction	25	75
Single-family, existing	25	75
Multifamily - individually heated, new construction	40	60
Multifamily - individually heated, existing	40	60

Exhibit 4.22
INITIAL COST OF AHP AND COMPETING CONVENTIONAL
AND ADVANCED CONVENTIONAL SYSTEMS IN CANADA

System	Cost (1979 DM)
AHP 2 (gas)	9,910
Conventional oil	3,062
Conventional gas	2,669
Conventional electric	2,512

Exhibit 4.23
ECONOMIC POTENTIAL OF HEATING SYSTEMS
IN CANADA (000 Installations/Year)

	1981-1985		1986-1990		1991-1995		1996-2000	
	New	Existing	New	Existing	New	Existing	New	Existing
Gas or oil furnace	79	31	14	11	11	15		14
Electric furnace or baseboard	45		37		27		28	
7 kW air-air electric HP	19		2		4		3	
9 kW air-air electric HP	14		27		29		61	
9 kW HP and oil or gas furnace	10		9					24
AHP 2			52	21	42	28	15	14
Total	167	31	141	32	113	43	107	52

Exhibit 4.24
ECONOMIC AND IMPLEMENTATION POTENTIAL FOR AHP 2 IN CANADA

	1986-1990		1991-1995		1996-2000	
	New	Existing	New	Existing	New	Existing
Economic potential (000)	52	21	42	28	15	14
Market share (%)	37	65	37	65	14	27
Implementation potential (000)	2.7	8	5.6	3.2	8.9	6.8
Market share (%)	1.89	2.63	4.92	7.34	8.36	12.90

Another factor inhibiting the market for heat pumps is lack of gas in the Maritimes and parts of the Central region. The Maritimes area not yet served by gas could become an acceptable heat pump market because it is near the coast and has a relatively moderate climate compared to the interior.

In addition, the market for heat pumps will be limited by lack of qualified service and government support. Most heating contractors are not yet familiar with heat pumps and probably would not be qualified to service them even if significant numbers of systems were on the market. Although Canada has a major government program to retrofit heating systems in existing buildings and substantial subsidies for insulation investments, no current subsidies apply to heat pumps.

Market Estimate

The economic potential market estimated by Canada for the competing systems in residential applications is summarized in Exhibit 4.23. The economic potential of AHP 2 is 21 percent of the new construction market, 40 percent of the retrofit market, and 25 percent of the total market in the period 1981-2000. Gas furnaces captures 25 percent of the total, and electric furnaces/baseboard, and the 9-kW air-air electric heat pumps about 20 percent. The market share for gas furnaces is probably underestimated due to conservative performance assumed. Gas furnace market share would certainly expand at the expense of AHP 2 if a more sophisticated analysis were performed.

Canada estimated the implementation potential for AHP 2 by applying nominal market penetration rates to the total new construction and natural gas retrofit markets. The rates, derived from the history of market penetration of similar equipment in homes, were given in the technical approach for the market study. Canada chose the medium or "nominal" penetration rate as appropriate for new construction, and the "high" rate for natural gas retrofit. Only in the period 1996-2000 does the implementation potential represent a significant portion of the economic potential (about half). Implementation potential is estimated in Exhibit 4.24, which also includes the economic potential for comparison.

DENMARK

National Energy Demand and Residential Consumption

In 1978, Denmark's total energy consumption was 20.5 Mtoe and final energy use 15.9 Mtoe. Oil imports met 79 percent of the total energy demand. Although Denmark currently is highly dependent on imported oil, this situation will be improved by increasing domestic oil and natural gas production in the Danish sector of the North Sea and by increasing the use of imported coal, mainly for electricity production and larger industrial and district heating plants. These measures could reduce Denmark's dependence on oil imports to approximately 42 percent in 1985, which represents an ambitious objective.

The residential sector's share of total final consumption is high compared to that of many other countries: 40 percent in 1978 against 35 percent in Sweden. Only heating is required in Danish residential systems.

Housing Stock and Current Heating Systems

In 1977, 5.1 million Danes lived in 2.0 million housing units, most of which are single-family houses. Only few units are individually heated apartments, and this proportion will remain constant in the future (see Exhibit 4.25).

In densely populated areas, district heating plants play a major role in supplying residential heat. Most urban apartments are connected to district heating plants (350,000) or block centrals (290,000). In 1977, district heating provided 24 percent of the space heating requirements in Denmark.

District heating will be extended in the future to meet the objectives of the National Energy Plan (NEP). Natural gas networks will be extended to allow a further decrease in individual oil heating. Conversion to district heating or gas heating may become mandatory. Electricity is expected to play a major role in space heating in rural areas. The changes in fuel use are projected in Exhibit 4.26.

Projected Heating Installations

The Danish market study team projected heating and cooling installations from 1981 to 2000 within two categories (see Exhibit 4.27):

- District heating (DH) or block central (BC) systems (i.e., heating systems serving from a block of buildings to urban districts)
- Building systems (i.e., installations in single-family and multifamily I and II housing units).

Although current projections indicate that the majority of heating systems will be installed in existing single-family houses, government regulations may mandate the connection of both new and existing buildings to district heating networks, when possible. Although connections to gas lines may also be mandated, it was decided in the market analysis to leave a free competition among fuels and to assess the percentage of applicability of each AHP given the fuel needed and estimated restrictions on fuel availability.

Heat Pump Systems and Markets

Electric utilities have provided strong support to the development of electric heat pumps since 1977. This support consists of a 10-year guarantee of heat pump maintenance costs, if the supplier, installer, and buyer satisfy certain conditions. The combined effect of governmental subsidy, utility support, and oil price rises resulted in 1979 in an explosive growth of heat pump installations, with 1,500 units sold in 1979 and about double that number in 1980. In contrast, only 60 to 70 units were sold in 1976.

Exhibit 4.25
HOUSING STOCK IN DENMARK (000)

Heating System	SF	MFI and MFII	MF, BC/DH	Total
Individual or building heating	870	180	n.a.	1,050
Block central (BC)	0	n.a.	290	290
District heating (DH)	390	n.a.	350	670
Total	1,190	180	640	2,010

Exhibit 4.26
FUELS USED FOR SPACE HEATING IN DENMARK (% Units)

	1977	2000
Electricity	2	20
Oil	72	30
Gas	2	20
District heating	24	30

Exhibit 4.27
AVERAGE ANNUAL INSTALLATIONS IN DENMARK, 1981-2000 (000 Units)

Market Segment	Building Systems (SF and MFII)	DH/BC	Total
Single-family			
New	15.8	5.2	21.0
Existing	81.0	51.0	132.0
Multifamily II			
New (50 dwellings)	0.21	0.07	0.28
Existing (50 dwellings)	0.40	0.25	0.65

Given the size of Denmark, its heat pump sales are of the same order of magnitude as the sales of heat pumps in Germany for the same years. As a consequence of this high growth rate, the utility support may be reduced and changed to an approval and free technical advice scheme.

The penetration of electrically driven heat pumps may be greater than that of fossil fuel-fired AHP systems because of a generally favorable attitude of both public and private decision makers towards electricity.

AHP 13, an electric motor/Rankine system using the ground as a heat source, is the only type of conventional heat pump currently installed in Denmark. Although the share of gas in residential space heating is projected to be multiplied by 2000, no gas-driven advanced heat pump was selected for the AHP market study in Denmark. However, a gas heat pump could perform well in Denmark, as it does in Germany, Sweden, and the United States, unless high-efficiency gas boilers appear to be more economical, which is the case in the Netherlands. Denmark examined the market potential of five AHP systems (see Exhibit 4.28).

Market Penetration Factors

As in Switzerland, purchasers of new heating systems in Denmark rely heavily on criteria other than initial cost of competitive systems in making their heating-system investment decisions. The Danish decision criteria, outlined in Exhibit 4.29, are heavily weighted toward energy costs in the single-family sectors and to payback period in the multifamily sectors. The tendency to use energy costs as a decision criterion may ensure a large market for energy-efficient heat pumps.

The penetration of heat pumps in the Danish market may be slowed by several implementation barriers, particularly the requirement for high reliability of complex equipment, and building codes that prohibit the use of noisy systems in single-family houses. (In multifamily buildings, separate construction and housing for the heating system will insulate residents from noise.)

Governmental energy conservation incentives will improve the relative economies of energy- and oil-saving equipment. Heat pumps will be included in the renewable energy systems category. A temporary subsidy of 30 percent of the investment cost up to a maximum of 100,000 Dkr (approximately 32,000 DM) is being granted to these systems during 1979-1980. This temporary subsidy may not be renewed after 1980.

Market Estimate

The economic potential of AHP systems in the Danish residential sector was estimated in five market segments including single-family houses, new and existing construction; centrally heated multifamily buildings (with an estimated average size of 50 dwellings), new and existing; and district heating (block centrals). Price assumptions are outlined in Exhibit 4.30.

Exhibit 4.28
COMPETITIVE HEATING SYSTEMS IN EACH DANISH MARKET SEGMENT

Market Segment	AHP Systems	Competing Conventional System
Single-family,		
new and existing	13 (electric, ground)	Oil boiler Electric resistance
Multifamily,		
centrally heated, new and existing	5 (Diesel) 13 (electric, ground)	Oil boiler Electric resistance
District heating, block central	13 (electric, ground) 4a (Diesel) 6 (Diesel)	Oil boiler

Exhibit 4.29
DANISH DECISION CRITERIA (%)

Market Segment	Life-Cycle Cost	First Cost	Payback Period	Energy Cost
Single-family, new	0	0	30	70
Single-family, existing	0	0	30	70
Multifamily, new	30	10	60	0
Multifamily, existing	30	10	60	0
District heating and block central	100	0	0	0

Exhibit 4.30
INITIAL COST OF AHP AND COMPETING CONVENTIONAL AND ADVANCED CONVENTIONAL SYSTEMS IN DENMARK

System	Cost (1979 DM)
Small (10-12 kW)	
AHP 13	19,995
Conventional oil	9,920
Conventional electric	4,960
Medium	
AHP 5	149,730
AHP 13	139,810
Conventional oil	79,980
Conventional electric	38,990
Large (any size above 1 MW)	
AHP 4a	174,840
AHP 5	149,730
AHP 6	159,960
AHP 13	139,810
Conventional oil	79,980

The demand for district heating or block central systems was estimated from the planned connections of single-family and multifamily homes to district heating networks. It was arbitrarily decided to establish groups of 50 single-family houses or apartments, which could represent the probable installation of an advanced heat pump. A more refined analysis of district heating economics and a detailed data base on local energy planning is necessary to better reflect the pattern of demand for district heating and block centrals. The present results must be interpreted with regard to the technical and economic characteristics of both supply (heating technologies) and demand (heat demand for space heating).

In single-family homes, AHP 13 performs well, taking from 38 to 50 percent of the market for two reasons: the relatively low current and projected price of electricity compared to oil, and to the high sensitivity of customers to energy costs and payback period. The economic potential of AHP 13 declines from 1981 to 2000 because of the general decline of the demand for individual systems in existing housing and an increased rate of connections to district heating.

The economic potential for advanced heat pumps and competing conventional systems is shown in Exhibit 4.31. In general, advanced heat pumps do penetrate the market in Denmark, although their initial costs are higher than those of conventional systems (see Exhibit 3.37) because Danish decision makers do not emphasize first cost in selecting heating systems.

The market for AHP 13 would be somewhat larger if it were not limited by its technical applicability of 80 percent in new construction and 60 percent in existing single-family houses. In multifamily buildings (estimated to have an average size of 50 dwellings), AHP 13 ranks well as early as 1981 in life-cycle cost and 1991 in payback. However, its low technical applicability (60 percent in new construction, 35 percent in existing buildings) limits its market potential. Oil boiler installations dominate during the period 1981-1990, But AHP 5 captures 50 percent of the market from 1991 to 2000, whereas AHP 13 takes 40 percent against 13 percent in the period 1981-1985.

In district heating or block central applications, the economic comparison was made for a boiler or heat pump size corresponding to approximately 50 dwellings. All AHP systems analyzed rank better than conventional oil boilers in terms of life-cycle cost. Because single life-cycle cost is the only criterion used in this sector, AHP 13 ranks first and captures all the market that is technically applicable. However, its techical potential is only 10 percent of the entire market because of the stringent conditions on heat source (ground) adequacy and also because connections to district heating will principally occur in existing single-family homes or apartment buildings, i.e., in urban areas. AHP 6 ranks second. Its use of wastewater also limits its technical applicability, which was assumed to be 20 percent. Its market share is about 18 percent. AHP 4a ranks close to AHP 6. Because it uses ground as heat source, its potential will be low, principally because AHP 13 will probably be preferred to AHP 4a where ground is available. AHP 5 will be introduced in 1985 and it will capture over half of the market immediately, reducing the installations of oil boilers from 68 percent of the market in 1981-1985 to 16 percent in 1986.

The implementation potential was not analyzed quantitatively for Denmark. However, the capacity of installers will probably be the most constraining factor after a system is introduced. As shown in Exhibits 4.32, 4.33, and

Exhibit 4.31
ECONOMIC POTENTIAL OF HEATING SYSTEMS IN DENMARK
(000 Average Annual Installations)

	1981-1985	1986-1990	1991-1995	1996-2000
Small				
Oil boiler	60	22	12	5
Electric heating	0	22	17	19
AHP 13	38	30	27	25
Medium				
Oil boiler	0.54	0.37	0.01	0.01
Electric heating	0.06	0.05	0.05	0.05
AHP 5	0	0.11	0.30	0.30
AHP 13	0.09	0.08	0.23	0.23
Large				
Oil boiler	0.75	0.21	0.21	0.21
AHP 4a	0.04	0.06	0.06	0.06
AHP 5	0	0.83	0.85	0.85
AHP 6	0.20	0.27	0.28	0.28
AHP 13	0.11	0.15	0.16	0.16

Exhibit 4.32

Economic and Implementation Potential of AHP 13 in Denmark
(SF market)

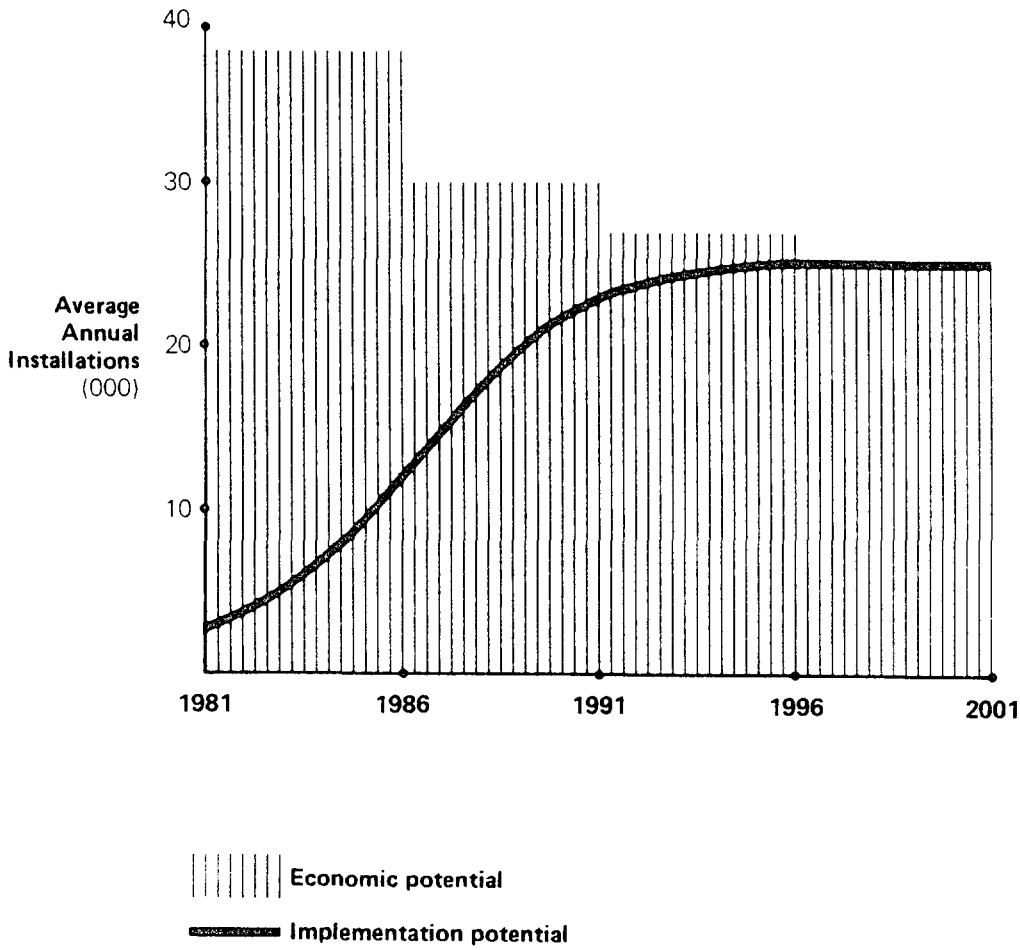


Exhibit 4.33

Economic and Implementation Potential of AHPs 5 and 13 in Denmark
(MF II market)

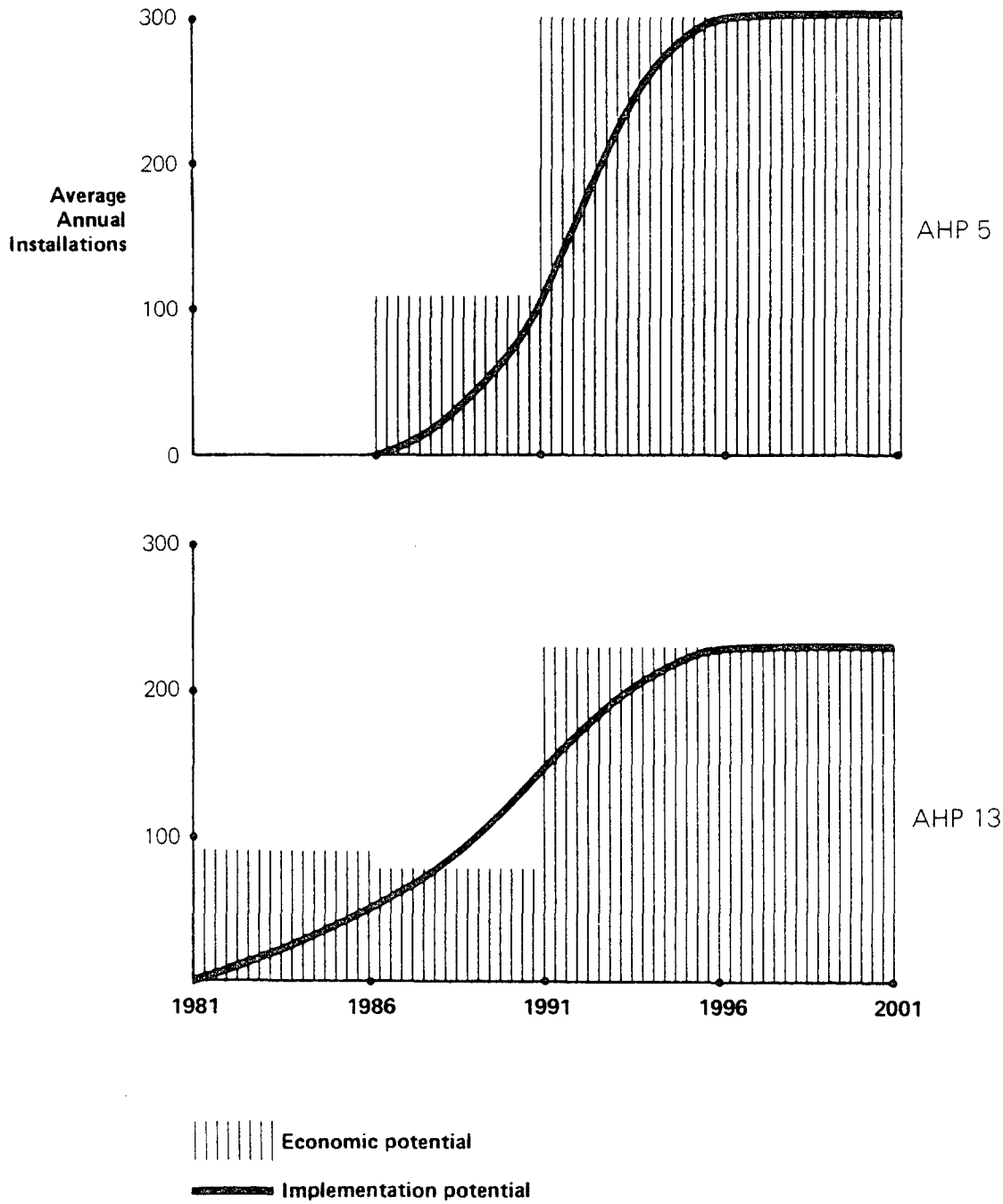
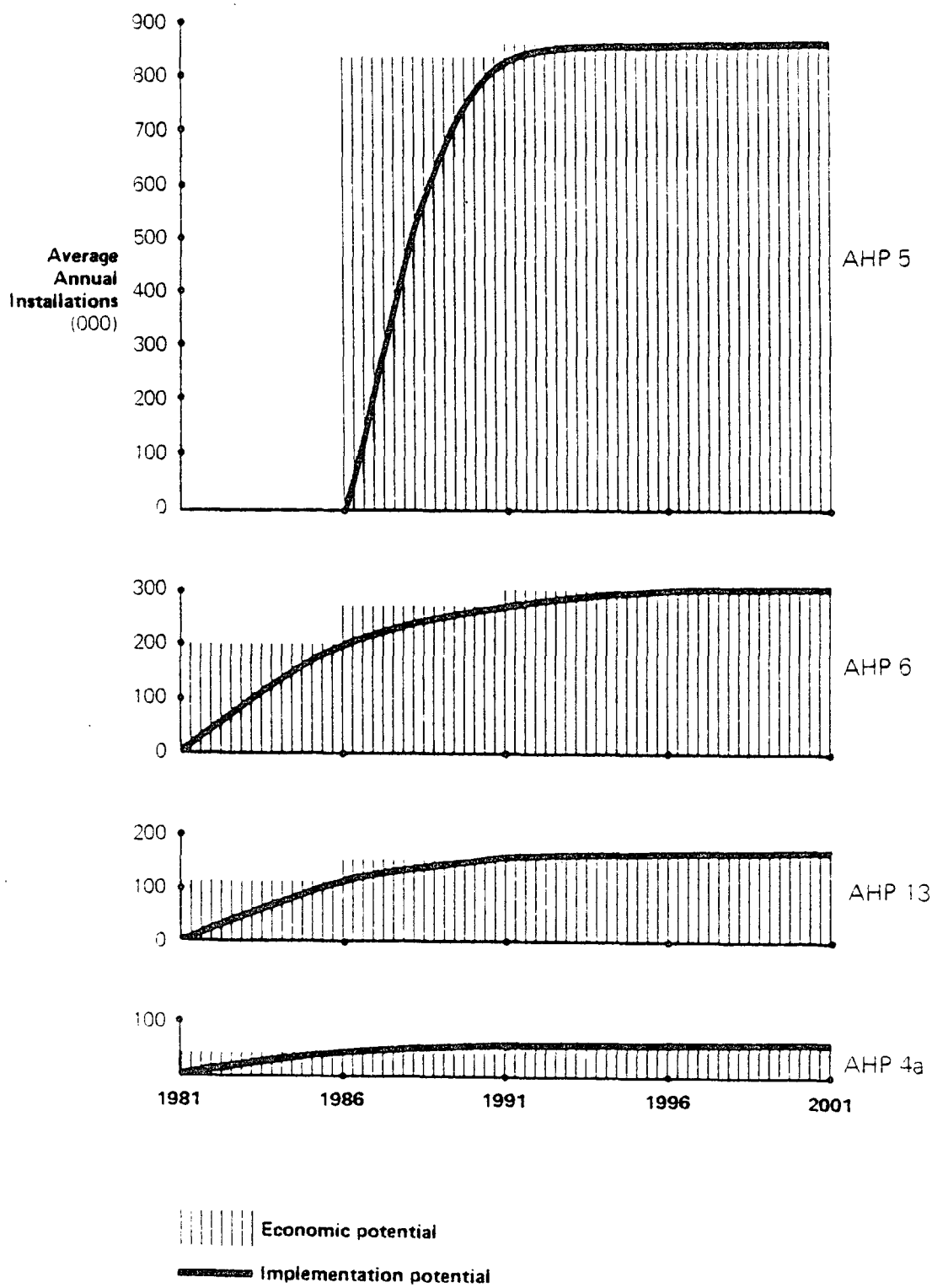


Exhibit 4.34

Economic and Implementation Potential of AHPs 4a, 5, 6, and 13 in Denmark
(DH market)



4.34, the implementation of advanced heat pumps would probably catch up with the economic potential after 5-7 years.

The decline in the economic potential of AHP 13 in single-family homes, resulting from a decline in demand for retrofit installations, will probably affect the sales of these systems because suppliers may be reluctant to invest in large production capacity during the period 1986-1990.

GERMANY

National Energy Demand and Residential Consumption

In 1978, Germany's total energy consumption was 273 Mtoe; its final end-use consumption was 201 Mtoe. Germany imports about 65 percent of its energy requirements, including 98 percent of its oil and 62 percent of its natural gas. Electricity production is expected to almost double by 1990, permitting Germany to reduce its net import dependence to 55 percent even though it will import 80 percent of its natural gas.

Direct use of process heat below 100°C (the market accessible to heat pumps) accounted for 51 percent of final consumption. Hot water heating and space heating of buildings alone account for about 40 percent of Germany's energy use, and tends to be supplied by fossil fuels. The potential market for heat pumps is very large; the resulting reduction in energy consumption could have a significant effect on Germany's import position.

Housing Stock and Current Heating Systems

In 1977, 25 percent of the residential units in Germany were single-family houses, 36 percent in individually heated apartments, and 39 percent centrally heated apartments. The building stock is allocated among heating systems and heat distribution systems, as shown in Exhibit 4.35.

Water distribution is the dominant medium in heating systems in Germany. The high market share for stoves and room heating units (space II systems) appear to include electric heating systems with thermal storage units.

Space II systems are still widely used in old buildings built before 1960. Many of these systems will probably be modernized by installing central water systems in the future. Central air systems will be installed only in those rare cases where the owner wishes to install central air conditioning.

Oil is projected to remain the principal heating fuel, although the trend toward increased use of gas will continue and greater use of electricity is expected from 1980 to 2000. District heating, under strong stimulation by federal policy, could expand its market share from 6.5 percent to 11 percent by the end of the century. Coal's share of the heating market, although currently substantial, is now dropping. It is not clear whether this trend will continue.

Exhibit 4.35
GERMAN HEATING SYSTEMS AND FUEL TYPES
(% Housing Units)

	SF	MFI	MFII
Heating Systems			
Central air	1	*	1
Central water	60	18	99
Space I: electric heating	*	1	*
Space II: stoves, room heating units	38	81	*
Fuel Type			
Electricity	7	19	1
Gas	15	20	15
Oil	61	24	69
District heating	1	*	10
Coal, coke	16	37	5

* Negligible

Projected Heating Installations

Over 500,000 installations of heating systems are projected to occur each year between 1981 and 2000. Annual demand for heating installations will average 386,000 units a year in single-family houses and 226,000 units a year in apartment buildings. Almost all installations in multifamily buildings will be for building central systems. The installations are categorized in Exhibit 4.36 by type of installation, fuel, and 5-year period. Percentages of installations by fuel type and market segment are shown in Exhibit 4.37.

The number of building central installations projected in apartment buildings (multifamily II) rises 39 percent by 2000 despite anticipated decreases in new construction and modernizations. This increase is due to a 91-percent rise in retrofit/replacement demand. Retrofit/replacement installations in single-family houses will increase by 85 percent, more than offsetting small declines in new construction and modernization installations, and resulting in an 18-percent growth in installations over the period. Installations in single-family houses represent two-thirds of all residential heating installations in the period 1981-1985, but this share declines to 61 percent of the total in the period 1996-2000.

The proportions of the installations that will occur in new construction, modernization, and retrofit/replacement installations will increase their share of installations in single-family houses from 34 percent to 54 percent and in multifamily buildings from 49 to 68 percent. There will be little change in fuel mix. Oil's share in the single-family market will drop from 66 to 62 percent or to about the level it enjoys in the present housing stock. Gas and electricity will gain share in both the single-family and multifamily housing stock at the expense of oil.

Heat Pump Systems and Market

At the end of 1978, about 6,000 heat pumps were installed in Germany, 80 percent in residential buildings. The market, although growing, was experiencing many of the hesitations common to new consumer equipment markets. As early as 1976 some electric utilities had offered special low electric tariffs to homeowners willing to install heat pumps, but few subscribers took advantage of these rates until early 1979.

The oil supply cut-offs and price uncertainties caused by the events in Iran resulted in a sharp increase in market growth for heat pumps in 1979. Estimates in Germany vary, but total 1979 heat pump production probably exceeded 6,000 units. Most of the new production has been for residential applications, with capacities ranging from 5- to 10-kW thermal output.

The 1980 market is projected to reach up to 10,000 units and some predictions are even higher. Some estimations predict that 600,000 or more heat pumps could be installed by 1990. After 1990, average annual installations may be on the order of more than 100,000 units.

Almost all the heat pumps currently being sold or installed in Germany are electric-compression designs. Only about 100 motor-driven units are in operation or under construction, and more than 50 percent of these are gas-driven. Motor-driven systems are usually larger than the electric heat pumps;

Exhibit 4.36
AVERAGE ANNUAL INSTALLATIONS IN GERMANY
(000 Housing Units)

		1981-1985		1986-1990		1991-1995		1996-2000	
		SF	MFII	SF	MFII	SF	MFII	SF	MFII
New Construction									
Oil		96	23	92	22	92	22	90	20
Gas		32	17	25	16	24	15	24	14
Electricity		12	1	17	1	16	1	16	1
District		4	7	4	8	4	8	4	8
Subtotal:	SF	144		138		136		134	
	MFII		48		47		46		43
Modernization									
Oil		49	24	43	22	36	20	30	20
Gas		21	14	19	13	17	13	13	13
Electricity		6	3	6	3	6	3	6	3
Other		1	2	1	2	1	2	1	2
Subtotal:	SF[a]	77		69		60		50	
	MFII[b]		43		40		38		38
Retrofit/Replacement									
Oil		79	45	125	72	135	79	127	81
Gas		34	33	55	54	64	61	64	64
Electricity		3	2	6	4	14	6	22	10
Other		1	9	1	13	3	14	3	15
Subtotal:	SF	117		187		216		216	
	MFII		89		143		160		170
TOTAL:	SF	338		394		412		400	
	MFII		180		230		244		250

a. Central system only.

b. Modernizations of MFI (individually-heated apartments) to MFII (building central systems).

Exhibit 4.37
AVERAGE ANNUAL INSTALLATIONS IN GERMANY
(%)

	1981-1985		1986-1990		1991-1995		1996-2000	
	SF	MFII	SF	MFII	SF	MFII	SF	MFII
New construction	43	27	35	21	33	19	33	17
Modernization	23	24	18	17	15	16	13	15
Retrofit/replacement	34	49	47	62	52	65	54	68
Oil	66	51	66	50	64	50	62	48
Gas	26	36	25	36	25	36	25	36
Electricity	6	3	7	4	9	4	11	6
Other	2	10	2	10	2	10	2	10

the gas-driven units range up to 1,270-kW thermal output. Very few absorption heat pumps are now used for heating; Battelle, in its review of the German market, identify a large (1.95-MW vaporizer-capacity) unit in a sports center in Garmisch-Partenkirchen.

There are 40 to 50 manufacturers and trading companies serving the market in Germany. A recent independent evaluation of heat pumps in Germany selected 100 different models from over 300 offered for test by manufacturers. Most of the companies are very small and still do not mass-produce their products. With such low production, delivery is now running up to 6 months behind demand. As production increases, however, costs will decline. The first residential heat pumps cost on the order of 20,000 DM. Current heat pump prices are in the 6,000-DM range, plus 2,000 DM to 4,000 DM for installation. Generous government subsidies reduce costs even further.

Current residential installations are 80 percent water-water or soil-water heat pumps and about 20 percent are bivalent systems. But most of the present production in Germany is for air-water systems. The backup systems operate in parallel with or in place of (bivalent alternative) the heat pump on the coldest days. At the present time it is not clear whether parallel or alternative bivalent operation will prove to be more popular in Germany.

Air-water heat source systems will probably remain by far the preferred technology in the large single-family market. There is also interest in soil and ground water sources, but difficulties in installing the heat exchanger tubes in the limited space available in high-density areas will limit the market for these technologies. A solar "energy roof" used as a heat source could overcome some of these barriers, especially in single-family applications. Interest in solar development is high in both Germany and Switzerland.

German experts expect a shift of demand toward motor-driven and absorption equipment. Offering larger energy savings than electric heat pumps, these technologies are now the focus of German government R&D. Some large motor-driven and absorption equipment has already been installed, but only a few manufacturers are producing units for small multifamily and single-family installations. It remains to be seen how well these advanced systems will compete with the conventional electric compression heat pump that now dominates almost the entire residential market in Germany.

The German market study team evaluated four heat pump systems for the single- and multifamily markets shown in Exhibit 4.38. Initial costs for competitive conventional and AHP systems are estimated in Exhibit 4.39.

Market Penetration Factors

Conventional heat pumps have already established a market in Germany, and it is now clear that German decision makers use two major criteria in deciding to change to an innovative heating system: the energy cost of the system and its first cost relative to conventional equipment or boiler replacement. The relative weights of these two criteria depend on the type of housing, the type of installation, and the decision maker. The estimates of German consumers' decision criteria developed in the study are shown in Exhibit 4.40.

Exhibit 4.38
COMPETITIVE HEATING SYSTEMS IN
EACH GERMAN MARKET SEGMENT

Market Segment	AHP System	Competing Conventional System
Single-family	2b (absorption)	Central water
New	4 (Diesel/Rankine)	oil
Existing	13 (electric	gas
	15/18 (ORC/Rankine)	Electric heat pump
Multifamily I & II	15/18 (ORC/Rankine)	Central water
New		oil
Existing		gas

Exhibit 4.39
INITIAL COST OF AHP AND COMPETING CONVENTIONAL AND ADVANCED SYSTEMS IN GERMANY (1980 DM)

	New	Modernization	Retrofit
Small Systems			
AHP 2 (oil)	26,280	18,060	6,000
AHP 2 (gas)	24,890	17,960	6,000
AHP 4	26,250	18,400	7,330
AHP 13	31,950	-	-
AHP 15/18 (oil)	23,930	15,575	5,280
AHP 15/18 (gas)	22,330	15,735	5,540
Conventional oil	24,035	15,035	2,080
Conventional gas	20,680	13,940	2,340
Conventional electric heat pump	27,400	20,150	9,260
Medium			
AHP 15 (oil)	62,680	-	15,330
AHP 15 (gas)	60,200	-	15,600
Conventional oil	56,730	-	3,330
Conventional gas	49,950	-	3,600

NOTE: Governmental subsidies included.

Exhibit 4.40
GERMAN DECISION CRITERIA (%)

Application	Energy Cost	First Cost
Single-family		
New construction	60	40
Modernization	45	55
Retrofit/replacement	45	55
Multifamily I		
Modernization	30	70
Multifamily II		
New construction	30	70
Retrofit/replacement	30	70

The first-cost criterion is less important in single-family houses where the owner usually occupies the building, and more important in multifamily buildings where the owner rents the building. First cost is of least importance in single-family new construction where the incremental cost of the heating system is buried in the total cost of the house. The relative weighting of the two criteria may also reflect the influence of governmental financial subsidies available to building owners interested in installing energy-saving equipment. These subsidies may influence single-family owners to consider energy cost as a major criterion, but multifamily owners remain interested primarily in low first cost.

The major technical factor inhibiting the penetration of electric air-water heat pumps into the residential heating market is the high-temperature water used by most distribution systems. Most of these systems are standard radiators and require water at 80-90°C. Electric compression heat pumps have difficulty producing water hotter than 55°C. Very often, a heat pump system may still be installed because the distribution system is oversized once the building is properly insulated and new windows are installed. Because motor-driven heat pumps can use engine waste heat to raise water temperature, they are less affected by this problem.

No significant legal or institutional barriers limit the installation of conventional electric-compression heat pumps in air-water applications in Germany. The electric tariff that consumers will pay is a major uncertainty, however. Although some electric utilities reduced tariffs to encourage heat pump installations before the Iranian disruptions, recent revisions in national electricity tariffs now favor heat pumps that can operate outside peak periods.

On the other hand, a host of environmental and water regulations complicate the installation of water, soil, and groundwater sources or may limit the use of motor-driven heat pumps. The use of ground or surface water as a heat source is restricted by environmental regulations. In addition, scarcity of land and dense population will restrict the use of soil, groundwater, and surface water sources, particularly in single-family houses. However, waste heat from rivers is a potential heat source for district heating and heating nearby multifamily houses.

Germany has an aggressive government program to stimulate implementation of energy-saving equipment in residential buildings. The Modernization and Energy Savings Law (ModEnG), effective July 1978, provides 4.35 billion DM in subsidies and tax cuts to home and building owners interested in installing heat pumps and other energy-conserving equipment.

Under ModEnG, the government will subsidize 25 percent of building owners' initial investment costs, based on a minimum investment of 4,000 DM per building and a maximum of 12,000 DM per apartment. Owners may instead decide to write off the investment from before-tax income over 10 years. There is no upper limit to the investment covered by the write-off provision. At present, the tax write-off is attracting higher-income homeowners who comprise the major heat pump market in Germany.

Market Estimates

The estimates made by Germany for the economic potential are unusually detailed and complete. Exhibits 4.41 and 4.42 are summaries of the economic potentials for single-family and multifamily (assumed building central) installations, respectively.

In single-family and new construction sectors, oil heating ranks behind AHP 4 and AHP 15/18 on both decision criteria as soon as these heat pumps become available to the market. As a result, AHPs 4 and 15/18 eliminate oil heating from these markets after 1984. The market structure changes again in 1986 when AHP 2 is introduced. AHP 2 ranks first on energy cost for oil and gas fuels after 1987 and drives AHP 4 and AHP 15/18 from these segments. AHP 15/18 stays in the oil heating market through 2000 because of government subsidies that allow it to outrank oil boilers on first cost. Gas boilers rank first on first cost throughout the period and the electric AHP 13 on energy cost for electricity fuel.

The pattern is similar in multifamily II new construction, except that conventional oil heating outranks AHP 15/18 on first cost and thus retains two-thirds of the oil heating market segments through 2000. Gas boilers continue to rank first on first cost.

In single-family retrofit/replacement, by far the most important market segment for single-family buildings, AHP 2 also shows a strong potential. After entry in 1986 it outranks AHP 4 and AHP 15/18 on energy costs and drives them out of the market. But oil and gas boilers continue to rank first on first cost and they retain 55 percent of the oil and gas retrofit/replacement installation even in 2000.

In multifamily retrofit/replacement markets, the system rankings on decision criteria are the same as for new construction: AHP 15/18 outranks boilers on energy cost but is outranked on first cost. Given decisionmakers' preference for first cost in this segment, oil and gas boilers retain 70 percent of the market in 2000.

In modernization installations, it is assumed that single-family space I and space II and multifamily I buildings are rebuilt with central water systems. Because major reconstruction is required in most installations, the system rankings on decision criteria are the same as for new construction over most of the period. AHP 2 dominates single-family and multifamily market segments that use energy cost as a decision criterion; boilers dominate the segments that base decisions on first cost. Germany predicts that AHP 15/18 will break into the single-family modernization market for oil fuel in 1993 when it should outrank oil boilers on first cost.

The economic potential for AHP systems is summarized in Exhibit 4.43. AHP 2 captures a 15.5-percent market share of single-family gas installations by 2000, and a 32-percent share of single-family oil installations. AHP 15/18 captures 12 percent of single-family oil installations, 14.5 percent of multifamily oil installations, and 11 percent of multifamily gas installations. In general, AHP systems burning oil appear to do better than those burning gas against the competition.

Exhibit 4.41

Economic Potential of All Heating Systems in Germany: Annual Average Installations in Single-Family Houses (000)[a]

Heating Systems	Year of AHP Introduction	1980	1985	1990	1995	2000
Oil heating: Total		**224**	**101**	**63**	**86**	**88**	**74**	**70**
New		96	38			0		
Modernization		49	20		17	14		0
Retrofit/replacement		79	43		69		74	70
Gas heating: Total		**87**	**40**	**48**	**51**	**49**
New		32	13	10		9
Modernization		21	8		7	6
Retrofit/replacement		34	19	30		35
Bivalent/alternative electric heat pump: Total		**18**	**25**	**30**	**40**
New		9	13		12
Modernization				6		
Retrofit/replacement		3	6		14	22
AHP 2 (oil): Total	1986	**137**	**138**	**129**
New				55		54
Modernization		n.a.	26		22	18
Retrofit/replacement			56		61	57
AHP 2 (gas): Total	1986	**0**	**51**	**54**	**52**
New		n.a.	0		15	
Modernization			0	11	10	8
Retrofit/replacement			0	25		29
AHP 4: Total	1982	**n.a.**	**123**	**0**
New		n.a.	58	0
Modernization		n.a.	29	0
Retrofit/replacement		n.a.	36	0
AHP 13: Total	1981	**3**	**4**
New		3	4
Modernization			n.a.
Retrofit/replacement			n.a.
AHP 15/18 (oil): Total	1985	**n.a.**	**38**	**37**	**51**	**48**
New		n.a.	38	27		36
Modernization		n.a.		0	14	12
Retrofit/replacement		n.a.			0	
AHP 15/18 (gas): Total	1985	**n.a.**	**47**	**51**	**0**
New		n.a.	19	15	0
Modernization		n.a.	13	11	0
Retrofit/replacement		n.a.	15	25	0
Other: Total		**6**	**8**
New			4
Modernization			1
Retrofit/replacement		1	3
Single-Family: Total		**338**	**394**	**412**	**400**
New		144	138	136	134
Modernization		78	69	60	50
Retrofit/replacement		117	187	216	

a Free-standing buildings only.

Exhibit 4.42

Economic Potential of All Heating Systems in Germany: Annual Average Installations in Multifamily Houses (000)[a]

Heating Systems	Year of AHP Introduction	1980	1985	1990	1995	2000
Oil heating: Total		**92**	**65**	**80**	**84**	**85**
New construction		23	16	15		14
Modernization		24	17	15	14	
Retrofit/replacement		45	32	50	55	57
Gas heating: Total		**64**	**45**	**58**	**62**	**65**
New construction		17	12	11	10	11
Modernization		14	10	9		
Retrofit/replacement		33	23	38	43	45
AHP 15/18 (oil): Total	1985		**27**	**36**	**37**	**36**
New construction		n.a.		7		6
Modernization		n.a.		7	6	
Retrofit/replacement		n.a.	13	22	24	
AHP 15/18 (gas): Total	1985		**19**	**25**	**27**	**28**
New construction		n.a.		5		
Modernization		n.a.		4		
Retrofit/replacement		n.a.	10	16	18	19
Other: Total		**24**		**31**	**34**	**39**
New construction		8		9		
Modernization				5		
Retrofit/replacement		11		17	20	25
Multifamily: Total		**180**		**230**	**244**	**250**
New construction		48		47	46	43
Modernization		43		40	38	36
Retrofit/replacement		89		143	160	170

a All building central.

Exhibit 4.43
ESTIMATES OF AHP ECONOMIC POTENTIAL IN GERMANY
BY INSTALLATIONS (000) AND MARKET SHARE (%) in Each 5-year Period

System	1981-1985	1986-1990	1991-1995	1996-2000
AHP 2 (oil)	na	685 (34.8%)	690 (33.5%)	645 (32.3%)
AHP 2 (gas)	na	183 (9.3%)	270 (13.1%)	310 (15.5%)
AHP 4	492 (29.0%)	0	0	0
AHP 13	15 (0.9%)	20 (1.0%)	20 (1.0%)	20 (1.0%)
AHP 15/18 (oil)				
Single-family	38 (2.2%)	125 (6.3%)	227 (11.0%)	240 (12.0%)
Multifamily	27 (3.0%)	180 (15.7%)	185 (15.2%)	180 (14.5%)
AHP 15/18 (gas)				
Single-family	47 (2.8%)	102 (5.2%)	0	0
Multifamily	19 (2.1%)	125 (10.9%)	135 (11.1%)	140 (11.2%)

Exhibit 4.44
MARKET PENETRATION ESTIMATES FOR AHP SYSTEMS
IN GERMANY BY INSTALLATIONS (000) AND MARKET SHARE (%)

System/ Penetration	1981-1985	1986-1990	1991-1995	1996-2000
AHP 2 (oil)				
Normal	na	65 (3.30%)	170 (8.3%)	270 (13.5%)
High	na	90 (4.60%)	253 (12.3%)	416 (20.8%)
AHP 2 (gas)				
Normal	na	14 (0.70%)	66 (3.2%)	130 (6.5%)
High	na	19 (1.00%)	99 (4.8%)	200 (10.0%)
AHP 4				
Normal	31.0 (1.80%)	0	0	0
High	66.0 (3.90%)	0	0	0
AHP 13				
Normal	1.5 (0.09%)	5 (0.30%)	8 (0.4%)	13 (0.7%)
High	2.0 (0.10%)	7 (0.40%)	13 (0.6%)	20 (1.0%)
AHP 15/18 (oil)				
Normal				
Single-family	0.3 (0.02%)	16 (0.08%)	35 (1.7%)	113 (5.7%)
Multifamily	0.2 (0.02%)	23 (2.00%)	53 (4.3%)	85 (6.8%)
High				
Single-family	0.3 (0.02%)	22 (1.10%)	53 (2.6%)	176 (8.8%)
Multifamily	0.2 (0.02%)	32 (2.70%)	80 (6.6%)	132 (10.6%)
AHP 15/18 (gas)				
Normal				
Single-family	0.3 (0.02%)	3 (0.02%)	0	0
Multifamily	0.1 (0.01%)	16 (1.40%)	38 (3.1%)	66 (5.3%)
High				
Single-family	0.4 (0.02%)	4 (0.20%)	0	0
Multifamily	0.2 (0.02%)	22 (1.90%)	58 (4.8%)	103 (8.3%)

Exhibit 4.45
MARKET PENETRATION ESTIMATES FOR AHP SYSTEMS
IN GERMANY BY 5-YEAR PERIOD INSTALLATIONS (000)
AND MARKET SHARE (%), LOW PENETRATION RATE

System	1981-1985	1986-1990	1991-1995	1996-2000
AHP 2 (oil)	na	25.0 (2.20%)	51 (4.8%)	73 (7.3%)
AHP 2 (gas)	na	4.0 (0.40%)	17 (1.6%)	60 (6.0%)
AHP 4	15.0 (1.30%)	0	0	0
AHP 13	0.9 (0.08%)	2.5 (0.2 %)	4 (0.4%)	6 (0.6%)
AHP 15/18 (oil)				
Single-family	0.2 (0.02%)	13.0 (1.2 %)	17 (1.6%)	50 (5.0%)
Multifamily	0.1 (0.02%)	0.8 (0.15%)	10 (2.1%)	13 (2.9%)
AHP 15/18 (gas)				
Single-family	0.2 (0.02%)	1.0 (0.90%)	0	0
Multifamily	<0.1 (0.01%)	0.5 (0.10%)	7 (1.5%)	10 (2.2%)

Even the normal penetration rate may prove too high because advanced heat pumps may not be suitable in the replacement market. Implementation potential for AHP systems is summarized in Exhibit 4.44. A low penetration rate can be defined based on the assumption that replacement installations would not be accessible to heat pumps. For example, when boiler failures occur in the winter, homeowners will not wait the longer time required to install a heat pump. In this case, the implementation potential is reduced (see Exhibit 4.45).

ITALY

National Energy Demand and Residential Consumption

Italy's total energy consumption in 1977 was 137 Mtoe, with final end-use of 106 Mtoe. Net oil imports provide approximately 69 percent of Italy's total energy demand; the remainder is met by coal and gas imports and domestic gas and hydroelectric/geothermal energy production. Nuclear power production is envisaged to contribute to the country's energy self-reliance in the 1990s. Increased domestic gas production and imports, as well as coal imports, will further reduce Italy's dependence on imported oil.

The residential, commercial, and institutional sectors consumed approximately 31 percent of Italy's final energy end-use. The residential sector alone (28 percent of total demand) used the following fuels: petroleum products (59 percent), gas (27 percent), electricity (10 percent), and solid fuels (4 percent). The possible development of electrically driven and oil- or gas-fired heat pumps in these sectors may help Italy achieve its oil imports reduction goal.

Housing Stock and Current Heating Systems

In 1976, Italy had 56.3 million residents living in 18.5 million housing units. The Italian residential sector was divided into three climatic regions: North, Center, and South. The number of dwellings in each region is listed in Exhibit 4.46. The percentages of units requiring heat are given in parentheses.

Central air systems are used to a minor extent in the Center of Italy, for centrally heated buildings. These systems will not represent an important potential in the future and were therefore neglected. Use of central water declines from more than 60 percent in the North to 20 percent (in single-family homes) and 17 percent (in individually heated apartments) in the South.

The distribution of existing housing stock in Italy is similar to the distribution in Germany, with relatively few single-family houses (25 percent), and more individually heated apartment buildings (41 percent), and centrally heated multifamily buildings (34 percent). Italian housing stock is categorized by heating system and fuel type in Exhibit 4.47.

New construction and modernizations are expected to reinforce this trend toward centrally heating multifamily buildings. More new residential construction (38 percent) is forecast for the centrally heated multifamily sector than for

Exhibit 4.46
ITALIAN HOUSING STOCK BY TYPE AND
REGION REQUIRING HEATING (000 Units)

Region	SF	MFI	MFII	Total
North	2,030 (96%)	3,300 (98%)	3,880 (100%)	9,210
Central	800 (77%)	1,240 (93%)	1,480 (100%)	3,520
South	1,700 (64%)	3,040 (89%)	980 (100%)	5,720
TOTAL	4,530 (81%)	7,580 (94%)	6,340 (100%)	18,450

Exhibit 4.47
ITALIAN HEATING SYSTEMS BY REGION
AND FUEL TYPE (%)

	Single-Family			Multifamily I			Multifamily II		
System	N	C	S[a]	N	C	S	N	C	S
Heating System									
Central air	0	0	0	0	0	0	0	2	0
Central water	43	29	21	41	26	11	86	87	85
Space I	0	0	0	0	0	0	14	0	15
Space II	57	71	79	59	74	89	0	0	0
Fuel Type									
Electricity	4	8	20	5	11	38	0	0	0
Gas	14	5	3	69	36	36	14	3	5
Oil	59	48	46	17	36	17	84	94	94
Solid fuel	23	39	31	9	17	9	2	3	1

a. Regions: North (N), Central (C), South (S).

the single-family (34 percent) or individually heated apartment (27 percent) sectors. Modernizations of older buildings are expected to outweigh new construction, which further increases the potential for building central heating systems.

Oil is the primary energy source for residential heating, particularly in centrally heated multifamily buildings. Natural gas, however, is often used in apartments with individual heating, particularly in the Northern region. Although electricity supplies less than 3 percent of the residential heating demand in the North, it is an increasingly important fuel in the Central region (over 6 percent) and the South (almost 20 percent).

Projected Heating and Cooling Installations

Despite its southern location, almost no cooling systems are projected for installation in the Italian residential sector. The structure of the housing stock is similar to that of Germany; the retrofit sector is very important and modernizations play an important role. Projections of heat-only installations are summarized in Exhibit 4.48 for each building type; most modifications of MFI systems result in MFII systems. Only replacements of central water systems are shown.

Heat Pump Systems and Markets

By 1978, about 100 electric heat pumps for space heating had been installed in the residential sector in Italy, excluding reversible window air conditioners. The industrial and agricultural market is larger (1,000 units), the main application being seed drying.

Outside air is the main heat source used, except for a few experimental facilities. Higher prices for electricity in Italy than in other European countries are an economic barrier to the development of conventional heat pumps. Italy evaluated two AHP systems for the market study (see Exhibit 4.49). Initial costs are estimated in Exhibit 4.50.

In terms of R&D efforts, on-site activated heat pumps (as opposed to electric heat pumps) receive the most interest in the near and medium term because of their potential energy savings and increased availability of natural gas. When nuclear power becomes available, electric heat pumps will gradually achieve greater popularity. Absorption heat pumps are attractive because they can use waste or solar heat.

Factors Affecting Market Penetration

First cost is the most important investment decision criterion in the single- and MFI market segments in Italy, whereas life-cycle costs and payback period are more important in the MFII segment (see Exhibit 4.51).

A market for conventional heat pumps was not established in Italy because of high electricity tariffs. In addition, these systems do not use water distribution systems, which are generally preferred in Europe. The slow development of conventional heat pumps will affect that of advanced heat pumps because

Exhibit 4.48
PROJECTED AVERAGE ANNUAL HEATING
INSTALLATIONS IN ITALY, 1981-2000
(000 Units)

Region	SF	MFI	MFII
North			
New	17	20	11
Modernizations	13	na	21
Replacements	91	141	56
Central			
New	4	7	5
Modernizations	6	na	10
Replacements	19	31	20
South			
New	5	9	7
Modernizations	9	na	15
Replacements	24	31	20
TOTAL			
New	26	36	23
Modernizations	28	na	46
Replacements	134	203	96

Exhibit 4.49
COMPETITIVE HEATING SYSTEMS IN
EACH ITALIAN MARKET SEGMENT

Market Segment	AHP System	Competing Conventional Systems
Single-family	2 (absorption)	Advanced gas boiler Advanced oil boiler
Multifamily	5 (Diesel)	Advanced oil boiler

Exhibit 4.50
INITIAL COST OF AHP AND COMPETING CONVENTIONAL AND ADVANCED CONVENTIONAL SYSTEMS IN ITALY

System	Cost (1979 DM)
Small	
AHP 2 (gas) (10-12 kW)	12,591
Conventional gas	5,591
Medium	
AHP 5 (174 kW)	253,763
Conventional oil	69,892

Exhibit 4.51
ITALIAN DECISION CRITERIA (%)

Application	Life-Cycle	Payback Period	First Cost
Single-family	0	40	60
Multifamily			
Individually heated	0	40	60
Centrally heated	50	50	0

both potential purchasers and installers have limited information and experience with these systems.

Other barriers to market penetration in Italy are similar to barriers identified in many other countries: i.e., the reliability and low attractiveness of AHP technology to the heating/ventilating/air conditioning (HVAC) industry. At present, the Italian government conducts only information campaigns about the need for energy conservation in buildings, but provides no financial incentives to accelerate the penetration of energy-saving equipment, including heat pumps.

Market Estimate

The Italian team analyzed the market potential of two AHP systems in two market segments: AHP 2 in the single-family market and AHP 5 in centrally located multifamily buildings. The selected competing technologies were advanced oil and gas boilers, with high seasonal performance factors (above 0.85).

The economic analysis was performed in Northern Italy only, which has a more severe climate than other Italian regions. This location results in more severe competition for AHPs from conventional systems.

For AHP 2, the extra initial cost, compared to an advanced gas boiler, was estimated at approximately 6,500 DM for 15-20 kW output. This extra cost cannot be accepted by 60 percent of the potential purchasers. For those consumers sensitive to the payback criterion in making decisions, the Italian national team concluded that the energy efficiency of AHP 2 was not sufficient to make it preferable to the gas boiler. However, the payback of AHP 2 versus the advanced gas boiler appears to be approximately 2 to 3 years in 1990, and the Italian market study agent considers that AHP 2 could probably capture a significant share of the Italian market.

The higher annual maintenance costs of AHP 5 in the multifamily market (6 percent in installed cost) offset the energy savings it offers compared to advanced gas or oil boilers. Its higher first cost and higher annual operation costs eliminate this system from the Italian market.

In summary, the economic potential of the two AHPs studied is estimated to be almost zero in Italy. A more detailed analysis (i.e., including more systems and analyzing the sensitivity to the assumptions made of the rankings of all heating technologies according to economic criteria) would probably identify market segments that could be penetrated by somewhat cheaper or more efficient AHPs.

JAPAN

National Energy Demand and Residential Consumption

In 1978, Japan's total energy consumption was approximately 356 Mtoe. Oil consumption accounted for 70 percent of this total; coal, 15 percent; nuclear and hydroelectric production, 10 percent; and gas, 5 percent. Final end-use consumption was 265 Mtoe.

Japan imports almost 90 percent of its energy resources, including almost 100 percent of its oil, and 80 percent of its coal and natural gas. Its dependency on imports is expected to decrease by 11 percent to 77 percent in 1990, mainly because of decreased use of oil and increased use of nuclear, hydro, geothermal, and solar energy. However, Japan will continue to import almost 100 percent of its oil and increase coal and natural gas imports to 89 and 94 percent, respectively, of its total consumption of these fuels.

An unusually small percentage of total final end-use consumption (approximately 20 percent) is allocated to residential heating because Japan's industry consumes an unusually high amount of energy, accounting for over 50 percent of end-use consumption. In addition, Japan's climate is essentially mild, particularly in the most densely populated area of the Pacific coast. As a result, the use of heat pumps for residential heating and cooling will not contribute significantly to reducing Japan's total energy consumption.

Housing Stock and Current Heating Systems

The heating characteristics of Japan's housing stock represent an extreme case; nearly all housing units are individually heated. Approximately two-thirds of the total number of housing units are single-family houses and one-third are individually heated apartments. The housing stock is categorized by heating and cooling system type and fuel type in Exhibit 4.52.

Almost all heating systems are space II room-heating systems. Approximately half of these are fueled by oil (kerosene stoves) and half by electricity (electric Kotatsu heaters). Japan and the United States are the only two countries participating in the market study that require cooling systems. Nearly 35 percent of Japan's housing units have room air conditioners (for reasons of cost and ease of operation). Little change to the current pattern of heating and cooling systems and fuels is predicted by the year 2000, except for an increased use of room air conditioners.

Projected Heating and Cooling Installations

Japan projects an average annual demand for heating and cooling systems of approximately 262,000 units over the period 1981-2000. This demand is categorized by market segment, 5-year period, region, and new construction demand versus retrofit/replacement demand in Exhibit 4.53. Regions are divided into two categories: those requiring both heating and cooling and those requiring heating only.

Exhibit 4.52
JAPANESE HEATING AND COOLING
INSTALLATIONS AND FUEL TYPES
(% Housing Stock)

	SF	MFI
Heating System		
Space II: stoves, room units	94	97
Space I: electric baseboard	2	1
Central air	2	1
Central water	2	1
Cooling System		
Room	34	34
Central	1	1
None	65	65
Fuel Type		
Oil	48	50
Electric	43	41
Gas	6	9
Other	3	0

Exhibit 4.53

Average Annual Demand for Heating and Cooling Systems in Japan

	1981-1985			1986-1990			1991-1995			1996-2000		
	SF	MF I	MF II	SF	MF I	MF II	SF	MF I	MF II	SF	MF I	MF II
Heating and Cooling Regions												
Tokyo A												
• New	13,448	6,724	204	21,054	10,527	319	32,802	16,401	497	40,867	20,433	387
• Retrofit/Replacement	–	–	–	13,739	6,870	208	35,046	17,523	531	71,584	35,792	1,095
Total	**13,448**	**6,724**	**204**	**34,793**	**17,397**	**527**	**67,848**	**33,924**	**1,028**	**112,451**	**56,225**	**1,472**
Tokyo B												
• New	2,709	1,355	41	3,234	1,617	49	3,234	1,617	49	2,429	1,215	23
• Retrofit/Replacement	–	–	–	5,934	2,967	90	10,514	5,257	159	14,738	7,369	223
Total	**2,709**	**1,355**	**41**	**9,168**	**4,584**	**139**	**13,748**	**6,874**	**208**	**17,167**	**8,584**	**246**
Tokyo C												
• New	4,372	1,686	66	6,996	3,498	106	10,903	5,452	165	13,939	6,969	132
• Retrofit/Replacement	–	–	–	4,544	2,272	69	11,682	5,841	177	23,159	11,580	351
Total	**4,372**	**1,686**	**66**	**11,540**	**5,770**	**175**	**22,585**	**11,293**	**342**	**37,098**	**18,549**	**483**
Subtotal	**20,529**	**9,765**	**311**	**55,501**	**27,751**	**841**	**104,181**	**52,091**	**1,578**	**166,716**	**83,358**	**2,201**
Heating Only Regions												
Tokyo D												
• New	855	427	13	1,056	528	16	1,109	554	17	845	423	8
• Retrofit/Replacement	–	–	–	1,978	989	30	3,505	1,752	53	6,316	3,158	96
Total	**855**	**427**	**13**	**3,034**	**1,517**	**46**	**4,614**	**2,306**	**70**	**7,161**	**3,581**	**104**
Tokyo E												
• New	17,820	8,910	270	23,430	11,715	355	31,970	15,985	484	34,848	17,424	330
• Retrofit/Replacement	–	–	–	15,343	7,672	232	33,878	16,939	513	61,057	30,528	925
Total	**17,820**	**8,910**	**270**	**38,773**	**19,387**	**587**	**65,848**	**32,924**	**997**	**95,905**	**47,952**	**1,255**
Tokyo F												
• New	3,564	1,782	54	3,631	1,815	55	3,142	1,571	48	2,112	1,056	20
• Retrofit/Replacement	–	–	–	6,576	3,288	100	10,514	5,257	159	12,632	6,316	191
Total	**3,564**	**1,782**	**54**	**10,207**	**5,103**	**155**	**13,656**	**6,828**	**207**	**14,744**	**7,372**	**211**
Hokkaido												
• New	4,752	2,376	72	6,600	3,300	100	9,240	4,620	140	10,560	5,280	160
• Retrofit/Replacement	–	–	–	5,346	2,673	81	11,682	5,841	177	21,054	10,527	319
Total	**4,752**	**2,376**	**72**	**11,946**	**5,973**	**181**	**20,922**	**10,461**	**317**	**31,614**	**15,807**	**479**
Subtotal	**26,991**	**13,495**	**409**	**63,960**	**31,980**	**969**	**105,040**	**52,519**	**1,591**	**149,424**	**74,712**	**2,049**
Total	**47,620**	**23,260**	**720**	**119,461**	**59,731**	**1,810**	**209,221**	**104,610**	**3,169**	**316,140**	**158,070**	**4,250**
Total per period		**71,500**			**181,002**			**317,000**			**478,460**	

Reflecting the current building stock, 99 percent of the average annual demand for installations will occur in single-family houses and individually heated apartments, with 60 percent necessary to retrofit and replace existing systems. Approximately half this demand will occur in regions requiring both heating and cooling and half in regions requiring heating only. In addition, only 17 percent of the demand occurs in regions where gas is not available.

Heat Pump Systems and Markets

Approximately 300,000 air-heat-source electric compression heat pumps capable of both heating and cooling had been installed in Japan's residential sector as of 1979. An auxiliary heat source (e.g., electricity) is required in the winter when the heat pump's COP is degraded by low-heat source temperatures. Unless the current COP is multiplied by 1.5 or 2, these units will not be cost-competitive with conventional heating systems. However, they are more cost-effective than the purchase of an individual heater and room air conditioner.

Ambient air heat sources appear to have the most promising future in Japan because of its mild climate. Units using solar collectors as heat sources rank second due to the abundance of solar energy in Japan. However, these systems will capture market share only if their price is lowered. Geothermal energy heat sources represent a third possibility, although applications will be limited because geothermal energy is not available in all parts of the country.

Consumption of natural gas is expected to increase, which could produce a market for gas-driven heat pumps. Relatively lower electricity prices resulting from the increased use of nuclear, solar, and geothermal energy could increase the market potential of electric heat pump units.

The advanced heat pump systems considered by Japan within the context of the market study are summarized in Exhibit 4.54.

Factors Affecting Market Penetration

In Japan, only two decision critieria are used by decision makers in selecting a heating system: initial cost and payback period. Approximately 75 percent of Japanese decision makers base their selection on the initial cost of the system, and 25 percent on the payback period. The relative importance of these criteria is the same in all market segments and for both new and retrofit/replacement applications. Assumptions about costs are listed by competing systems in Exhibit 4.55.

Various institutional and environmental regulations will restrict the use of several AHP systems. Severe regulations restrict the extraction of groundwater in urban areas in order to prevent the ground from subsiding, thus eliminating the use of groundwater heat-source heat pumps. Surface-water heat-source pumps are prevented from using river water; in addition, all available water sources around large cities are exploited almost to their limit for potable water.

Japan's dependency on imports to supply its energy needs makes energy conservation a matter of high priority. Homeowner loans are available to subsidize

Exhibit 4.54
COMPETITIVE HEATING AND COOLING SYSTEMS
IN EACH JAPANESE MARKET SEGMENT

Market Segment	AHP System	Competing Conventional System
Single-family	2, 9, 13, 15	Stoves, electric resistance, conventional oil boiler
Multifamily,		
Individual	2, 4, 9, 13, 15	Stoves, electric resistance, conventional oil boiler
Central	13	Stoves, electric resistance, conventional oil boiler
District heating	4a, 17, 19, 20	Conventional oil boiler

Exhibit 4.55
INITIAL COST OF AHP AND COMPETING CONVENTIONAL AND ADVANCED CONVENTIONAL SYSTEMS IN JAPAN

System	Cost (1979 DM)
Small (11 kW)	
AHP 2	11,076
AHP 9	1,704
AHP 13	15,491
AHP 15/18	3,678
Conventional (heating only)	2,423
Conventional (H/C)	8,148
Medium (110 kW)	
AHP 13	189,763
Conventional (heating only)	81,479
Conventional (H/C)	24,225

Exhibit 4.56
ECONOMIC POTENTIAL OF SF AND MFI HEATING
AND COOLING SYSTEMS IN JAPAN 1986-2000
(000 Average Annual Installations/% Market Share)

	1986-1990	1991-1995	1996-2000
AHP 2 (gas)	0	0	0
AHP 9 (oil)	83.3 (100%)	156.2 (100%)	250.1 (100%)
AHP 15/18 (oil)	0	0	0
AHP 15/18 (gas)	0	0	0
AHP 19[a]	0	0	0
AHP 20[a]	0	0	0
Conventional oil	0	0	0
TOTAL	83.3	156.2	250.1

a. District heating systems.

Exhibit 4.57
ECONOMIC POTENTIAL OF SF AND MFI
HEATING-ONLY SYSTEMS IN JAPAN 1986-2000
(000 Average Annual Installations/% Market Share)

	1986-1990	1991-1995	1996-2000
AHP 4a[a]	0	0	0
AHP 13	23.9 (25%)	39.4 (25%)	56.0 (25%)
Conventional oil	71.9 (75%)	118.2 (75%)	168.1 (75%)
TOTAL	95.8	157.6	224.1

a. District heating systems.

Exhibit 4.58
ECONOMIC POTENTIAL OF MFII
HEATING-ONLY SYSTEMS IN JAPAN 1986-2000
(Average Annual Installations/% Market Share)

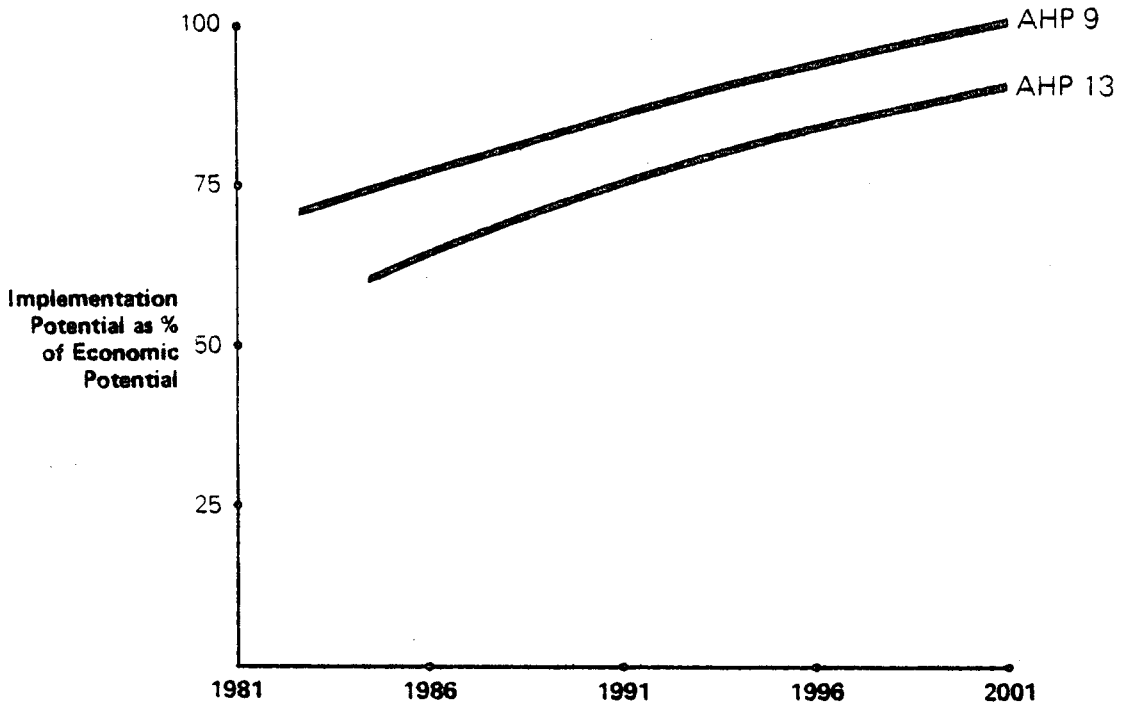
	1986-1990	1991-1995	1996-2000
AHP 13	242.25 (25%)	397.75 (25%)	512.25 (25%)
AHP 4a	0	0	0
Conventional oil	726.70 (75%)	1,193.25 (75%)	1,536.75 (75%)
TOTAL	969.00	1,591.00	2,049.00

Exhibit 4.59
AHP IMPLEMENTATION POTENTIAL IN JAPAN

	1986-1990	1991-1995	1996-2000
AHP 9			
Annual average installations (000 units)	66.6	140.6	250.1
SF, MFI market	37.0%	45.0%	53.0%
Percentage of economic potential	80.0%	90.0%	100.0%
AHP 13			
Annual average installations (000 units)	16.9	32.3	50.9
SF, MFI, MFII market	9.0%	10.0%	11.0%
Percentage of economic potential	70.0%	80.0%	90.0%

Exhibit 4.60

AHP Diffusion Rate in Japan



improvements in residential thermal efficiency, and the government is considering the introduction of a statutory code or practice for energy efficiency in new houses. However, with regard to incentives for homeowners to install heat pump systems, at present only the solar system qualifies for preferential tax treatment.

Market Segments

The economic potential market for competing systems in Japan is summarized in Exhibits 4.56, 4.57, and 4.58. AHP 9 performs very well in the single-family and multifamily I segments requiring heating and cooling. After its introduction in 1983, it captures 100 percent of this market, having a lower initial cost and payback period than its competitors. AHP 19 captures 100 percent of this market in 1981 and 1982, losing to AHP 9 once it is introduced. AHPs 2, 15/18, 19, and 20 have no market potential after 1985.

AHP 13, competing in all segments requiring heating only, ranks above its competitors on payback period. As a result, it captures 25 percent of the market for heating. The conventional oil system is the least expensive competing system, and as a result, captures the remaining 75 percent of this market. AHP 4a has no market potential.

Overall, AHPs 9 and 13 capture 65 percent of the total single-family and multifamily I market segment, while AHP 13 captures 12 percent of the total multifamily II market segment. However, Japan assumed an extremely low initial cost for AHP 9, which could mean that the economic potential for this sytem is overestimated.

Japan estimated the implementation potential of AHPs 9 and 13, as shown in Exhibit 4.59. Japan assumed a rapid diffusion rate to estimate the implementation potential of these systems. The implementation potential as a percent of economic potential is shown in Exhibit 4.60.

THE NETHERLANDS

National Energy Demand and Residential Consumption

In 1978, the Netherlands' total energy consumption was 64 Mtoe, and final end-use consumption was 54 Mtoe. Gas represents 51 percent of the total energy consumed, oil 43 percent, coal 5 percent, and nuclear energy 1 percent. The residential sector accounts for 28 percent of final end-use consumption.

Because of the Netherlands' domestic gas reserves, total domestic energy production exceeds demand by 21 percent. Gas exports offset current oil imports, which represent 38 percent of the Netherlands' total energy demand and account for 94 percent of its total oil consumption. Coal imports supply another 6 percent of energy demand. However, increased dependency on imports is predicted for the future as domestic gas reserves are depleted, and by 1990 energy demand is expected to exceed domestic production by 44 percent. Oil imports are predicted to increase from 38 percent to 51 percent of total

energy consumption as the use of natural gas decreases from 51 percent of total energy consumption to 34 percent.

The changing energy situation in the Netherlands could have a decisive influence on the future heat pump market. In the past, heat pumps had no chance to compete against inexpensive gas boilers burning low-cost natural gas. Although natural gas will continue to be the most important residential fuel, the depletion of gas reserves and the resulting dependency on oil imports has led to the formulation of an energy policy that will eventually raise gas prices to oil-equivalent levels. As natural gas prices rise, heat pumps could become competitive with conventional gas-fired systems.

Housing Stock and Current Heating Systems

As in the majority of market study countries, most housing units in the Netherlands are individually heated with natural gas. At present, approximately 70 percent of all housing units are single-family houses, and another 20 percent are individually heated apartments. The market segment proportions of the Netherlands' housing stock is very similar to that of Belgium.

Housing stock is categorized by heating system type and fuel type in Exhibit 4.61. Approximately half the systems are central water distribution systems and half are space II systems (i.e., stoves, room heating units).

Natural gas is expected to continue to be the dominant fuel used for home heating through 2000. The only significant change from the current pattern of heating systems will be in single-family houses, where the use of central water systems is expected to increase to a share of approximately 70 percent of all single-family houses corresponding to a decrease in the use of space II systems.

Projected Heating and Cooling Installations

In the 1981-2000 period, an annual average of 222,000 heating systems are projected to be installed in the Netherlands. Almost all these systems will be installed in single-family houses and individually heated apartments (see Exhibit 4.62). The number of installations in the MFII market segment is relatively small. Each system is serving more dwellings, however. As such, they represent 11 percent of the total number of dwellings.

New construction will represent only 32 percent of the installations, while replacements will represent 51 percent and modernizations 17 percent. As in Germany, almost all installations will be central water distribution systems including modernizations of space II (stoves, room-heating units) systems.

Heat Pump Systems and Markets

Very few heat pump systems have been installed in residential dwellings in the Netherlands at this time. Short-term market projections are not available, and there is doubt whether heat pumps will be able to compete with natural gas systems in this century. Heat pump systems will be competitive only if natural gas prices rise to oil-equivalent levels.

Given the energy situation in the Netherlands, gas-fired heat pump systems seem to be the most promising. Currently, 94 percent of all dwellings are

Exhibit 4.61
NETHERLANDS HEATING SYSTEMS
AND FUEL TYPES (% Housing Units)

	SF	MFI	MFII
Heating System			
Central water	49	20	100
Space II: stoves, room units	49	80	0
Central air	2	0	0
Fuel Type			
Gas	93	95	82
Oil	7	5	18

Exhibit 4.62
AVERAGE ANNUAL INSTALLATIONS
IN THE NETHERLANDS 1981-2000
(000 Units)

	Central Air	Central Water	Total
Single-family			
New construction	1	70	71
Replacements	3	95	98
Modernizations	0	29	29
Total	4	194	198
Multifamily I			
New construction	0	0	1
Replacements	0	8.5	9
Modernizations	0	14	14
Total	0	22.5	24
Multifamily II			
New construction	0	0.2	0.2
Replacements	0	0.5	0.5
Modernizations	0	0	0.0
Total	0	0.7	0.7

connected to the natural gas distribution grid. The market for electrically driven heat pumps will be limited by the capacity of power stations and the electricity distribution grid, as well as relatively high electricity prices.

Ground-source heat pumps are of particular interest in the Netherlands because of favorable groundwater levels and earth-temperature characteristics. Although applications are limited by the large ground area required for current heat exchangers, design improvements (i.e., vertical positioning of the ground heat exchangers) could increase technical applicability.

Although the Netherlands' moderate air temperatures make air-source systems efficient, high humidity levels make defrosting necessary and will decrease the capacity and SPFs of these systems to some extent.

The Netherlands selected six heat pump systems for analysis in the market study (see Exhibit 4.63). Cost assumptions for AHPs and competing systems are listed in Exhibit 4.64.

Factors Affecting Market Penetration

In the Netherlands, first-cost and yearly heating costs were used by the national team as the major decision criteria for selecting a new heating system. Yearly heating costs include the present value of the investment cost, maintenance costs, and energy costs. The importance of each criterion is categorized by market segment in Exhibit 4.65. Various environmental and institutional barriers limiting the applicability of several heat pump systems are delineated in Exhibit 4.66.

The Netherlands' conservation program for the residential sector centers around the National Insulation Program. Since 1974, subsidies have been granted to insulate new and existing dwellings. In addition, insulation standards for new dwellings have been raised considerably. However, no legislation currently encourages investment in such energy-saving equipment as heat pumps.

Market Estimates

Advanced heat pump systems will not capture any portion of the market in the Netherlands over the entire period. The market is served entirely by improved boilers (60 percent of total market) and conventional boilers (40 percent). The economic potential market estimated by the Netherlands for competing systems in residential applications is summarized in Exhibit 4.67.

Some improvements to advanced heat pump systems would make them more competitive and increase their economic potential. In the single-family and multifamily I segments, a decrease in first cost of 16,000 DM would make AHP 7 competitive in 1996 because it would gain a portion of the market using yearly heating costs as a decision criteria. Similarly, a decrease in first cost of 3,700 DM would make AHP 9 competitive in 1996. On the contrary, the energy consumption of AHP 2 is too high to allow this system to be competitive, even with a first-cost reduction. Similarly, AHPs 14 and 5 have very low energy-saving potential and are therefore not competitive. In the multifamily II segment, AHP 8 would be competitive in 1996 with a first cost of 12,000 DM, capturing the portion of the market using yearly heating cost as a decision criterion.

Exhibit 4.63
COMPETITIVE HEATING SYSTEMS IN
EACH NETHERLANDS MARKET SEGMENT
(New Construction)

Market Segment	AHP System	Competing Conventional System
Single-family (new and retrofit)	2b, 7, 9, 14, 15/18	Conventional and improved boilers
Multifamily (retrofit), individually heated	2b	Conventional and improved boilers
Multifamily (new and retrofit), centrally heated	8	Conventional and improved boilers

Exhibit 4.64
INITIAL COST OF AHP AND COMPETING CONVENTIONAL AND ADVANCED SYSTEMS IN THE NETHERLANDS

System	Cost (1979 DM)[a]
Small	
AHP 2	11,371
AHP 7 (9.4 kW)	22,259
AHP 9 (14.4 kW)	9,762
AHP 14 (10 kW)	10,030
AHP 15/18 (11.8 kW)	12,444
Conventional gas (12 kW)	3,969
Advanced conventional gas (12 kW)	4,505
Medium	
AHP 8 (70 kW)	196,845
Conventional gas (211 kW)	152,005
Advanced conventional gas (211 kW)	156,296

a. 18% AVT included.

Exhibit 4.65
NETHERLANDS DECISION CRITERIA (%)

	First Cost	Yearly Heating Cost
Single-family	40	60
Multifamily	50	50

Exhibit 4.66
INSTITUTIONAL/ENVIRONMENTAL BARRIERS
TO AHP IMPLEMENTATION IN THE NETHERLANDS

System	Barrier
Groundwater heat source	Expected restrictions on the widespread use of groundwater as a heat source
Gas engine	Air pollution controls against nitrous oxide emissions
Soil heat source	Municipal charges for using soil for heat storage in public areas
Electric	Government restrictions on the operation of electric heat pumps during peak loading periods might be restricted or prohibited in the future

Exhibit 4.67
ECONOMIC POTENTIAL OF HEATING SYSTEMS IN THE NETHERLANDS
(000 Average Annual Installations)

Heating System	1981-1985		1986-1990		1991-1995		1996-2000		Total (%)	
	New	Ret*	New	Ret	New	Ret	New	Ret	New	Ret
AHP 2b	-	-	0	0	0	0	0	0	-	-
AHP 7	0	0	0	0	0	0	0	0	-	-
AHP 8	0	0	0	0	0	0	0	0	-	-
AHP 9	-	-	0	0	0	0	0	0	-	-
AHP 14	-	-	0	0	0	0	0	0	-	-
AHP 15/18	-	-	0	0	0	0	0	0	-	-
Improved boiler	55.1	46.2	50.1	67.2	36.1	91.6	29.1	145.1	60	60
Conventional boiler	37.1	34.2	33.1	48.2	24.1	64.6	19.1	100.1	40	40
TOTAL	92.2	80.4	83.2	115.4	60.2	156.2	48.2	245.2	100	100

* Retrofit.

Improved boilers have a very large economic potential when they are introduced in 1981 (the economic potential averages 101,285 units per year in the period 1981-1985). However, as with all new technologies, their penetration will be limited by a number of factors such as consumer acceptance. Assuming a slow market diffusion rate, their implementation potential will be equal to 5,400 units per year (3-percent market share) in 1981-1985 and, assuming a fast diffusion rate, it will be 14,200 units (8-percent market share) per year. In the last period (1996-2000), implementation potential will increase to 37,800 units per year for a slow diffusion and 174,123 units per year for a fast diffusion (the latter being equal to the economic potential).

These figures correspond to a compounded growth rate of 14 percent per year for a slow diffusion rate and 18 percent per year for a fast diffusion rate. The market that cannot be served by improved boilers will be served by competing conventional systems.

In conclusion, advanced heat pump systems could capture a small market share in the Netherlands with considerable first-cost reduction and technical improvements. However, it will be difficult for them to become competitive with improved boilers.

SPAIN

National Energy Demand and Residential Consumption

In 1978, Spain's total energy consumption was 75 Mtoe. Final energy use was 51 Mtoe. Oil imports met 66 percent of the total energy demand; the remainder was supplied by hydroelectric and nuclear power production (16 percent), domestic and imported coal (13 and 4 percent, respectively), and gas imports (2 percent). Spain's dependence on oil imports is expected to decrease to a level of 43 percent by 1990, as domestic energy production increases. Although Spain's residential sector consumed only 13 percent of the final energy demand, expected improvements in the Spanish standard of living will accelerate energy demand in the residential sector (5.6 percent growth per year as opposed to 3.6 percent for the final total demand).

Although the demand for cooling in parts of the country may favor sales of systems with heating and cooling, such demand will probably be very low. National energy policy, which includes relatively stringent fuel-use restrictions, will also limit the types of heating installations selected for new construction, particularly in the multifamily market segment.

Housing Stock and Current Heating Systems

The housing stock in 1975 consisted of 12.2 million dwellings for a population of approximately 36 million. The distribution of this stock by type of building and type of heating system is summarized by region in Exhibit 4.68.

Single-family houses represent 47 percent of the total number of dwellings, while centrally heated multifamily buildings represent only 1 percent of all

Exhibit 4.68
SPANISH HOUSING TYPES BY REGION (000 Units)

Region	SF	MFI	MFII	Total
Center/North	3,217	3,455	145	6,817
South/Mediterranean Coast	2,622	3,053	22	5,697
Total	5,839	6,568	167	12,154
Percentage of Housing Stock	(47%)	(52%)	(1%)	

dwellings. Heating systems are installed in only 12 percent of all dwellings. The majority of the current heating systems are LPG stoves and direct electric heaters. Only 28 percent of the heated dwellings have a central distribution system, and these systems are generally oil-fired (see Exhibit 4.69).

Projected Heating and Cooling Installations

The Spanish market study team analyzed the potential markets for heat pump installations in new construction only. Replacement, modernization, and retrofit markets were not analyzed because they were not believed to represent any significant potential for AHP systems. Although Spanish purchasers generally prefer oil-fired central water heating systems, particularly in modernizing single-family houses, possible government restrictions on oil use will not favor oil-fired AHPs or conventional oil installations.

The new construction market was divided into three segments: single-family, multifamily I (individually heated apartments), and multifamily II (centrally heated apartments). As Spanish standards of living improve, more heating systems will be installed in new construction. Forecasts predict that 16 percent of all residential dwellings will have heating systems in 1980 and 27 percent will be heated by 2000, resulting principally from increased construction of multifamily buildings. Electric resistance heating will be the primary system installed in new SF construction (75 percent of the market) and will be used in 12 percent of new apartments in the MFI sector.

One result of increased heating installations will be a sharp rise in the number of central water systems in the MFII sector, which dominates new construction until 2000. Their market share will increase from 5 percent of all heating installations in 1980 to 20 percent in 2000. Oil, gas, and coal will be the primary fuels used to heat central-water systems in the MFII housing segment.

The heating installations projected in Exhibit 4.70 are calculated by region and by building type. Few cooling systems are projected to be installed in the residential sector and were not considered in the AHP market study analysis.

Reflecting the Spanish government's intent to implement a strong energy policy, planned fuel-use restrictions will influence the structure of the future demand for heating systems. The estimated effect of these restrictions is calculated for the SF and MFI sectors, by region, in Exhibit 4.71. In the single-family segment, oil continues to supply 25 percent of demand through 2000 because of the lower availability of natural gas in the North/Central region. Present projections indicate continued severe restrictions on the use of oil in individually heated apartments.

For centrally heated multifamily buldings, oil will be the dominant fuel initially, but will be progressively replaced by electric heating and electric heat pumps as a result of government fuel-use restrictions. As a result, the entire market segment may not be allocated to the best technology. The technology ranking second would be installed in the remaining parts of the market segment.

Exhibit 4.69
SPANISH RESIDENTIAL HEATING
SYSTEMS AND FUEL TYPES
(% Heated Housing Units)

	North/Central			South/Mediterranean Coast		
	SF	MFI	MFII	SF	MFI	MFII
Heating System						
Central air	0	0	0	0	0	0
Central water	17	0	100	13	0	100
Space I	73	10	0	74	7	0
Space II	10	90	0	13	93	0
Fuel Type						
Electric	73	10	0	74	7	0
Gas	10	90	0	14	93	0
Oil	17	0	50	12	0	100
Solid fuel	0	0	50	0	0	0

Exhibit 4.70
AVERAGE ANNUAL HEATING INSTALLATIONS IN SPAIN
(000 Units)

	North/Central			South/ Mediterranean Coast			Total		
	SF	MFI	MFII	SF	MFI	MFII	SF	MFI	MFII
1981-1985	7	390	5	2	38	0	9	428	5
1986-1990	9	440	7	6	36	0	15	476	7
1991-1995	11	482	9	9	34	0	20	516	10
1996-2000	14	463	11	12	32	1	26	515	12
TOTAL	41	1,795	32	29	140	1	70	1,935	34

Exhibit 4.71
EFFECT OF GOVERNMENT RESTRICTIONS OF
FUEL AVAILABILITY IN SPAIN IN SF AND MFI
HOUSING SECTORS (Maximum Percentage Available)

	North/Central			South/Mediterranean Coast		
Sector	Electricity	Gas	Oil	Electricity	Gas	Oil
Single-family						
1981-1985	60	30	60	70	70	25
1986-1990	55	40	50	60	35	45
1991-1995	55	35	40	65	40	20
1996-2000	55	25	25	65	30	15
Multifamily I						
1981-1985	40	60	5	40	60	5
1986-1990	50	60	5	50	60	5
1991-1995	55	55	5	55	55	5
1996-2000	65	55	0	65	55	0

Exhibit 4.72
COMPETITIVE HEATING SYSTEMS IN
EACH SPANISH MARKET SEGMENT
(New Construction Only)

Market Segment	AHP System		Competing Conventional System
Single-family	2	(oil)	Oil boiler
	2	(gas)	Gas boiler
	13	(electricity)	Electric heating
			Conventional heat pump
Multifamily I (individually heated apartments)	2	(oil)	Gas boiler
	2	(gas)	Electric heating
			Conventional heat pump
Multifamily II (centrally heated apartments)	13	(electric)	Oil boiler
	15/18	(gas)	Gas boiler
			Electric heating
			Conventional heat pump

Exhibit 4.73
EFFECT OF GOVERNMENT RESTRICTIONS ON FUEL AVAILABILITY IN THE MFII HOUSING SECTORS IN SPAIN (Maximum Percentage Available)

	Electricity	Gas	Oil
1981-1985	15	30	70
1986-1990	20	30	50
1991-1995	60	30	35
1996-2000	80	20	20

Exhibit 4.74
SPANISH DECISION CRITERIA (%)

Application	First Cost	Payback Period	Life-Cycle Cost
Single-family			
1981-1985	72	28	0
1986-1990	50	33	17
1991-1995	38	35	28
1996-2000	25	42	33
Multifamily I			
1981-1985	79	12	9
1986-1990	65	21	13
1991-1995	54	27	19
1996-2000	45	32	23
Multifamily II			
1981-1985	73	18	9
1986-1990	62	22	16
1991-1995	55	23	22
1996-2000	37	30	25

Exhibit 4.75
ECONOMIC POTENTIAL OF HEATING SYSTEMS IN SPAIN
(000 Installations/Year)

	1981-1985	1986-1990	1991-1995	1996-2000
Single-family				
Oil boiler	2	5	5	4
Gas boiler	3	5	7	7
Electric heat	4	4	3	6
Conventional heat pump		1	5	8
AHP 2 (oil)				1
AHP 2 (gas)				
AHP 13				1
Subtotal	9	15	20	27
Multifamily (individually heated)				
Oil boiler	17	21	21	0
Gas boiler	240	269	234	178
Electric heat	162	124	112	115
Conventional heat pump	9	63	130	196
AHP 2 (oil)				
AHP 2 (gas)			19	25
Subtotal	428	477	516	514
Multifamily (centrally heated)				
Oil boiler	3.2	3.5	2.7	1.0
Gas boiler	1.1	2.1	2.7	1.8
Electric heat	0.5	0.6	1.0	2.3
Conventional heat pump	0.1	0.8	3.0	5.8
AHP 13				
AHP 15 (gas)			0.3	0.8
Subtotal[a]	5.0	7.0	10.0	12.0

a. Estimated.

Heat Pump Systems and Markets

Heat pumps were first installed during the 1970s in both the commercial and residential sectors. A total of 2,800 air-source heat pumps were installed during the period 1974-1978, 30 percent in the residential sector and 70 percent in the commercial sector. Because of their favorable climatic conditions, approximately 70 percent of these installations were in the Southern and Eastern regions.

To project future heat pump installations, the Spanish market study team analyzed three AHP systems in three housing sectors (see Exhibit 4.72). No Diesel, Otto, or Stirling systems were selected because it was believed that they would have very low market acceptance, especially among public building contractors who construct the majority of new buildings. However, solar heat pumps, if available, could possibly penetrate the market after 1990.

Market Penetration Factors

The Spanish market study team devised a comprehensive set of decision criteria that reflects the increasing importance of higher energy prices, consumer education, and government energy policies in heating-system investment decisions. To calculate the effect of these factors on the market penetration of AHP systems, Spain changed the value of decision criteria during each period and for each housing sector (see Exhibits 4.73, 4.74).

However, the higher technical complexity of heat pumps compared to heating systems conventionally used in Spain strongly limits the possible penetration rate of AHPs. Customers, installers, housing contractors and HVAC equipment manufacturers are not familiar with heat pumps, and a considerable amount of education will be needed before these systems are accepted and demanded by a large part of the market.

Market Estimate

The economic potential market estimated by Spain for advanced heat pumps and competing systems is summarized in Exhibit 4.75. The major outcome of the economic evaluation of the competing heating technologies is that conventional heat pumps have a very good potential in Spain, because of their relatively low initial cost compared to AHPs and to their use of relatively cheap electricity. The only AHP system that actually achieves a substantial penetration in individually heated apartments is the gas-fired AHP 2. The poor performance of AHP 13 is partly explained by the small size of the single family home new construction sector, in addition to the system's high-investment cost.

SWEDEN

National Energy Demand and Residential Consumption

Sweden's total energy consumption in 1978 was 49.2 Mtoe, and final end-use consumption 33.9 Mtoe. Domestic hydroelectricity, nuclear power, and wood provided 45 percent of the total energy demand. Compared to other countries

participating in the AHP market study, Sweden imports oil, which meets 56 percent of its total energy demand. It is unlikely that new energy sources or coal or gas imports will be adequate to meet the anticipated increase in energy demand. As a result, oil will remain an important source of energy for the next decade.

Heating of residential, commercial, and institutional sectors consumes over 38 percent of Sweden's final energy use and over 43 percent of the final consumption of petroleum products. A large proportion of the heating demand in these sectors is supplied by district heating systems, currently using rather high distribution temperatures (80-120°C), as well as large boilers. Hence, when using heat pumps in district heating systems, the distribution temperatures should be lowered. As a result, the potential market for heat pumps is limited. Moreover, direct electric resistance heating accounts for a large part (over 20 percent) of space heating in single-family houses. Most of these systems were installed during the last decade while electricity prices were low.

Advanced heat pumps will be most applicable in houses or buildings with individual central water heating systems, with some potential in the medium size (approximately 1-10 MW) boiler range. Such boilers currently supply heat to a small group of buildings or parts of district heating areas.

Housing Stock and Current Heating Systems

Although Sweden's 3.5-million-unit housing stock can be divided into two climatic regions (i.e., North and South), few of Sweden's 8.2 million residents live in the northern region; therefore, the market study focuses on heating installations in the South. We considered one single set of conditions for the entire country. However, when answering the technical applicability of advanced heat pumps we took the difference existing between the Southern and the Northern parts of the country into account. The Swedish building stock was divided into four broad categories of heating systems to reflect the different decision makers in each:

- Direct electric resistance heating (ER)
- House or building boilers (HB)
- Block centrals, or plants heating a group of buildings (BC)
- District heating (DH).

Almost all multifamily buildings are centrally heated, i.e., the multifamily I category does almost not exist in Sweden, except for direct electric resistance heating.

The differences among heating systems used in single-family houses and those used in multifamily buildings are categorized in Exhibit 4.76. There are also wide differences in buildings' age; in recent years, most installations occurring in single-family houses were direct electric resistance systems, whereas most multifamily buildings were connected to either block central or district heating networks. Some of the large heating plants produce combined heat and power. Except for electric heating, oil is almost the only heating fuel.

Projected Heating Installations

Predicting which type of system will be used in the future is difficult because, at the time of printing, the future availability of nuclear power

Exhibit 4.76
SWEDISH HOUSING STOCK BY HEATING SYSTEM
(000 Housing Units)

Heating System	SF	MF	Total	% Total Units
Electric resistance	293	37	330	10
House boiler	1,017	534	1,551	45
Block central	38	500	538	16
District heating (oil)	54	990	1,044	30
TOTAL	1,402	2,061	3,463	

and extension of district heating systems, which depend on political decisions, is not known. To account for this uncertainty concerning the type of heating system that will be required, the Swedish analysis defined four scenarios with different emphases on electricity, district heating, and block centrals. These scenarios are defined in Exhibit 4.77. In each scenario, the Swedish team analyzed which shares of SF and MF markets would be held by each heating system type in new construction and retrofit/replacement installations. Average annual installations are calculated in Exhibit 4.78. Total installation vary slightly from one scenario to another because it was assumed that some comversions are easier than others.

Heat Pump Systems and Markets

The first heat pumps installed in single-family houses were imported air-to-air systems. Presently, approximately 75 percent of the heat pumps using air as heat source are imported. Approximately 300 to 500 of these systems were sold in the 1977-1979 period. Most of the heat pumps using soil as heat source are produced in Sweden. Installations in single-family houses were approximately 400 units in 1977, 600 in 1978, and 1,100 in 1979, with more than 2,000 projected sales in 1980. In addition to electric heat pumps, oil-fired heat pumps may find a market in single-family houses, multifamily buildings, and small-scale district heating or block central plants. Another area of interest is heat pumps with seasonal water or soil storage.

Sweden analyzed four AHP systems in various markets (see Exhibit 4.79). Estimates of initial costs for AHP systems are outlined in Exhibit 4.80. The analysis was carried out for these systems using the four energy scenarios described in Exhibit 4.77. Energy price projections differed in each scenario to reflect the corresponding assumptions about energy availability.

Factors Affecting Market Penetration

In Sweden, public authorities or housing cooperatives play a larger role in the housing sector than in many other countries. They affect decisions in construction in general and the selection of heating systems in particular.

Public authorities control the selection of heating systems in over 60 percent of the multifamily sector. In the single-family and private multifamily sectors, such decisions must reflect municipal plans concerning the type of heating system (e.g., district heating, electric heating). The selection of one heating system type over another will depend on Sweden's energy policy and possible political influences.

For the choice of a specific system or technology within each heating system type, weightings of decision criteria estimated in Exhibit 4.81 represent the behavior of Swedish heating system purchasers. The weights reflect the degree of sensitivity of both public officials and private purchasers to energy costs. In multifamily buildings, when the energy costs are not borne by the heating system purchaser, first cost is used.

The government encourages such energy conservation measures in the Swedish residential sector, as retrofit, insulation, connection to district heating, and improved efficiency of boilers. To offset the higher initial cost of heat pumps, the Swedish government grants a subsidy to heat pump purchasers,

Exhibit 4.77
RANKING OF HEATING SYSTEMS IN SWEDISH SCENARIOS

	Scenario			
	1	2	3	4
Direct electric resistance heating	High	High	Low	Low
House or building boiler	Low	Low	Low	Low
Block central	Low	High	Very high	High
District heating	High	Low	Low	High

Exhibit 4.78
HEATING SYSTEM INSTALLATIONS IN
SWEDISH HOUSING UNITS BY SCENARIO
(000 Average Annual Installations in Number of Dwellings)

		Housing Units			
Scenario	Housing Type	ER	HB*	BC	DH
1	Single-family				
	new	26	6	1	7
	existing	26	35	2	6
	Multifamily				
	new	5	1	2	17
	existing	12	5	2	34
2	Single-family				
	new	22	6	10	2
	existing	26	35	8	1
	Multifamily				
	new	5	1	6	13
	existing	8	5	37	2
3	Single-family				
	new	12	8	18	2
	existing	13	35	17	1
	Multifamily				
	new	1	1	10	13
	existing	1	5	42	2
4	Single-family				
	new	12	8	13	7
	existing	13	35	10	6
	Multifamily				
	new	1	1	6	16
	existing	1	5	31	13

* The number of home boiler installations in multifamily buildings declines strongly from 1981 to 2000.

Exhibit 4.79
COMPETITIVE HEATING SYSTEMS
IN EACH SWEDISH MARKET SEGMENT

Market Segment	AHP System		Competing Conventional System
Single-family (house boiler)	2	(oil absorption)	Oil boiler
	13	(electric, soil, horizontal coil)	Conventional electric heat pump
Multifamily (house boiler)	4a	(Diesel)	Oil boiler
	13	(electric, soil, vertical coil)	Conventional electric heat pump
1-MW range (block central and district heating)	5	(Diesel)	Oil boiler
	13	(electric, soil, vertical coil)	
10-MW range (district heating)	5	(Diesel)	Oil boiler

Exhibit 4.80
INITIAL COST OF AHP AND COMPETING
CONVENTIONAL SYSTEMS
(1979 DM)

	New[a]	Retrofit[b]
Small Systems		
AHP 2	19,300	6,600
AHP 13	24,000	13,000
Conventional oil	15,000	4,300
Conventional heat pump	---	11,500
Medium Systems		
AHP 4a	190,000	110,000
AHP 13	173,000	100,000
Conventional oil	103,000	30,000
Conventional heat pump	170,000	84,000
Large Systems		
Block central (1-MW)		
AHP 5	350,000	
AHP 13	340,000	
Conventional oil	87,000	
District heating (10-MW)		
AHP 5	3,200,000	
Conventional oil	560,000	

Note: Basic auxiliary equipment valid for all systems not included.

a. Includes costs, distribution system and, for medium systems, backup systems.

b. Distribution system not included.

Exhibit 4.81
SWEDISH DECISION CRITERIA (%)

Market Segment	First Cost	Payback Period	Life-Cycle Cost
Single-family (house boiler)			
New	40	40	20
Existing	10	80	10
Multifamily (house boiler)			
New	30	30	40
Existing	30	30	40
Block central	0	50	50
District heating	0	0	100

depending on whether systems are monovalent or bivalent, which may amount to approximately 3,000 SKr for single-family houses. Additional loans at reduced interest rate can be used to finance the remaining part of the investment. (In 1979, the rate on these loans was 10 percent, compared to 14-15 percent for ordinary housing loans.) Such subsidy and loan incentives will increase the market penetration of heat pumps by reducing the economic barriers resulting from high investment cost.

The current HVAC industry's ability and capacity to serve the expected growing demand for heat pumps is in question for several reasons. First, systems must meet Swedish design and dimension requirements; as a result, imports will presumably play a minor role. A lack of domestic production capacity may limit the penetration of heat pumps in the next few years. Second, it is not clear whether a sufficient number of installers can be trained early enough to install the heat pumps demanded by the market.

Market Estimates - Economic Potential

The Swedish market evaluation was conducted for several scenarios corresponding to different assumptions about the adoption of district heating and block central heating. Results of only one scenario are reported here (see Exhibit 4.82). The corresponding price scenario assumes a 4-percent annual escalation rate for domestic fuel oil prices and a 2-percent annual escalation rate for electricity prices.

The estimates of economic potential are summarized in Exhibit 4.83 for advanced heat pump systems in three size ranges:

- Small systems: applicable in single-family houses
- Medium systems: applicable in multifamily buildings
- 1-MW systems: applicable in block central and district heating systems
- 10-MW systems: applicable in district heating systems.

The results, given both in number of installations and in market share, include the effects of technical barriers and subsidies.

In the single-family market segment, AHP 13 has a good economic potential due to its high technical performance, which gives it a good ranking on the basis of life-cycle cost. However, because its technical applicability is reduced by the limited availability of soil, its economic potential reaches only 14 percent of the single-family market. AHP 2 ranks well on the basis of payback period; it is first in some cases and second to conventional heat pumps in others. On the basis of life-cycle cost, AHP 2 appears frequently in second position, following AHP 13, and therefore captures some of the market that AHP 13 cannot because of its technical limitations. The economic potential of AHP 2 is approximately 25 percent of the single-family market. Installations in single-family houses by type of heating systems are summarized in Exhibit 4.84. Together, all small sizes of AHP systems penetrate 38 percent of the single-family house boiler market. The remaining 62 percent is shared by boilers and conventional electric heat pumps.

Exhibit 4.82

Heating System Installations in Sweden
(scenario 4)

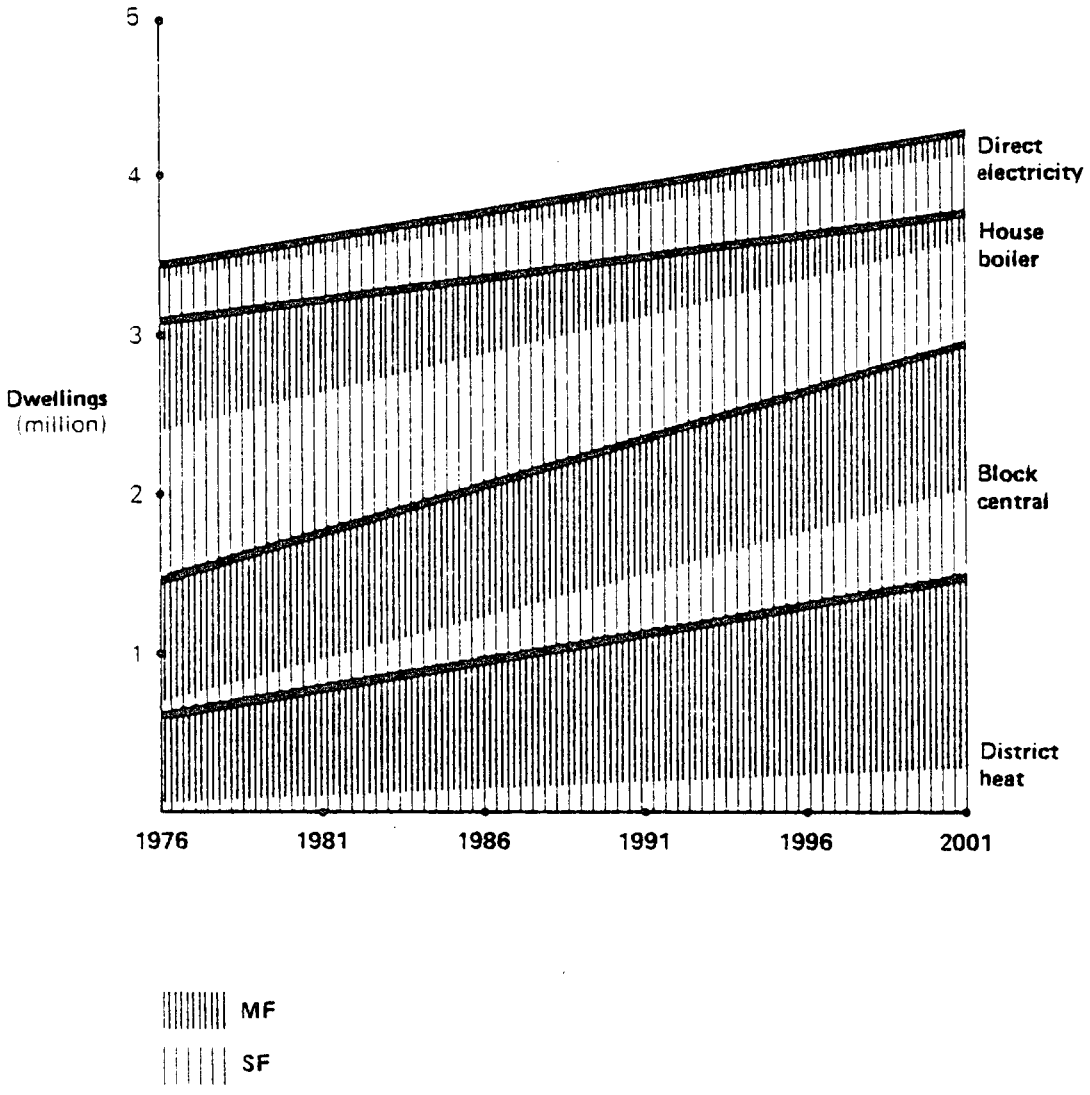


Exhibit 4.83
ECONOMIC POTENTIAL FOR AHP SYSTEMS IN SWEDEN
(Average Annual Installations/% Market Share)

AHP System	1981-1985	1986-1990	1991-1995	1996-2000
Small (≃10 kW)(a)				
AHP 13	6,620 (15%)	5,480 (13%)	5,960 (14%)	5,840 (14%)
AHP 2	0	10,680 (25%)	10,200 (24%)	9,980 (24%)
Subtotal	6,620 (15%)	16,160 (38%)	16,160 (38%)	15,820 (38%)
Medium (100-200 kW)(b)				
AHP 4a	0	0	0	0
AHP 13	136 (14%)	108 (14%)	66 (15%)	24 (16%)
Subtotal	136 (14%)	108 (14%)	66 (15%)	24 (16%)
1-MW (BC and DH)(c)				
AHP 5	0	225 (55%)	255 (53%)	274 (53%)
AHP 13	84 (22%)	90 (22%)	104 (22%)	112 (22%)
Subtotal	84 (22%)	315 (77%)	359 (75%)	386 (75%)
10-MW (DH)(d)				
AHP 5	0	5 (87%)	4.4 (88%)	5 (87%)

(a) Market share is calculated for the SF home boiler segment.

(b) Market share is calculated for the MF house boiler segment.

(c) Market share is calculated over the installation of 1 MW boiler in both block central and district heating plants.

(d) Market share is calculated over the market for 10 MW boiler in distributed heating.

Exhibit 4.84
HEATING SYSTEM INSTALLATIONS IN SINGLE-FAMILY HOUSES IN SWEDEN
(Economic Potential - 5-Year Totals) (Scenario 4)

Heating System	1981-1985	1986-1990	1991-1995	1996-2000
Direct electric	115,000	120,000	130,000	140,000
House boiler				
Conventional HP:	92,340	82,950	82,950	80,580
Oil boiler:	94,560	51,250	51,250	50,300
AHP 13:	33,100	27,400	29,800	29,200
AHP 2:	0	53,400	51,000	49,920
Total:	220,000	215,000	215,000	210,000
Block central	95,000	100,000	125,000	140,000
District heating	55,000	65,000	65,000	75,000

Exhibit 4.85
HEATING SYSTEM INSTALLATIONS IN MULTIFAMILY HOUSES IN SWEDEN
(Economic Potential, Dwellings, 5-year totals) (Scenario 4)

Heating System	1981-1985	1986-1990	1991-1995	1996-2000
Direct electric	10,000	10,000	10,000	10,000
House boiler				
Conventional HP	17,040	13,300	9,450	4,201
Oil Boiler	31,850	20,750	11,700	3,451
AHP 4a	0	0	0	600
AHP 13	1,110	5,950	3,850	1,750
Total	50,000	40,000	25,000	10,000
Block central	170,000	180,000	195,000	205,000
District heating	160,000	145,000	140,000	135,000

AHP 13 (vertical) is the only AHP system to penetrate the multifamily house boiler market segment (see Exhibit 4.85). Again, its economic potential is a function of limited technical applicability, and R&D improvements in SPF or cost cannot increase its market penetration. Therefore, it obtains only about 15 percent of the market. AHP 4a's high cost and poor technical performance are not competitive and provide no economic potential; it ranks poorly for all decision criteria. Diesel/Rankine systems seem more applicable in larger sizes.

In the 1-MW size range, AHP 5 (Diesel/Rankine) has an economic potential equal to 50-55 percent of the market because of its good ranking on life-cycle cost (always first) and payback period (first or second), the only two criteria considered for block central systems. AHP 13 (vertical) also captures 27 percent of the 1-MW market. However, conventional heat pumps were not included in the analysis of this market segment, although they could compete to a certain extent with AHP systems.

AHP 5 also captures a large part (87 percent) of the small-size (10-MW) district heating boilers market, but this potential corresponds, on the average, to only 2 percent of the capacity installed in district heating systems each year. The 10-MW AHP 5 could also be installed in block centrals, where it would have a large market potential.

Market Implementation Potential

The major constraints to the introduction and penetration of advanced heat pump systems are lack of acceptance by manufacturers and lack of installation capabilities. Other barriers, such as consumer reluctance, are believed to be of less importance in Sweden than in other countries. However, by neglecting them here, we may have over-estimated the implementation potential of AHPs. There were 1,600 heat pumps (1,100 using soil) installed in single-family houses in 1979 by an estimated 50 installers. As a result of the current education program for installers, there will be a potential for installation of 5,000 small units per year in 1985.

Assuming a 31-percent growth rate for the number of installers, we can plot an education/installation constraint that will limit the penetration of AHP 13 during the first period (see Exhibit 4.86) and reflect its low implementation potential. Exhibit 4.86 also includes a manufacturing capacity constraint plotted for AHP 2 after its introduction in 1985. The implementation potential of AHP 2 quickly reaches the value of the economic potential. Implementation potential estimates are summarized in Exhibit 4.87.

Only a few large-capacity heat pump units have been installed and very little information exists on the future potential for their production and installation. Installers will probably be capable of installing 20 to 30 1- and 10-MW units in 1985 and 100 units in 1990. This installation constraint is plotted in Exhibit 4.88, which also includes the economic and implementation potential of AHP 5 and AHP 13. It is believed to reflect all barriers possibly affecting the penetration of AHP in these sectors. The economic potential for medium-size advanced heat pumps in the multifamily market segment is small, and would not be significantly affected by removal of implementation barriers, except perhaps in the first few years after introduction.

Exhibit 4.86

Installation/Manufacturing Constraints on the Economic Potential of AHPs 2 and 13 in Sweden
(SF market)

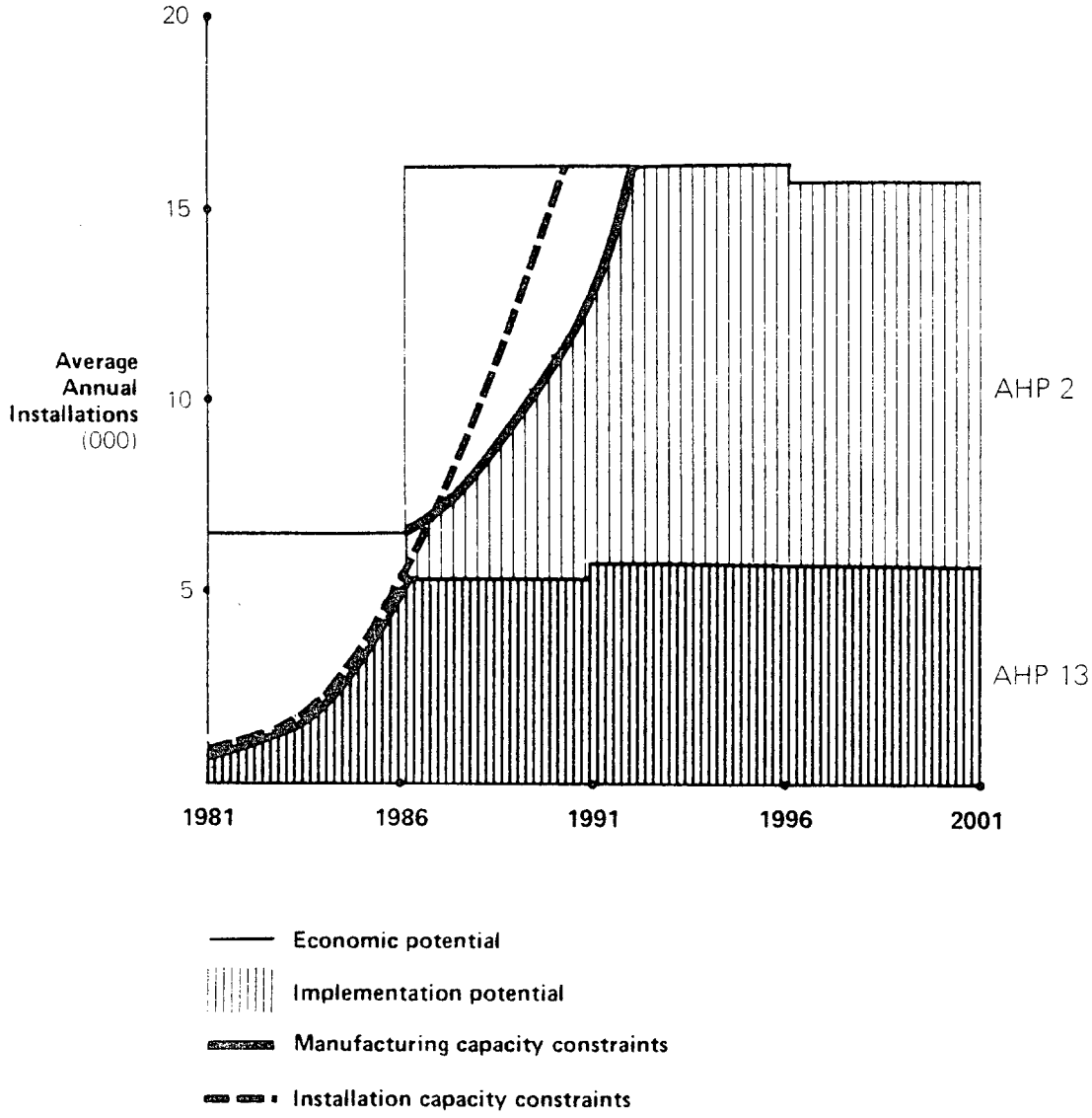
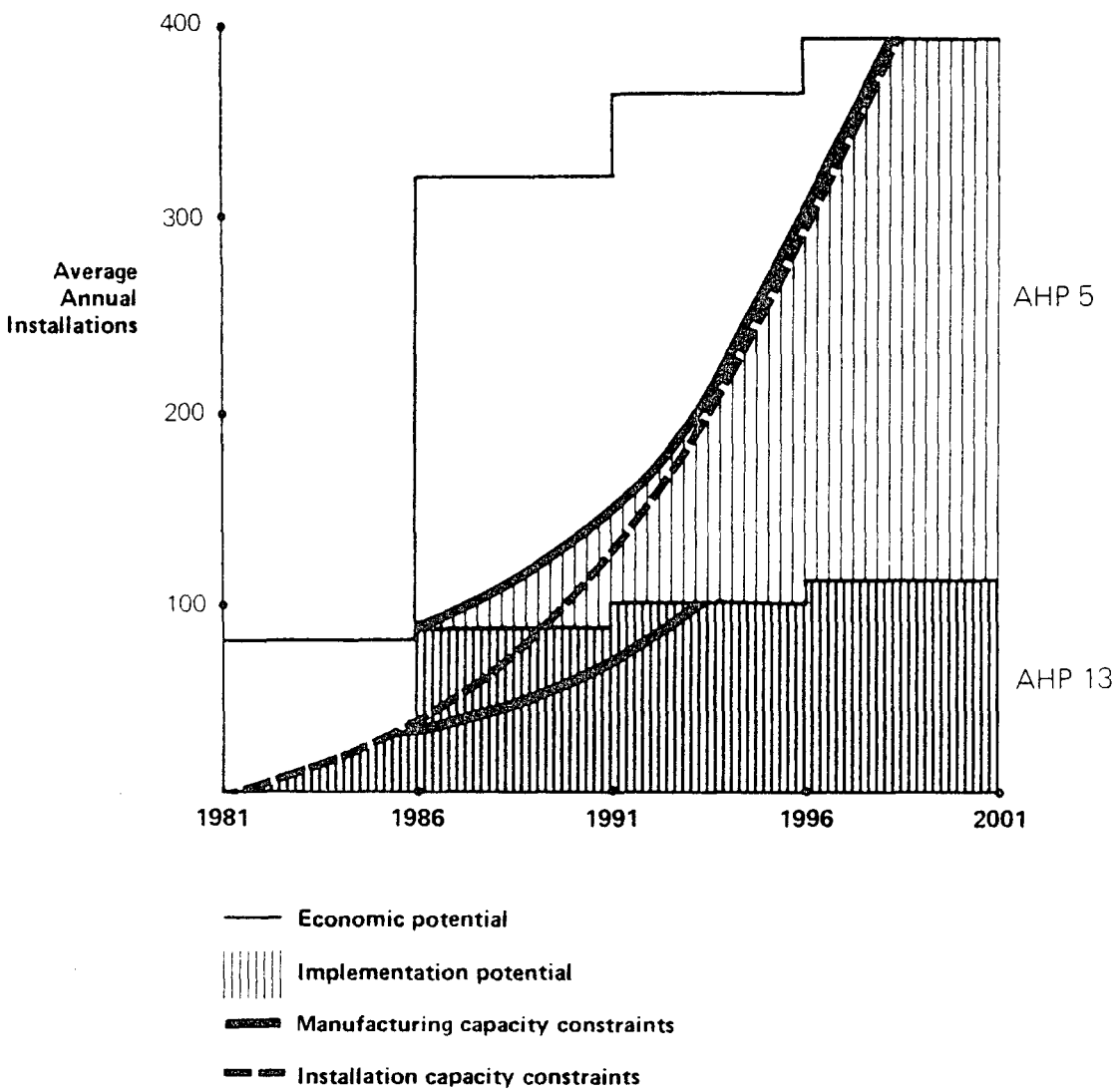


Exhibit 4.87
IMPLEMENTATION POTENTIAL FOR AHP SYSTEMS IN SWEDEN
(Average Annual Installations/% Market Share)

AHP System	1981-1985	1986-1990	1991-1995	1996-2000
Small				
AHP 13	3,450 (8%)	5,480 (13%)	5,960 (14%)	5,840 (14%)
AHP 2	0	3,410 (8%)	10,200 (24%)	9,980 (24%)
Subtotal	3,450 (8%)	8,890 (21%)	16,160 (38%)	15,820 (38%)
Medium				
AHP 13	78 (8%)	108 (14%)	66 (15%)	24 (16%)
Large (1-10 MW)				
AHP 13	20 (5%)	58 (14%)	96 (20%)	112 (22%)
AHP 5	0	28 (7%)	90 (19%)	242 (46%)
Subtotal	20 (5%)	86 (21%)	186 (39%)	354 (68%)

Exhibit 4.88

Installation Constraints on Economic and Implementation Potential of AHPs 5 and 13 in Sweden



SWITZERLAND

National Energy Demand and Residential Consumption

Switzerland's total energy consumption in 1978 was 24 Mtoe, and its total end-use consumption 17 Mtoe. Switzerland depends on imported fossil fuels for 58 percent of its energy; over 54 percent of its fuel requirements are met by imported oil and 3 percent by natural gas imports. Hydroelectricity and nuclear power are almost the only energy produced domestically. Import dependence is predicted to be 56 percent by 1990, when oil imports will decrease to 48 percent and nuclear production will increase from 8.5 percent to 17 percent. Natural gas will supply only 6 percent of all energy demand in 1990, one of the lowest market shares for natural gas of any country in the AHP market study.

Residential space heating alone represents almost 50 percent of end-use consumption, indicating a large potential market share for heat pumps in Switzerland.

Housing Stock and Current Heating System

The Swiss housing stock is unusually concentrated in multifamily centrally heated units. Of the total 2.7 million units that house 6.3 million residents, 82 percent are in the multifamily II category, 17 percent in single-family houses, and 1 percent individually heated apartments.

The building stock is heated primarily by oil and through water distribution systems, as shown in Exhibit 4.89. Oil-fired water distribution systems will probably continue to be the primary heating installations in Switzerland, with some increase of electric heating in single-family houses and in district heating in the cities. Unlike the projected increase in gas consumption in many other countries, Switzerland's use of natural gas in residential heating is not expected to expand.

Projected Heating and Cooling Installations

In the period 1981-2000, Switzerland expects 46,000 heating installations annually in building central units and only 38,000 in single-family houses and individually heated apartments (see Exhibit 4.90). Switzerland is the only country in the market study in which installations in centrally heated apartments are projected to exceed those in individually heated housing units.

Replacements represent 78 percent of the installations; replacements of central water systems alone represent 73 percent. To penetrate the Swiss market, manufacturers must adapt heat pumps to water distribution systems, which often require temperatures of 80-90°C.

Switzerland's analysis covered new and replacement/modernization/retrofit (r/m/r) installations in multifamily buildings and single-family houses. For r/m/r segments, the installations were allocated by fuels in Exhibit 4.91. These projections appear to be based on national energy policy. District heating's share will rise from 3 percent to 15 percent of r/m/r installations, and electricity, whose share will rise from 8 percent to 27 percent. Oil's market share of r/m/r drops from 73 percent to 32 percent over the period 1981-2000, and the market share for gas rises from 10 percent to 20 percent.

Exhibit 4.89
SWISS HEATING SYSTEMS AND FUEL TYPES (%)

	SF	MF
Heating System		
Building central water	90	92
Space I (electric furnace)	6	1
Space II (stoves, room heating units)	4	7
Fuel type		
Electricity	6	1
Gas	3	2
Oil	87	90
Coal, coke	4	7

Exhibit 4.90
PROJECTED INSTALLATIONS IN SWITZERLAND, 1981-2000
(000 Annual Average)

		Central Water	Space I (Baseboard and Resistance Electric Heating)
Single-family			
New		5.2[a]	3.1
Replacement		27.2	
Modernization/retrofit		2.6	—
	Total	35.0	3.1
Multifamily			
New		3.3[b]	0.3
Replacement		39.5	
Modernization/retrofit		3.7	—
	Total	46.5	0.3

a. Includes 1,700 units from space I and space II.

b. Includes 2,800 units from space I and space II.

Exhibit 4.91
REPLACEMENT, MODERNIZATION, AND RETROFIT INSTALLATIONS BY FUEL TYPES IN SINGLE-FAMILY AND MULTIFAMILY BUILDINGS (000 Average Annual)

	1981-1985		1986-1990		1991-1995		1996-2000	
	SF	MF	SF	MF	SF	MF	SF	MF
Oil	18.1	29.6	16.9	25.9	14.5	20.1	10.8	14.5
Gas	2.5	4.1	3.7	5.6	5.0	7.0	6.5	8.6
Coal	1.5	2.4	1.7	2.6	2.2	3.1	2.4	3.2
Electricity	2.0	3.3	3.9	6.0	6.3	8.8	9.1	12.2
District heating	0.7	1.2	2.0	3.0	3.5	4.8	5.1	6.8
Total SF	24.8		28.2		31.5		33.9	
Total MF		40.6		43.1		43.8		45.3

Heat Pump Systems and Markets

Some large water-source heating systems were installed in Switzerland during World War II, some of which are still in operation after more than 30 years. Today's heat pump production is extremely recent, however, and a major market has yet to develop. About 1,000 heat pumps are installated in Switzerland at the present time, mostly electric compression units in single-family houses. Because its cold, relatively extreme climate reduces Switzerland's potential use of conventional air-water heat pumps, there is a good deal of interest in systems using soil, groundwater, or river water as heat sources. There are about 10 gas-motor heat pumps either installed or on order. Swiss heating-system installations include several hundred solar collectors with ground heat storage systems, which are gaining popularity.

In the future, Swiss experts expect that motor-driven heat pumps will compete with electric units. They will replace many of the present oil boilers, especially in large installations. Because so much of the housing stock is in centrally heated apartments, Diesel-engine heat pumps could have a larger market share in Switzerland than in countries with more gas and more single-family houses. There has even been a study of the possibility of exploiting the warm springs and geothermal energy around the old Roman spa of Baden as heat sources.

About 100 heat pump manufacturers or installation firms, many of which represent foreign companies, currently have operations in Switzerland. Domestic production of heat pumps is just beginning.

The Swiss market study team analyzed four heat pump systems for four market segments (see Exhibit 4.92). Although they were not analyzed in detail, Switzerland is also interested in seven other AHP systems (see Exhibit 4.93). Initial costs for the four AHP systems analyzed in the market study are estimated in Exhibit 4.94.

Factors Affecting Heat Pump Penetration

The Swiss analysis assumed that total annual cost would be the only criterion used by decision makers in selecting heating systems. This choice of criterion, assumed to hold for all market segments, reflects the country's traditional willingness to accept heavy capital investment to obtain lower operating costs and, ultimately, better economic performance.

A number of regulations, usually at the level of the cantons, complicate the use of heat sources other than air. Extraction of heat from groundwater or soil is usually permitted as long as the refrigerant is freon, but some cantons limit the extraction of heat or forbid it altogether in densely populated areas. Extraction from surface water is generally allowed as long as the water is not cooled more than 4°C. Heat-pump installations using water as a heat source are subject to an annual tax.

In addition to regulations governing heat sources, some cantons may limit the installation of engine exhausts in buildings or restrict noise levels. For example, some ventilator fans or air-water heat pumps have violated noise laws. As in Germany, most existing buildings have high-temperature (80-90°C)

Exhibit 4.92
COMPETITIVE HEATING SYSTEMS IN EACH SWISS MARKET SEGMENT

Markets	System	Competing Conventional Systems
Single-family, new construction	2 (absorption) 4 (Diesel/Rankine)	Oil, gas (central water) Electric resistance
Single-family, existing	2 (absorption) 4 (Diesel/Rankine)	Oil, gas (central water)
Multifamily, centrally heated -- new construction	3 (two-stage absorption) 15/18 (ORC/Rankine)	Oil (central water) District heating
Multifamily, centrally heated -- existing	3 (two-stage absorption) 15/18 (ORC/Rankine)	Oil (central water)

Exhibit 4.93
AHP SYSTEMS TECHNICALLY APPLICABLE IN SWITZERLAND

System	Application/Potential
4a (Diesel/Rankine)	1% share of MF market (with restriction)
6 (Diesel/Rankine)	0.1% share of DH market
8 (Otto/Rankine)	Commercial
13 (Electric)	1% share of SF/MF market
14 (Absorption)	0.5% share of SF market
17 (Rankine)	0.1% share of DH market
19 (Absorption)	0.1% share of DH market

Exhibit 4.94
INITIAL COST OF AHP AND COMPETING CONVENTIONAL AND ADVANCED CONVENTIONAL SYSTEMS (Switzerland)

	Cost (1979 DM)[a]
Small	
AHP 2 (gas)	24,000
AHP 4	36,000
Conventional oil	22,000
Conventional gas	17,000
Conventional electric	25,000
Medium	
AHP 15/18	120,000
Conventional oil	75,600
Conventional gas	57,100
Conventional electric	80,538
Large	
AHP 3	500,000
Conventional gas	420,000

a. Includes cost of distribution system and backup system.

Exhibit 4.95
ECONOMIC POTENTIAL FOR HEATING SYSTEMS IN SINGLE-FAMILY HOUSES IN SWITZERLAND
(000 Average Annual Installations)

	1981-1985		1986-1990		1991-1995		1996-2000	
	New	r/m/r	New	r/m/r	New	r/m/r	New	r/m/r
AHP 2	0.43	0.5	0.8	1.4	1.6	3.1	2.0	5.0
(% of market)	(5)	(2)	(10)	(5)	(20)	(10)	(25)	(15)
Conventional gas	0.43	2.0	0.4	2.3	0.4	1.9	0.4	1.4
AHP 4	0.43	.5	.8	1.4	1.6	3.2	2.0	5.0
(% of market)	(50	(2)	(10)	(5)	(20)	(10)	(25)	(15)
Conventional oil	3.9	17.6	2.9	15.5	1.2	11.3	0.4	5.8
Conventional electric	1.7	2.0	1.7	3.9	1.6	6.3	1.6	9.2
Other:	1.7		1.7		1.6		1.6	
Coal		1.5		1.7		2.2		2.4
District heating		0.7		2.0		3.5		5.1
TOTAL	8.6	24.8	8.3	28.2	8.0	31.5	8.0	33.9

Exhibit 4.96
ECONOMIC POTENTIAL FOR HEATING SYSTEMS
IN MULTIFAMILY HOUSES IN SWITZERLAND
(000 average annual installations)

	1981-1985		1986-1990		1991-1995		1996-2000	
	New	r/m/r	New	r/m/r	New	r/m/r	New	r/m/r
AHP 3	0.1	1.2	0.2	2.2	0.4	4.4	0.7	6.8
(% of market)	(3)	(3)	(5)	(5)	(11)	(10)	(19)	(15)
AHP 15/18	0.1	1.2	0.2	2.2	0.4	4.4	0.8	6.8
(% of market)	(3)	(3)	(5)	(5)	(11)	(10)	(19)	(15)
Conventional oil	2.4	28.4	2.1	23.7	1.8	15.7	1.1	7.7
Conventional gas	0.7	2.8	0.7	3.4	0.7	2.6	0.7	1.8
Conventional electricity	0.4	3.3	0.4	6.0	0.3	8.8	0.4	12.2
Coal		2.4		2.6		3.1		3.2
District heating		1.2		3.0		4.8		6.8
TOTAL	3.7	40.5	3.6	43.1	3.6	43.8	3.7	45.3

water distribution systems, which limits the potential application of heat pumps in the replacement market.

As in many other countries, the Swiss heating supply and service industry has not yet developed specialists in the installation and maintenance of heat pumps. The lack of experienced dealers increases the reluctance of home or building owners to install heat pumps.

Unlike neighboring countries, most notably Germany, Switzerland has no government programs to subsidize the improvement of new and existing building stock. No tax write-offs or subsidies currently are available to reduce the effective capital cost of AHP systems to the consumer.

Swiss utilities, however, are marketing heat pumps in preference to conventional electric resistance systems. Although low electricity tariffs have been established for heat pumps, these rates are based on interruptible service during peak load periods. As a result of the need for storage, the construction and installation of AHP systems becomes even more complicated and expensive.

Market Estimates

Switzerland's economic calculations show that, over the period 1980-2000, oil and gas furnaces have lower total annual cost than the heat pumps profiles 2, 4, and 15 in the replacement/modernization/retrofit market, and conventional gas furnaces lower cost in the new construction market. Nevertheless, Switzerland has allocated small economic market shares to heat pumps starting in 1981-1985. Heating systems were allocated by installation in single-family houses in Exhibit 4.95 and in multifamily houses in Exhibit 4.96. The estimates of economic potential were based on expert judgment and not explicitly on economic comparisons of the systems. The allocation of the r/m/r market is consistent with the previous allocation of fuels. In new construction, Switzerland oil usage declines in favor of heat pumps. Switzerland made no estimate of implementation potential.

UNITED KINGDOM

National Energy Demand and Residential Consumption

In 1978, the United Kingdom's total energy consumption was 211 Mtoe. Of this total, oil accounted for approximately 44 percent, coal 33 percent, natural gas 18 percent, and nuclear and hydroelectric power 5 percent. Total final end-use consumption was 148 Mtoe, of which 25 percent was consumed for space and hot water heating in the residential sector.

The United Kingdom is endowed with oil and natural gas resources in the North Sea, as well as coal resources. Imports currently supply 26 percent of its energy demand, including 55 percent of the demand for oil and only 4 percent of the demand for natural gas. Domestic coal production is adequate to meet present and future demand. Its domestic reserves of oil and natural gas will enable the United Kingdom to maintain net energy independence from about 1980 to 1986-1988.

By 1990, import dependency is predicted to be approximately 7 percent, when oil imports are expected to supply only 8 percent of the demand for oil as opposed to 55 percent in 1977. At the same time, natural gas imports will supply 20 percent of the United Kingdom's gas requirements, up from 4 percent in 1977.

Housing Stock and Current Heating Systems

Most of the United Kingdom's 56 million residents live in individually heated housing units. Only 4 percent of the 19.8 million housing units in the United Kingdom are in centrally heated buildings.

The building stock is categorized by heating system type and fuel type in Exhibit 4.97. Approximately half the heating systems are space II systems (stoves, room-heating units); most of the remainder are central-water systems. Natural gas is the predominant heating fuel.

The use of space II systems is expected to decline gradually by 2000, to be replaced by central-water and central-air systems. Natural gas is expected to remain the dominant heating fuel.

Projected Heating and Cooling Installations

In the period 1981-2000, an average of approximately 1.45 million central heating systems are expected to be installed annually in the United Kingdom in single-family houses and individually heated apartments. Installations in centrally heated multifamily buildings were not considered because this market segment is very small in the United Kingdom.

Exhibit 4.98 delineates annual demand within the four market segments analyzed by the United Kingdom:

- Single-family houses with access to the United Kingdom's gas network (SF with gas)
- Single-family houses without access (SF without gas)
- Individually heated apartments with access (MF with gas)
- Individually heated apartments without access (MF without gas).

These market segments were selected because there is a very comprehensive and reliable gas network in the United Kingdom, and because of the strong preference among consumers to use gas when it is available.

Between 1981-2000, approximately 72 percent of the heating system installations will occur in single-family houses and individually heated apartments with access to the existing gas network. Furthermore, approximately 85 percent of the installations will result from the r/m/r of existing systems. Finally, approximately 76 percent of the installations during this period will occur in single-family houses.

Exhibit 4.97
UNITED KINGDOM HEATING SYSTEMS AND FUEL TYPES (%)

	SF and MFI
Heating System	
Space II (stove, room unit)	49
Central water	38
Space I (electric furnace or baseboard)	8
Central air	5
Fuel type	
Gas	47
Coal	28
Electric	20
Oil	5

Exhibit 4.98
PROJECTED AVERAGE ANNUAL HEATING SYSTEM INSTALLATIONS (000 units)
(Central Air and Water Distribution Systems Only)

Market Segment	1981-1985	1986-1990	1991-1995	1996-2000
SF with gas				
New	136	165	123	117
Retrofit	594	734	648	650
Total	730	899	771	767
SF without gas				
New	24	29	22	21
Retrofit	255	315	278	279
Total	279	344	300	300
Total SF				
New	160	194	145	138
Retrofit	849	1,049	926	929
Total	1,009	1,243	1,071	1,067
MF with gas				
New	53	65	48	46
Retrofit	181	228	202	205
Total	234	293	250	251
MF without gas				
New	9	11	9	8
Retrofit	77	98	86	88
Total	86	109	95	96
Total MF				
New	62	76	57	54
Retrofit	258	325	288	293
Total	320	401	345	347
Total SF & MF				
With gas	964	1,192	1,021	1,018
Without gas	365	453	395	396
Total	1,329	1,645	1,416	1,414

Heat Pump Systems and Markets

Only a few imported electric-driven heat pump systems have been installed in the United Kingdom's residential sector. These heat pumps, generally optimized for cooling, are poorly suited to the residential market in the United Kingdom, which has only heating demand.

The generally moderate-to-cold climate in the United Kingdom, which produces a substantial annual heat demand, is optimal for heat pumps. Thus, the long-term market potential for these systems must be considered large.

As in so many other countries near the North Sea, the primary competitor for heat pumps is likely to be natural gas furnaces. The ability of heat pumps to compete will depend on gas prices. Given the climate, heat pumps could be competitive with conventional gas boilers if gas is priced near oil equivalent levels.

Five AHP systems were considered in the United Kingdom market study (see Exhibit 4.99). Several AHP systems that are technically applicable in the United Kingdom were eliminated from this analysis as a result of cost, market, or other limitations (see Exhibit 4.100). Although AHP 7 was not analyzed, it is applicable in the United Kindgom. At present, it has no market potential because of its comparatively high initial cost relative to other AHPs and competing conventional systems. AHPs 3, 6, 19, and 20 are not applicable in the United Kingdom, which has very little district heating. In addition, AHPs 4a, 5, and 16 are not applicable because of the limited number of centrally heated buildings. Finally, AHP 10 is not applicable because of the limited availability of vacant land for soil storage.

Market Penetration Factors

In the United Kingdom, first cost and life-cycle costs are the most important decision criteria used in evaluating new heating systems. The importance of each criterion is estimated in Exhibit 4.101. These estimates were based on the assumption that more homeowners are in the SF sectors than in the MF sectors. In general, homeowners have more capital available for purchasing more expensive heating systems, which save money in the long term. In addition, they can add the cost of an expensive heating system to their mortgages. In the MF sectors, a large portion of the housing is owned by a local authority, which bears the installation costs while the householders pay the operating costs.

Although no specific legal or institutional barriers restrict the use of heat pumps, several factors could limit their market penetration. For example, engine-driven systems are noisy and their use may eventually be banned. In addition, the initial cost of retraining workers to install and service heat pumps will slow market penetration. The problem is less severe in the case of gas and electric systems, where an installation and servicing infrastructure already exists, and more severe in the case of oil systems, where there is no infrastructure because of the very small number of oil-heating installations.

The United Kingdom relies primarily on voluntary efforts to encourage energy conservation rather than subsidies or tax credits. A long-running publicity campaign explains both the "why" and "how" of conservation. Although grants

Exhibit 4.99
COMPETITIVE HEATING SYSTEMS IN EACH
MARKET SEGMENT IN THE UNITED KINGDOM

Market Segment	AHP System	Competing Conventional System
Single-family and multifamily with gas	2b (Absorption) 9 (Stirling) 13 (Rankine) 14 (Absorption) 15/18 (Rankine/Rankine)	Gas, solid fuel central systems (conventional and advanced)
Single-family and multifamily without gas	2b (absorption) 4 (Rankine) 9 (Stirling)	Oil, solid fuel central systems (conventional and advanced) Electric storage Electric heat pump

Exhibit 4.100
INITIAL COST OF AHPS AND COMPETING CONVENTIONAL AND ADVANCED CONVENTIONAL SYSTEMS (IN THE U.K.)

System	Cost (1979 DM)[a]
Small	
AHP 2	8,180
AHP 4	6,580
AHP 9	4,700
AHP 13	15,040
AHP 14	4,400
AHP 15/18	5,360
Conventional oil	1,540
Conventional gas	1,620
Conventional coal	1,730
Conventional electric	1,800
Conventional heat pump	4,620
Advanced conventional oil	1,900
Advanced conventional gas	2,030
Advanced conventional coal	2,250

a. Includes backup system, not distribution system.

Exhibit 4.101
UNITED KINGDOM DECISION CRITERIA (%)

Market	First Cost	Life-cycle Cost
Single-family		
With gas	50	50
Without gas	50	50
Multifamily		
With gas	75	25
Without gas	75	25

and loans are available for private housing insulation, no current legislation encourages investment in energy-saving equipment such as heat pumps.

Market Estimates

The United Kingdom used its own variation of the general ranking approach for estimating the economic potential market for each system. For the portion of the market segments using first cost as a decision criterion, advanced heat pumps gain no market share because their cost is generally at least double that of a conventional or advanced conventional system. The United Kingdom market study team used the general ranking approach for these market segments. However, for the the market segments using life-cycle cost as a decision criterion, it was decided that all of the market could not be allocated to the system ranking first (in all cases, conventional systems), because of the broadly defined market segmentation. Instead, systems were allocated based on relative differences in life-cycle costs, as follows:

- SF and MF with gas:

  - 60 percent of buyers select conventional and advanced gas and solid-fuel systems

  - 30 percent of buyers choose AHP 14; 10 percent of buyers choose AHP 15/18

- SF and MF without gas:

  - 70 percent of buyers choose conventional and advanced oil and solid fuel systems

  - 20 percent of buyers choose electric storage systems and conventional electric heat pumps

  - 10 percent of buyers choose AHP 4.

The economic potential market estimated by the United Kingdom for the competing system in residential applications is summarized in Exhibit 4.102. The economic potential market for advanced heat pump systems is higher in the segments where gas is available. AHP 14 and 15/18 capture approximately 18 percent of the market segments with gas after their introduction in 1985, whereas AHP 4 captures only 4.4 percent of the market segments without gas. AHPs 2, 9, and 13 are not economically competitive and capture no market share.

The implementation potential for AHPs 4, 14, and 15 was estimated based on the assumption that it will take 7 years for the market to accept fully the new technologies. During these 7 years, the ratio of implementation potential to economic potential progresses as follows: 10 percent in year 1, 20 percent in year 2, 30 percent in year 3, 50 percent in year 4, 75 percent in year 5, 90 percent in year 6, and 100 percent in year 7. The results are summarized in Exhibit 4.103.

The United Kingdom analyzed several possible R&D measures to increase the economic and implementation potential market of AHP systems. The first measure is

Exhibit 4.102
ECONOMIC POTENTIAL OF HEATING SYSTEMS
IN THE UNITED KINGDOM, 1981-2000
(000 Average Annual Installations)

Market Segment/System	1981-1985	1986-1990	1991-1995	1996-2000
SF and MF with gas				
AHPs 2, 9, 13	0	0	0	0
AHP 14*	127.1	142.0	134.3	134.0
AHP 15/18*	42.4	47.3	44.8	44.7
Competing conventional systems	794.5	1,002.7	841.9	839.3
TOTAL	964.0	1,192.0	1,021.0	1,018.0
SF and MF without gas				
AHPs 2, 9	0	0	0	0
AHP 4	16.2	20.2	17.4	17.4
Competing conventional systems	348.8	432.8	377.6	378.6
TOTAL	365.0	453.0	395.0	396.0

* Introduced in 1985.

Exhibit 4.103
AHP IMPLEMENTATION POTENTIAL IN THE UNITED KINGDOM
(000 Average Annual Installations)

AHP System	Year	1	2	3	4	5	6	7
AHP System 14								
Economic		127.1	142.0	142.0	142.0	142.0	142.0	142.0
Implementation		12.7	28.4	42.6	71.0	106.5	127.8	142.0
AHP System 15/18								
Economic		42.4	47.3	47.3	47.3	47.3	47.3	47.3
Implementation		4.2	9.5	14.2	23.7	36.7	42.6	47.3
AHP System 4								
Economic		12.3	16.2	16.2	16.2	16.2	16.2	20.2
Implementation		1.2	3.2	4.8	8.2	12.1	14.5	20.2

Note: AHP Systems 14 and 15/18, which serve market segments with gas, will be introduced in 1985; System 4, for markets without gas, in 1980.

a reduction in first cost of the AHP systems, either by government subsidy or through the use of cheaper and more efficient manufacturing methods. The analysis showed that, in the segments with gas, sales of AHPs 14 and 15/18 would be affected only slightly by a 25-percent reduction in first cost; however, sales would increase substantially with a 50-percent reduction. In the sector without gas, there is a gradual but accelerating increase in sales of AHP 4 as the first cost is reduced.

The second measure considered is an increase of gas prices in the United Kingdom. At present, gas is cheaper than oil. However, in the future, there is a strong possibility that the government could allow gas prices to rise to the level of oil prices to slow down gas reserve depletion. This analysis showed that the sales of AHP systems would remain unchanged if gas and oil prices are assumed equal after 1985. Although AHP 14 would capture market share from the advanced gas boiler under this scenario, it would lose market share to conventional solid-fuel systems, which would become significantly cheaper on a life-cycle cost basis.

UNITED STATES

National Energy Demand and Residential Consumption

In 1978, the United States consumed 1,875 Mtoe, serving a total end-use demand of 1,353 Mtoe. In 1977, the United States imported 24 percent of its energy requirements, including 5 percent of its natural gas. Net dependence on imports is projected to rise to 27 percent by 1990; although the United States, like Canada, will become a major exporter of coal. Oil imports will rise by half, and gas imports will almost triple.

About 34 percent of end-use demand in 1977 was in the residential/commercial sector. Although this sector's share of total U.S. consumption increased in 1976 and 1977, by 1990 residential/commercial demand will represent only 29 percent of total U.S. consumption. Since 1975, space heating has accounted for 51 percent of total residential energy use, but only 18 percent of all energy use, due to the heavy share of transportation (26 percent in U.S. total consumption).

Housing Stock and Current Heating Systems

Like the Canadian market, the U.S. housing stock must be divided into regions because of its large size and different climates. The housing stock is categorized in Exhibit 4.104 by four regions, the smallest number from which to draw meaningful conclusions.

The distribution of the stock among building types is similar to that in Canada, but more U.S. than Canadian apartments are centrally heated. About 72 percent of the stock is in single-family houses and 93 percent in individually heated units. Most centrally heated buildings are older buildings in the Northeast, a region that is not expected to grow substantially in the rest of this century. In all other regions, the trend away from centrally heated apartments is expected to continue.

Exhibit 4.104
U.S. HOUSING STOCK BY REGION AND BUILDING SIZE
(000 Housing Units)

Region	SF	MFI	MFII	Total	Percentage of Total Units
Northeast	10,071	4,182	3,394	17,647	22
North Central	15,737	4,553	715	21,005	27
South	20,566	4,271	918	25,755	32
West	10,864	3,611	432	14,907	19
TOTAL	57,238	16,617	5,459	79,314	
Percentage of Total Units	72	21	7	100	

Heating fuels and heating/cooling distribution systems vary considerably from region to region (see Exhibit 4.105). According to market study projections, central water distribution will continue to be the dominant system used in the old housing stock in the Northeast and North Central regions, and there will be a substantial replacement market for water-based systems. Almost all installations in the new construction market will use air distribution systems, as the result of traditional building practice and the demand for air conditioning.

Natural gas is the energy source used in 48 percent of the U.S. residential space heating market. This percentage will increase in the near future, because natural gas is now considerably cheaper than oil, and natural gas companies are temporarily being allowed to accept new customers. Oil's market share, 29 percent in 1975, is expected to decline in favor of gas and electricity in the period 1980-2000. The United States and Japan are the only countries in the AHP study with substantial demand for air conditioning.

Projected Heating and Cooling Installations

The future demand for heating and cooling installations will be overwhelmingly concentrated in single-family systems, either installations in single-family houses or in individually heated apartments (see Exhibit 4.106). The annual demand for heating and cooling systems is estimated to average 4.2 million units per year in the period 1980-2000; and 99 percent will be installed in single-family systems. The penetration of air conditioning in new construction is substantially higher than in the existing stock.

Heat Pump Systems and Market

According to 1978 figures, about 500,000 heat pumps a year are sold in the United States, in contrast to annual gas, oil, and electric furnace sales of about 2 million units and room air conditioner sales of about 3.8 million units a year. Annual sales of heat pumps tripled between 1975 and 1978 because of natural gas curtailments during that period. Sales growth has stopped since new natural gas hook-ups have become available. About 75 percent of heat pump shipments have been to residential customers and 25 percent to commercial customers. About 65 percent of the installations are in new construction (55 percent in single-family houses), with the remainder either replacements or retrofits.

Almost all the current production is in electric-compression air-to-air systems, but there has been encouraging growth in the market for water-source heat pumps. Shipments grew from 40,000 units in 1977 to about 65,000 units in 1978, an increase of 65 percent. A great many water-source installations appear to include heat recovery systems. There are presently very few engine-driven heat pump installations in the United States.

There are about 50 suppliers of heat pumps in the United States market, but only about 30 produce their own heat pumps. One manufacturer (Janitrol) was producing a heating-only heat pump until very recently.

In the near term, the increased availability of relatively inexpensive natural gas will prevent growth in the market for electric compression heat pumps.

Exhibit 4.105
U.S. HEATING SYSTEMS AND FUEL TYPES (%)

Region/ Building Type	Gas/ Air	Oil/ Air	Other/ Air	Gas/ Water	Oil/ Water	Other/ Water	Elec- tric	Total
Northeast								
SF	20.1	14.7	0.7	18.6	44.9	0.6	0.4	100
MF	20.5	13.9	0.4	13.4	49.8	0.6	1.4	100
North Central								
SF	64.4	12.7	0	15.6	4.9	0	2.4	100
MF	65.1	9.5	0	16.7	3.5	0.4	4.8	100
South								
SF	53.8	13.4	0.9	3.5	6.8	0.1	21.5	100
MF	42.0	9.9	0	3.9	6.4	0.2	37.6	100
West								
SF	72.9	7.1	0	8.0	2.9	0.2	8.9	100
MF	64.9	5.4	0.9	8.2	1.9	0.9	17.8	100

Exhibit 4.106
DEMAND FOR HEATING AND COOLING SYSTEMS
IN NEW CONSTRUCTION AND EXISTING HOUSING
(Average Annual Installations)

Region/ Building Type	1981-1985	1986-1990	1991-1995	1996-2000
Northeast				
SF				
New	161,671	160,326	134,410	123,288
Existing	389,723	372,965	356,206	402,841
MFI				
New	41,147	41,073	34,434	31,584
Existing	100,361	95,854	91,547	103,533
MFII				
New	3,428	3,999	2,850	2,614
Existing	8,288	7,931	7,575	11,036
North Central				
SF				
New	357,589	365,745	268,823	324,915
Existing	745,868	704,099	662,330	736,454
MFI				
New	83,711	85,621	62,931	76,063
Existing	174,607	164,828	163,157	259,510
MFII				
New	1,790	1,831	1,346	1,627
Existing	3,733	3,524	4,151	4,701
South				
SF				
New	809,703	815,822	938,723	831,515
Existing	1,195,326	1,106,871	1,018,416	806,056
MFI				
New	151,883	153,031	176,085	155,975
Existing	224,217	207,625	191,032	207,017
MFII				
New	2,668	2,688	2,746	2,740
Existing	3,937	3,646	3,354	4,274
West				
SF				
New	361,947	403,591	338,057	359,493
Existing	518,484	482,190	445,844	486,097
MFI				
New	75,887	82,647	70,295	73,862
Existing	108,072	100,507	92,942	101,321
MFII				
New	3,184	3,492	2,881	3,100
Existing	4,414	4,104	3,795	5,078

However, gas prices are being gradually deregulated under the Natural Gas Policy Act of 1978, and should increase faster than electricity prices in the next few years. Thus, electric compression heat pump sales could begin to increase again in the near future. However, gas-fired heat pumps will gradually become more attractive than electric heat pumps during the next decade. Gas heat pumps, either absorption or motor-driven, should be introduced to U.S. markets beginning in 1983.

Much current R&D is directed toward solar-assisted or solar-activated heat pumps, and industry sources expect such systems to appear on the market by the mid-1980s. This development will encourage growth in the market for water-heat-source heat pumps.

The U.S. market study team has analyzed eight AHP systems for the markets indicated in Exhibit 4.107. AHPs 2, 9, 15/18, and 16 can provide both heating and cooling. AHPs 4, 5, 7, and 13 are capable of heating only.

Market Penetration Factors

Considerable research has been done in the United States on the decision criteria that determine choice of heating systems in various market segments. In addition, the use of a computer model allowed the U.S. analysts to consider a large number of different types of decision-makers and market situations. The weightings of decision criteria listed in Exhibit 4.108 were used.

U.S. consumers use first cost as their major decision criterion, with payback and life-cycle cost together entering into decisions in up to half of some market segments. These criteria reflect the fact that operating expenses are still low, relative to capital costs, for most U.S. decision makers. The U.S. decision criteria contrast sharply with those of such countries as Germany and Switzerland.

There are no important institutional or environmental barriers to the introduction of conventional electric compression heat pumps in the United States. However, local regulations could complicate the use of soil or groundwater heat sources, especially in areas with scarce water supplies.

The federal government extends tax credits to homeowners for a host of energy conservation retrofit measures, including insulation, improved windows or storm windows, automatic set-back thermostats, furnace-burner replacements, and solar energy. Unlike some other countries in the IEA, the United States offers no tax credits or investment subsidies for heat pumps.

Market Potential

Estimates of the economic potential for five AHP systems indicate that advanced heat pumps will be economically feasible in approximately six percent of the U.S. single-family and multifamily I residential market segments in the

Exhibit 4.107
COMPETITIVE HEATING SYSTEMS
IN EACH U.S. MARKET SEGMENT

Market Segment[a]	AHP System		Competing Conventional System[b]
Single-family, Multifamily	2	(absorption)	Oil, gas central air
	4	(Diesel/Rankine)	Oil, gas central water
	9	(Stirling/Rankine)	Electric heating and cooling
	13	(electric)	Electric heat pump
Single-family, Multifamily I Multifamily II	7	(Otto/Rankine)	Oil, gas central
	15/18	(organic/Rankine)	Oil, gas central water
			Electric heating and cooling
			Electric heat pump
Multifamily II	5	(Diesel/Rankine)	Oil, gas central air
	16	(Brayton/Rankine)	Oil, gas central water
			Electric heating and cooling
			Electric heat pump

a. Both new construction and replacement/modernization/retrofit.

b. All conventional systems compete with AHP systems in all markets.

Exhibit 4.108
U.S. DECISION CRITERIA (%)

Market Segment/ Building Type	Life-Cycle Cost	Payback Period	First Cost
Single-family			
New	--	20	80
Existing	--	50	50
Multifamily I			
New			
Owner-occupied	10	30	60
Rental unit	25	25	50
Existing			
Owner-occupied	--	50	50
Rental unit	--	20	80
Multifamily II			
New	25	25	50
Existing	0	20	80

1981-2000 period. The U.S. market study team also categorized market potential by two sizes of AHP systems:

- Small (i.e., 10- to 20-kW capacity) for installation in single-family and individually heated apartments
- Medium (i.e., 50- to 200-kW), applicable to centrally heated multifamily buildings.

In addition, economic potential is estimated in Exhibit 4.109 by both number of installations per year and in percentage of market share.

Generally, AHP systems with both heating and cooling score better than heating-only AHP systems. High first cost, the major decision criterion for consumers in both market segments, limits the general economic potential of AHP systems with both heating and cooling capabilities; however, those systems which rank well in the market portion using life-cycle costs as an investment criterion have significant economic potential. Government education/information programs that emphasize the importance of life-cycle costs in purchasing heating and cooling systems could significantly increase the potential markets for AHP systems with both heating and cooling capability in the United States.

Three AHP systems originally included in the U.S. market study were eliminated from Exhibit 4.109: AHPs 4 and 7 have no economic potential in the United States; AHP 13 has very low economic potential (its market share is 0.02 percent in the 1996-2000 period only, and it penetrates only one region).

Economic Potential

SF and MFI Markets

In the single-family and individually heated market segment, the only heat pump that captures any significant share of the economic potential is AHP 2, an absorption system that can be fired by oil or natural gas and is capable of heating only or both heating and cooling. Its total market share (i.e., for heating and cooling and for heating only), based on the national team's assumptions for performance, installed cost, and operating and maintenance costs, is projected to reach 6 percent by the 1996-2000 period. However, its economic potential in the heating and cooling market is over 10 percent.

The regional pattern of economic potential held by AHP 2 reflects the general regional distribution of economically accessible markets for all heat pump systems in the United States. AHP 2 captures part of the market in all four U.S. regions, with the highest economic potential occurring in the North Central and Northeast regions, as well as the northeast portion of the South. Its smallest share of the economic potential occurs in the West.

Exhibit 4.109
U.S. ECONOMIC POTENTIAL FOR AHP SYSTEMS
(Average Annual Installations/% of Market)

Market Segment/System	1981-1985	%	1986-1990	%	1991-1995	%	1996-2000	%
SF/MFI (small systems)[a]								
AHP 2 (H)	0		8,395	5.00	100,780	6.02	111,970	6.30
AHP 2 (H/C)	0		179,630		269,480		208,040	
AHP 15/18 (H)	0		870	.05	830		0	
AHP 15/18 (H/C)	0		1,750		410		0	
AHP 9 (H)[b]	470	0.01	0	.02	0		0	
AHP 9 (H/C)[b]	4,630		1,270		0		0	
TOTAL	5,100	0.01	267,470	5.07	371,500	6.02	320,010	6.30
MFII (large systems)								
AHP 15/18 (H)	0		370	5.40	340	4.50	330	4.00
AHP 15/18 (H/C)	0		1,310		1,270		1,080	
AHP 5	280	0.90	480	1.60	420	1.20	410	1.00
AHP 16 (H)	0		0		0		0	0.40
AHP 16 (H/C)	0		0		130		130	
TOTAL	280	0.90	2,160	7.00	2,150	6.10	1,950	5.40

a. Three systems are not reflected in the exhibit because their economic potential was zero (AHPs 4,7) or negligible (AHP 13).

b. Introduced in 1983.

The weighting of consumers' decision-making criteria in the U.S. market analysis affects the economic potential of each AHP system.* A larger weight on life-cycle cost would definitely increase the potential for AHP systems because of their long-term potential for reducing energy consumption. For example, AHP 2 ranks well mostly on the basis of payback period and life-cycle cost. Other AHP systems, i.e., AHP 9 (the Stirling-Rankine system) and AHP 15/18 (the organic Rankine/Rankine system) rank well on the basis of life-cycle cost and therefore gain a small share in the new-construction/individually heated-apartment segment.

AHP 9 also gets a small share of the heating and cooling economic potential because of its relatively good ranking on payback.

The Stirling/Rankine heat pump (AHP 9) will take a small share of the market as soon as it is introduced in 1983; however, this share is lost when the absorption heat pump (AHP 2) and the organic Rankine/Rankine system (AHP 15/18) become available in 1986.

The major economic competitors to AHP systems in the SF/MFI market in the United States are conventional heating and cooling systems and conventional heat pumps, which capture 9-10 percent of the economic potential for U.S. installations.

MFII Market

In the medium capacity market (i.e., installations in centrally heated multifamily buildings), the economic potential of AHP systems follows a similar pattern as for the small-capacity systems. That is, gas-fired systems capable of both heating and cooling and ranking high on the life-cycle cost decision criterion achieve the greatest economic potential. Advanced heat pump systems capture approximately 6 percent of the MFII market segment.

Of the three systems analyzed in the MFII segment of the U.S. market, the organic Rankine/Rankine heat pump (AHP 15/18) achieves 4-5 percent of the potential market due to its ranking well, on the basis of life-cycle costs. (However, its market share is close to 10 percent of the market requiring cooling.) Sixty percent of all AHP 15/18 installations in this market segment will be gas-fired, unlike the majority of AHP 15/18 installations in SF units, which will be oil-fired. Regionally, AHP 15/18 captures a larger share of the market in the West and Northeast.

AHP 5 (Diesel/Rankine) ranks very low in U.S. economic potential because it is a heating-only system and because it ranks well only on the life-cycle cost investment criterion used only in the new-construction market. The Brayton/Rankine heat pump (AHP 16) has the smallest share of the potential market in the U.S. MFII segment. Its gas-fired heating and cooling version would gain market

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* Given the large number of market segments in the United States, it is difficult to give an overall summary of the rankings. There are 460 market segments corresponding to 4 building types, 10 regions, 2 types of applications (heating only and both heating and cooling) in 2 types of installations (new and retrofit).

share only in the Southern region, where it ranks well on the life-cycle cost investment criterion. Again, if U.S. consumers gave greater weight to the life-cycle investment decision criterion and less to initial cost in selecting heating and cooling systems, AHP systems would be accepted in a larger portion of the technically accessible market.

Market Implementation Potential

Implementation potentials were calculated using penetration curves obtained by analogy with historical penetration of innovative technologies (see Exhibit 4.110). The potential for both nominal and high penetration rates is listed by market segment for each AHP system in Exhibit 4.111.

Implementation barriers and market resistance will slightly lower the actual sales potential of AHP systems in U.S. market segments in the 1986-1990 period (to 2-3 percent of the potential market for small sizes, and to 3-5 percent for medium sizes). However, potential sales increase slightly in the 1991-2000 period, implying that consumers will gradually be less reluctant to purchase AHP systems (see Exhibits 4.112 and 4.113).

The low market sales projections of AHP systems in the United States through 2000 reflect the fact that although the majority of purchasers base their investment decisions on first cost, AHP systems rank best on the life-cycle decision criterion. More precise information on decision criteria is necessary to improve the market penetration estimates of AHP systems.* The weights given to decision criteria will also probably change as purchasers become increasingly sensitive to life-cycle and energy costs of heating and cooling equipment. In addition, some purchasers do not base their investment decisions on economic criteria alone (which may be true for purchasers of conventional heat pump systems). As a result, a complete analysis of the decision-making process used to select heating and cooling systems might increase the projected market sales of AHP systems in the United States by a few percentage points and would definitely increase the reliability of the market estimates.

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* The U.S. market estimates are still being refined, mostly through data improvements. One element of this refinement is a better understanding of the sizing of heating and cooling systems in the MFII segment.

Exhibit 4.110

Penetration Rates for Advanced Heat Pumps

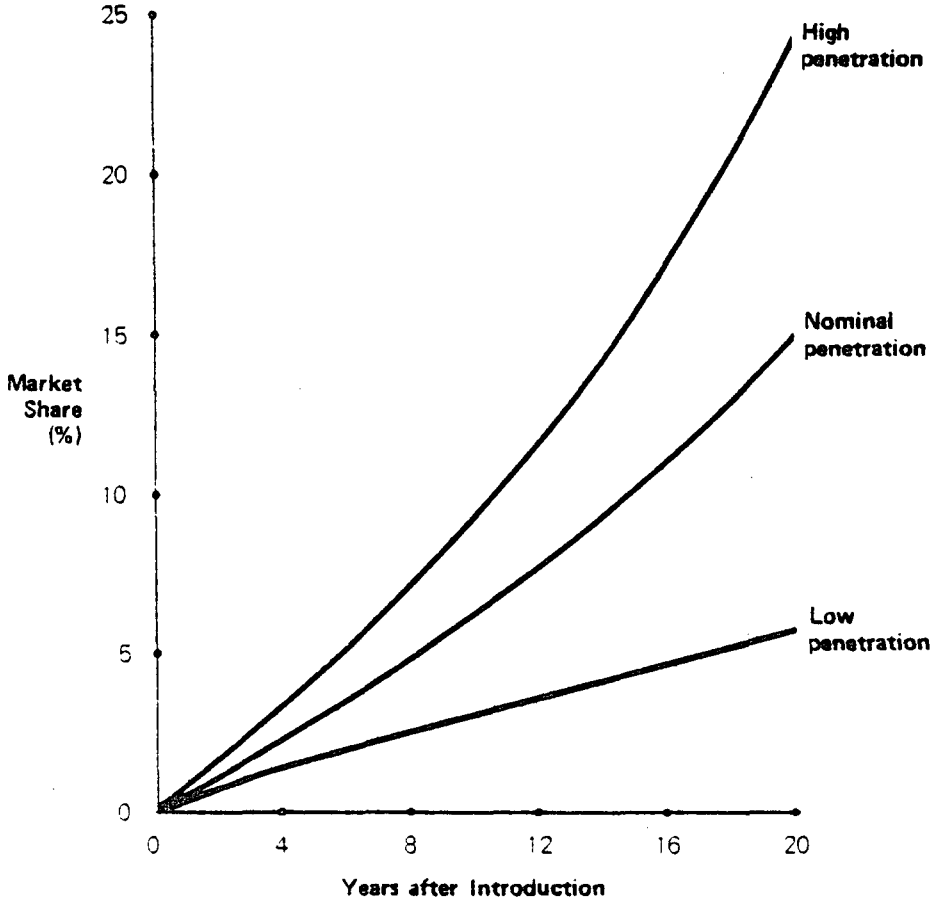


Exhibit 4.111
U.S. MARKET IMPLEMENTATION POTENTIAL FOR AHP SYSTEMS
(Average Annual Installations/% of Market)

Market Segment/ System	1981-1985	%	1986-1990	%	1991-1995	%	1996-2000	%
SF/MFI (small systems)								
AHP 2	0		117,500 160,300	2.2[a] 3.0[b]	262,900 370,260	4.5[a] 6.0[b]	320,000	6.3
AHP 15/18	0		2,620	0.05	1,240	0.02	0	
AHP 9	5,100	0.1	1,270	0.02	0		0	
TOTAL	5,100	0.1	121,390 164,190	2.3[a] 3.1[b]	264,140 371,500	4.5[a] 6.0[b]	320,000	6.3
MFII (large systems)								
AHP 15/18	0		670 920	2.2[a] 3.0[b]	1,610	4.5	410	1.0
AHP 5	280	0.9	480	1.6	420	1.2	1,410	4.0
AHP 16	0		0		130	0.4	130	0.4
TOTAL	280	0.9	1,150 1,400	3.8[a] 4.5[b]	2,160	6.1	1,950	5.4

a. Nominal penetration rate.

b. High penetration rate.

Exhibit 4.112

U.S. Economic and Implementation Potential for AHP System 2
(small SF-MF I)

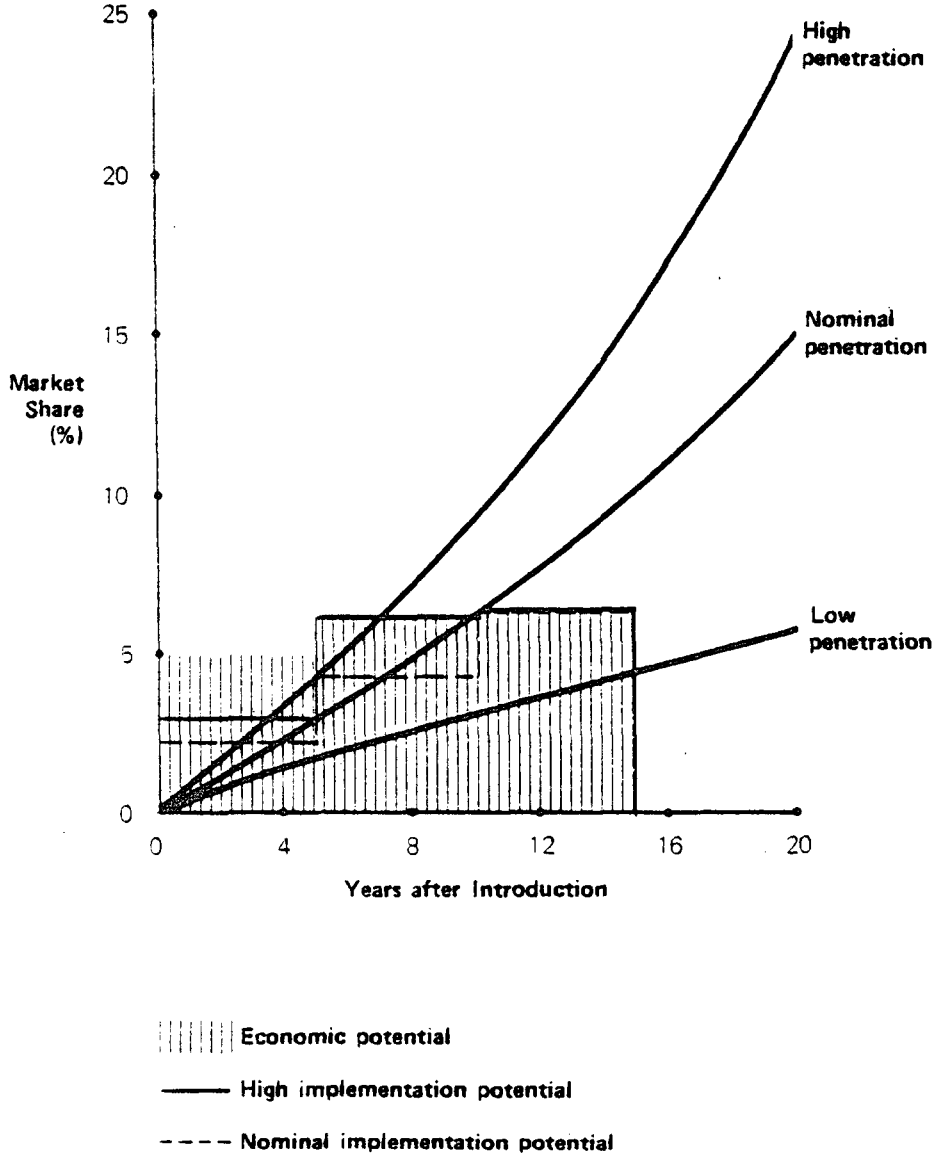
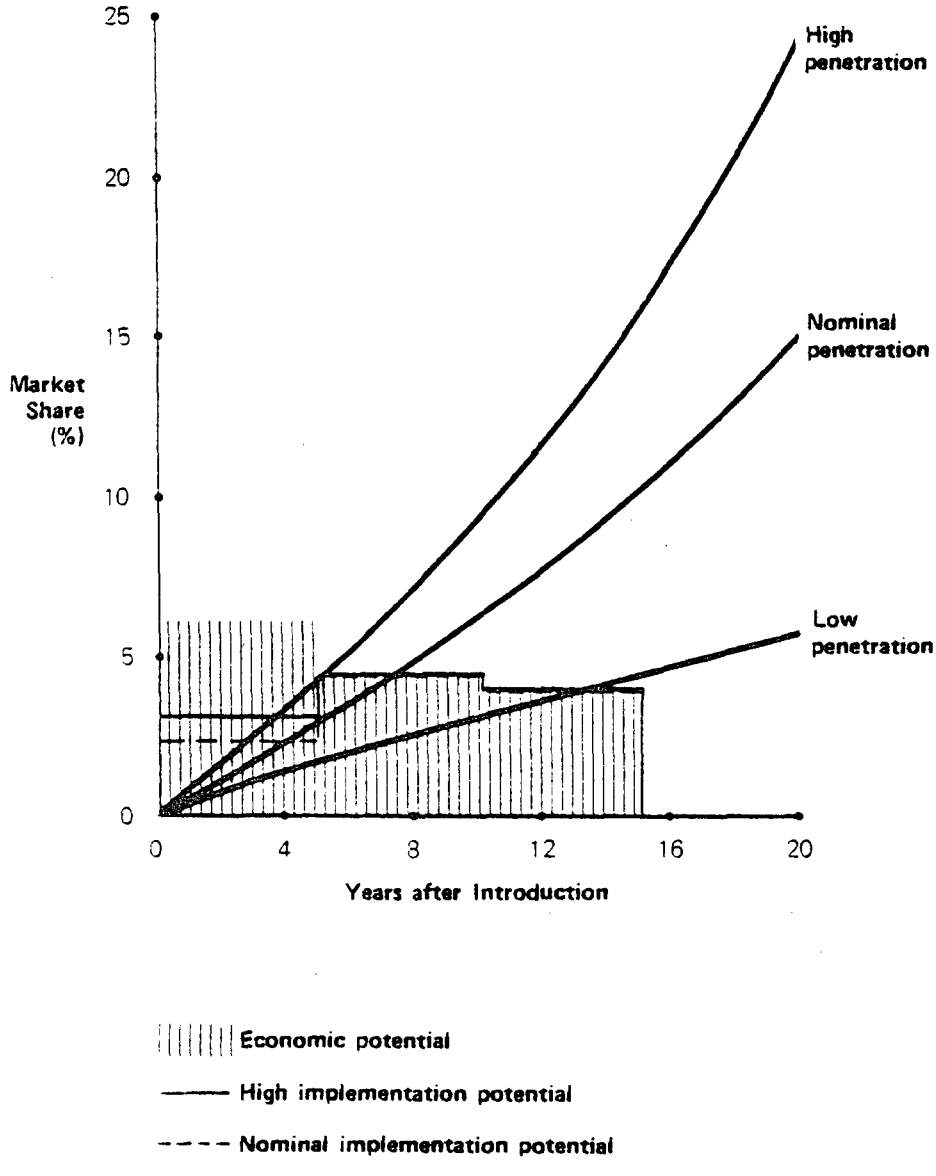


Exhibit 4.113

U.S. Economic and Implementation Potential for AHP System 15-18
(large-MFII)



Appendixes

APPENDIX A

AHP Market Study Participants: Current Contact Persons

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Participants in the AHP Market Study

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APPENDIX B

TECHNICAL CHARACTERISTICS OF AHP SYSTEMS

The technical characteristics of each AHP system analyzed in the market study are described in the following case study profiles. These profiles were prepared for each AHP system by Battelle-Institut e.V. of Frankfurt-am-Main, based on information submitted by laboratories developing the systems. The information in these profiles includes data on system design, capacity, performance, capital and maintenance costs, estimates of expected service life, and year of introduction.

AHP SYSTEM 2

System Type: Organic Absorption

1. Description

Heat Pump:

Cycle:	Single stage absorption
Working fluid:	(2a) Organic working fluid/organic solvent; (2b) R22/E181
Source:	(2a) Ambient air; (2b) ambient air (or groundwater)
Sink:	(2a) Air; (2b) water: feed 40-55°C, return 35-50°C

Drive:

Cycle:	Not applicable
Working fluid:	Not applicable
Fuel:	Not applicable

Use:

(2a):	Domestic central space heating and cooling
(2b):	Domestic central space and water heating

2. Design data

Heat output at source temperature:	(2a):	26.4 kW @ +8°C;
	(2b):	12 kW @ -2°C
Heat input (including heater efficiency):	(2a):	21.1 kW @ 75%;
	(2b):	10.8 kW @ 95%
Electrical input (fans, pumps, controls):	(2a):	1.0 kW
	(2b):	0.9 kW

3. Backup

	(2a)	(2b)
Type:	Not known	None - boiler
Fuel:	-	operation of unit
% maximum capacity:	-	170

4. Controls

Capacity:	Not known	$T_a > 3°C$	heat input
		$-4 < T_a < 3°C$	ejector pump
Defrost:	Not known	$T_a < -4°C$	boiler operation
Backup:	Not known	See above	

5. Performance

Air Temp. (°C)	Source Temp. (°C)	Heating/Cooling Output (kW) (2a)	(2b)	Heating/Cooling COP (2a)	(2b)	COP' (2a)	(2b)
-10	-10	23	10.8	1.05	1.0	0.35	0.95
0	0	25	11.0	1.15	1.1	1.05	1.05
+10	-10	27	7.2	1.25	1.4	1.10	1.17
+25	+25	-	-	-	-	-	-
+35	+35	10	-	0.50	-	0.48	-

6. Capital costs*

Output		3/4	10/12	15/20	50	100	400
Unit Cost (DM)		-	-	-	-	-	-
Installed	(2a):			5000	na	na	na
Cost (DM)	(2b):	5000	7000	8000	na	na	na

* Estimated costs at 1979 price and exchange rates, without taxes; not including heat distribution or backup costs.

7. Maintenance costs: 3 percent of installed capital cost per annum.

8. Service life

Source equipment, 15/20 years; heat pump, 15/20 years; weighted mean, 15/20 years.

9. Year of introduction: 1985/1986

AHP SYSTEM 3

System Type: Ammonia 2-Stage Absorption

1. Description

Heat Pump:
Cycle: Absorption, 2-stage
Working fluid: NH_3H_2O
Source: Coking plant wastewater, 40-50°C
Sink: District heating - feed 90°C, return 50°C

Drive:
Cycle: Not applicable
Working fluid: Not applicable
Fuel: Coke oven gas (5.4 kWh/m^3)

Use: District heating

2. Design data

Heat output at source temperature (40-50°C): 3,700 kW
Heat input: 2,400 kW
Electrical input (fans, pumps, controls): 30 kW

3. Backup

Type: District heating boiler

4. Controls

Capacity: None
Defrost: Not necessary

5. Performance

Air Temp. (°C)	Source Temp. (°C)	Heating/Cooling Output (kW)	Heating/Cooling COP	Heating/Cooling COP'
-10		2,968	1.03	1.01
0	50			
+10				
+25	-			
+35	-	-	-	-

6. Capital costs*

Output	3/4	10/12	15/20	50	100	400	≥2950
Unit Cost (DM)	-	-	-	-	-	-	1.35 M
Installed Cost (DM)	-	-	-				1.70 M

* Estimated costs at 1979 price and exchange rates, without taxes; not including heat distribution or backup costs.

7. Maintenance costs: 2 percent of installed capital cost per annum.

8. Service life

Source equipment, 20 years; heat pump, 20 years; drive, 20 years; weighted mean, 20 years.

9. Year of introduction: 1981

AHP SYSTEM 4

System Type: Diesel-Rankine, Air Source

1. Description

Heat Pump:

Cycle: Reversed Rankine

Working fluid: R_{12}

Source: Ambient air

Sink: Water - feed 55-60°C, return 45-50°C for radiators
Diesel - feed 45°C, return 38-40°C for floor warming

Drive:

Cycle: Diesel

Working fluid: Air

Fuel: Extra light fuel oil; 11/62 kWh/kg

Use: Domestic central space and water heating

2. Design data

Heat output at source temperature (+3°C): 15.00 kW

Heat input: 3.50 kW

Electrical input (fans, pumps, controls): 0.35 kW

3. Backup

Type: Boiler

Fuel: Oil

% maximum capacity: Parallel operation 66%, 34% of total annual load; alternative operation 50%, 50% of total annual load.

4. Controls

Capacity: Motor speed control above 10°C source temperature

Defrost: Hot gas

Backup: Cut-in @ +3°C ambient air temperature

5. Performance

Air Temp. (°C)	Source Temp. (°C)	Heating/Cooling Output (kw)	Heating/Cooling COP	COP'
-10	-10	10.7	1.2	1.0
+ 3	+ 3	15.0	1.4	1.3
+10	-10	17.2	1.6	1.4
+25	na	-	-	-
+35	na	-	-	-

6. Capital costs*

Output	3/4	10/12	15/20	50	100	400	>2000
Unit Cost (DM)	-	-	-	-	-	-	-
Installed Cost (DM)	-	7000	9000	-	-	-	-

* Estimated costs at 1979 price and exchange rates, without taxes; not including heat distribution or backup costs.

7. Maintenance costs: 4 percent of installed capital cost per annum.

8. Service life

Source equipment, 20 years; heat pump, 10 years; drive, 10 years; weighted mean, approx. 12 years.

9. Year of introduction: 1982

AHP SYSTEM 4a

System Type: Diesel/Rankine, Horizontal Ground Source

1. Description

Heat Pump:

Cycle: Reversed Rankine

Working fluid: R_{22}

Source: Horizontal ground coil, brine circuit

Sink: Water - feed @ 45°C, return @ 34°C

Drive:

Cycle: Diesel

Working fluid: Air

Fuel: Diesel oil or heavy fuel oil

Use: School space heating; could also be district or commercial building heating.

2. Design data

Heat output at source temperature (+1°C): 400.0 kW

Heat input: 90.0 kW

Electrical input (fans, pumps, controls): 9.2 kW

3. Backup

Type: District heating

Fuel: Heavy fuel oil and waste

% maximum capacity: 125; 20% of annual load

4. Controls

Capacity: Speed reduction, compressor cylinder unloading

Defrost: Not necessary

Backup: Cut-in @ 0°C air temperature

5. Performance

Air Temp. (°C)	Source Temperature (°C) (Ground)	(Brine)	Heating/ Cooling Output (kW)	Heating/Cooling COP	COP'
-10	4	-7	400 max.	1.73	1.57 (.93)*
0	5	-6	400 max.	1.73	1.57
+10	10	3	400 max.	1.96	1.50
+25	-	na	na	-	-
+35	-	na	na	-	-

* Includes district heating.

6. Capital costs*

Output	3/4	10/12	15/20	50	100	400	≥2000
Unit Cost (DM)	-	-	-	-	-	173,500	-
Installed Cost (DM)	-	-	-	-	-	347,000**	-

* Estimated costs at 1979 price and exchange rates, without taxes; not including heat distribution or backup costs.

** +69,400 DM for district heating supply.

7. Maintenance costs: 2 percent of installed capital cost per annum.

8. Service life

Source equipment, 25 years; heat pump, 10 years; drive, 10 years; weighted mean, 18 years.

9. Year of introduction: 1980

AHP SYSTEM 5

System Type: Diesel-Rankine

1. Description

Heat Pump:

Cycle:	Rankine, reciprocating compressor
Working fluid:	R_{12}
Source:	Air
Sink:	Water - (1) T_d = 57/80°C, T_r = 38/60°C; (2) T_d = 45°C, T_r = 35°C.

Drive:

Cycle:	Diesel
Working fluid:	Air
Fuel:	Diesel oil

Use: Hot water central heating, district heating, or commercial building

2. Design data

	(1)	(2)
Heat output at source temperature (0°C):	816 kW	174 kW
Heat input:	467 kW	124 kW
Electrical input (fans, pumps, controls):	37 kW	3 kW

3. Backup

	(1)	(2)
Type:	boiler	none
Fuel:	oil	-
% maximum capacity:	50%	-

4. Controls

Capacity:	Speed control and compressor capacity control
Defrost:	Not known
Backup:	Not known

5. Performance

Air Temp. (°C)	Source Temperature (°C) (1)	(2)	Heating/Cooling Output (kW) (1)	(2)	Heating/Cooling COP (1)	(2)	COP* (1)	(2)
-10	-10	-10				1.6	1.6	1.0
0	0	0	816	128	1.7	1.3	1.4	1.2
+10	+10	+10				1.7	1.2	
+25	-	+25	-	55	-	1.0	-	-
+35	-	+35	-	55	-	0.8	-	-

* Includes district heating.

6. Capital costs*

Output (kW)	3/4	10/12	15/20	50	174[b]	876[a]	≥2000
Unit Cost (DM)	-	-	-	-	A: 133,332	200,000	-
Installed Cost (DM)	-	-	-	-	B: 172,043	-	-

* Estimated costs at 1979 price and exchange rates, without taxes; not including heat distribution or backup costs.

7. Maintenance costs (includes replacement motor every 10,000 hrs)

(1) 13 percent of installed capital cost per annum
(2) 6 percent of installed capital cost per annum

8. Service life

Source equipment, 20 years; heat pump, 15 years; drive, 10 years; weighted mean, 15 years.

9. Year of introduction: Before 1985

AHP SYSTEM 6

System Type: Diesel-Rankine

1. Description

Heat Pump:
Cycle: Rankine, 2-stage turbo compressor
Working fluid: R_{114}
Source: Sewage - T_{min} = 7°C, T_{max} = 18°C
Sink: District heating, water - T_{feed} = 90°C, T_{return} = 50°C

Drive:
Cycle: Diesel
Working fluid: Air
Fuel: Heavy fuel oil

Use: District heating

2. Design data

Heat output at source temperature (10°C): 10,200 kW
Heat input: 5,500 kW

3. Backup

Type: District heating

4. Controls

Capacity: Not known
Defrost: Not necessary
Backup: District heating parallel operation

5. Performance

Air Temp. (°C)	Source Temp. (°C)	Heating/Cooling Output (kW)	Heating/Cooling COP	Heating/Cooling COP'
-10	7.0	-	1.8	-
0	7.5	-	1.8	-
+10	8-16.0	-	2.0	-
+25	-	-	-	-
+35	-	-	-	-

6. Capital costs*

Output (kW)	3/4	10/12	15/20	50	100	400	10,000
Unit Cost (DM)	-	-	-	-	-	-	-
Installed Cost (DM)	-	-	-				5.2×10^6

* Estimated costs at 1979 price and exchange rates, without taxes; not including heat distribution or backup costs.

7. Maintenance costs: 4 percent of installed capital cost per annum

8. Service life

Source equipment, 20 years; heat pump, 20 years; drive, 20 years; weighted mean, 20 years.

9. Year of introduction: 1981

AHP SYSTEM 7

System Type: Otto-Rankine

1. Description

Heat Pump:

Cycle: Rankine, reciprocating compressor
Working fluid: R_{22} (or R_{12} for higher distribution temperatures)
Source: Air (or water)
Sink: Water - (1) R_{22}: T_r = 48°C max., T_d = 80% @ 45/55°C, 20% @ 90°C, or all @ 70°C max.;
(2) R_{12}: T_r = 55°C max., T_d = 80% @ 55/65°C, 20% @ 90°C, or all @ 75°C max.

Drive:

Cycle: Otto
Working fluid: Air
Fuel: Natural gas

Use: Domestic and commercial central space and water heating

2. Design data

Heat output at source temperature (10°C): 11.80 kW;
air-cooled engine: 8.80 kW
Heat input: 8.90 kW
Electrical input (fans, pumps, controls): 0.25 kW

3. Backup

Type: Boiler (if system sized for less than maximum load)
Fuel: Gas
% maximum capacity: Up to 100%

4. Controls

Capacity: Engine speed
Defrost: Not known
Backup: Not known; probably external air temperature

5. Performance

Air Temp. (°C)	Source Temp. (°C)	Heating/Cooling Output (kW) (3)	(4)	Heating/Cooling COP (3)	(4)	COP' (3)	(4)
-10	-10	8.5	9.0	0.93	0.60	0.88	0.57
0	0	9.6	6.6	1.10	0.72	0.99	0.67
+10	+10	12.0	5.5	1.31	0.98	1.24	0.93
+25	na	-	-	-	-	-	-
+35	na	-	-	-	-	-	-

6. Capital costs*

Output (kW)	9.4	11.8	15.3	46	103	386
Unit Cost (DM)	14,233	14,909	17,864	27,031	47,965	-
Installed Cost (DM)	Not known					

* Estimated costs at 1979 price and exchange rates, without taxes; not including heat distribution or backup costs.

7. Maintenance costs: 4 percent of installed capital cost per annum

8. Service life

Source equipment, 20 years; heat pump, 20 years; drive, 10 years; weighted mean, 15 years.

9. Year of introduction: 1980

AHP SYSTEM 8

System Type: Otto-Rankine

1. Description

Heat Pump:
Cycle: Rankine, reciprocating compressor
Working fluid: (1) R_{12}; (2) and (3) R_{22}
Source: (1) amibient air; (2) surface water; (3) ground water
Sink: Water - (1) T_d = 67°C, T_r = 45°C; (2) T_d = 39°C, T_r = 31°C; (3) T_d = 76°C, T_r = 60°C

Drive:
Cycle: Otto engine
Working fluid: Air
Fuel: Natural gas

Use: Small-scale district heating and commercial building heating

2. Design data

Heat output at source temperature (1: 0°C; 2: 3°C; 3: 10°C): 98 kW; 861 kW; 245 kW
Heat input: (1) 92 kW; (2) 561 kW; (3) 126 kW
Electrical input (fans, pumps, controls): Not known

3. Backup

Type: Boiler
Fuel: (1) gas; (2) oil; (3) gas
% maximum capacity: (1) unknown; (2) 10%; (3) 50%

4. Controls

Capacity: (1) and (2) not known; (3) speed
Defrost: (1) hot gas; (2) and (3) not necessary
Backup: Not known

5. Performance

Air Temp. (°C)	Source Temp. (°C) (1)	(2)	(3)	Heating/Cooling Output (kW) (1)	(2)	(3)	Heating/Cooling COP (1)	(2)	(3)	COP' (1)	(2)	(3)
-10	-10	-	-	-	-	-	-	-	-	-	-	-
0	0	+3	+10	98	861	245	1.1	1.5	2.0	-	-	-
+10	-10	-	-	-	-	-	-	-	-	-	-	-
+25	-	-	-	-	-	-	-	-	-	-	-	-
+35	-	-	-	-	-	-	-	-	-	-	-	-

6. Capital costs*

Output (kW)	3/4	10/12	15/20	50	100	460	360 (1)	360 (3)	360 (2)
Unit Cost (DM)	-	-	-	-	-	-	74,000	202,500	470,000
Installed Cost (DM)							78,000	283,500	500,000

* Estimated costs at 1979 price and exchange rates, without taxes; not including heat distribution or backup costs.

7. Maintenance costs: 5 percent of installed capital cost per annum

8. Service life

Source equipment, 25 years; heat pump, 15/20 years; drive, 15/20 years; weighted mean, 20 years.

9. Year of introduction: 1981

AHP SYSTEM 9

System Type: Stirling-Rankine

1. Description

Heat Pump:
Cycle: Reversed Rankine (inertia reciprocating compressor)
Working fluid: R_{22}
Source: Ambient air
Sink: Air - feed 34-37°C, return 21°C

Drive:
Cycle: Stirling (free piston)
Working fluid: Helium
Fuel: Natural gas

Use: Domestic central space heating and cooling

2. Design data

Heat output at source temperature (+8°C): 12.6 kW
Heat input: 7.2 kW
Electrical input (fans, pumps, controls): 1.1 kW

3. Backup: Not known; probably unnecessary as unit sized for cooling load.

4. Controls

Capacity: Modulation of burner
Defrost: Not known

5. Performance

Air Temp. (°C)	Source Temp. (°C)	Heating/Cooling Output (kw)	Heating/Cooling COP	COP'
-10	-10	15.0	1.1	1.0
+ 0	0	13.5	1.3	1.1
+10	+10	11.7	1.5	1.2
+25	+25	-	-	-
+35	+35	10.3	0.8	0.66

6. Capital costs*

Output (kW)	3/4	10/12	15/20	50	100	400	≥2000
Unit Cost (DM)	-	-	2,750	-	-	-	-
Installed Cost (DM)	-	-	5,000	-	-	-	-

* Estimated costs at 1979 price and exchange rates, without taxes; not including heat distribution or backup costs.

7. Maintenance costs: 5 percent of installed capital cost per annum

8. Service life

Source equipment, 15 years; heat pump, 15 years; drive, 15 years; weighted mean, 15 years.

9. Year of introduction: 1983

AHP SYSTEM 10

System Type: Chemical Heat Pump - Solid Sorption

1. Description

Heat Pump:
Cycle: Solid sorption
Working fluid: Metal salt + H_2O
Source: Soil
Sink: Water: T_d = 40-60 °C, T_r = 35-50°C

Drive:
Cycle: Solar radiation
Working fluid: Water
Fuel: Solar; electricity for auxiliaries

Use: Domestic central space and water heating

2. Design data

Heat output at source temperature (0°C): 25.00 kW max.
Heat input: Variable
Electrical input (fans, pumps, controls): 0.30 kW (charging)
0.15 kW (discharging)

3. Backup: Not necessary

4. Controls

Capacity: Control of pumping rate from ground store/solar collectors
Defrost: Not necessary

5. Performance

Air Temp. (°C)	Source Temp. (°C)	Heating/Cooling Output (kW)	Heating/Cooling COP	Heating/Cooling COP'
-10	60-70°C	-	-	-
0	60-70°C	-	1.0	0.9
+10	60-70°C	-	-	-
+25	na	-	-	-
+35	na	-	-	-

6. Capital costs*

Output (kW)	3/4	10/12	15/20†	50	100	400	≥2000
Unit Cost (DM)	-	-	21,250**	-	-	-	-
Installed Cost (DM)	-	-	-	-	-	-	-

* Estimated costs at 1979 price and exchange rates, without taxes; not including heat distribution or backup costs.
** Does not include solar collectors or ground coil units; cost estimated @ 2,125 DM/MWh stored for all unit sizes.
† 25 kW.

7. Maintenance costs: Approx. 1 percent of installed capital cost per annum.

8. Service life

Source equipment, 30 years; heat pump, 30 years; drive, 10/15 years; weighted mean, approx. 30 years.

9. Year of introduction: 1982

AHP SYSTEM 13

System Type: Electric-Rankine - Ground Source

1. Description

Heat Pump:
Cycle: Reversed Rankine
Working fluid: R22
Source: Ground: a) vertical coil, b) horizontal coil; brine filled
Sink: Water: feed 55°C, return 45°C

Drive:
Cycle: Electric motor

Use: Domestic central space and water heating

2. Design data

	a)	b)	
Heat output at 0°C source temperature:	14.5	11.0	kW
Heat input:	0	0	kW
Electrical input (fans, pumps, controls):	5.0	4.5	kW

3. Backup

Type: Direct electric, parallel operation
Fuel: Electric
% maximum capacity: 25%

4. Controls

Capacity: On/off
Defrost: Not necessary
Backup: Not known

5. Performance

Air Temp. (°C)	Source Temperature (°C) (a)	(b)	Heating/Cooling Output (kw) (a)	(b)	Heating/Cooling COP (a)	(b)	COP' (a)	(b)
-10	10°C brine	not known	14.0	10	3.0	2.5	0.81	0.67
0			14.5	11	3.4	3.0	0.92	0.79
+10			15.5	13	3.9	3.6	1.03	0.95
+25	not available							
+35								

6. Capital costs*

Output (kW)	3/4	10/12 a)	10/12 b)	15/20 a)	15/20 b)	50	100	400	>2000
Unit Cost (DM)	-	-	-	8,100	-	-	-	-	-
Installed Cost (DM)	-	-	11,000	15,000	-	-	-	-	-
	-	-	13,000	17,000	-	-	-	-	-

* Estimated costs at 1979 price and exchange rates, without taxes; not including heat distribution or backup costs.

7. Maintenance costs: 1.5 percent of installed capital cost per annum

8. Service life

Source equipment, 20 years; heat pump, 10/15 years; drive, 10/15 years; weighted mean, 15 years.

9. Year of introduction: a) 1982/85; (b) 1980

AHP SYSTEM 14

System Type: Absorption

1. Description

Heat Pump:
Cycle: Absorption, single stage
Working fluid: NH_3/H_2O
Source: Ambient air
Sink: Water: T_d = 60-70°C, T_r = 40-50°C

Drive:
Cycle: Not applicable
Working fluid: Not applicable
Fuel: Natural gas

Use: Domestic central space and water heating

2. Design data

Heat output at 0°C source temperature: 10.0 kW
Heat input: 9.6 kW
Electrical input (fans, pumps, controls): 0.4 kW

3. Backup

Type: Not known

4. Controls

Capacity: Not known
Defrost: Not known
Backup: Not known

5. Performance

Air Temp. (°C)	Source Temp. (°C)	Heating/Cooling Output (kW)	Heating/Cooling COP	Heating/Cooling COP'
-10	-10	not known	0.70	0.8
0	0	not known	0.90	0.9
+10	+10	10	1.03	1.0
+25	+25			0.8*
+35	+35			0.5*

* Not included in design: estimates only.

6. Capital costs*

Output (kW)	3/4	10/12	15/20	50	100	400	≥2,000
Unit Cost (DM)	-	4000	est. 7000	-	-	-	-
Installed Cost (DM)	-	-	-	-	-	-	-

* Estimated costs at 1979 price and exchange rates, without taxes; not including heat distribution or backup costs.

7. Maintenance costs: 2 percent of installed capital cost per annum.

8. Service Life

Source equipment, 20 years; heat pump, 20 years; weighted mean, 20 years.

9. Year of Introduction: 1985

AHP SYSTEM 15

System Type: Rankine-Rankine

1. Description

Heat Pump:
Cycle: Reversed Rankine, centrifugal compressor
Working fluid: Unknown (possibly R11, R113, or R114)
Source: Ambient air
Sink: a) Water: feed 55°C, return 45°C
b) Air

Drive:
Cycle: Rankine, centrifugal turbine
Working fluid: As heat pump
Fuel: Natural gas

Use:
a) Domestic central space and water heating
b) Domestic central space heating and cooling

2. Design data

Heat output: a) 11.0 kW @ 0°C;
b) 11.7 kW @ +8°C
Heat input: 9.0 kW
Electrical input (fans, pumps, controls): 0.2 kW

3. Backup: Gas boiler, 100% efficiency

4. Controls: Not known

5. Performance

Air Temp. (°C)	Source Temp. (°C)	Heating/Cooling Ouput (kw) (a)	(b)	Heating/Cooling COP (a)	(b)	COP' (a)	(b)
-10	-10	10.6	-	1.1	-	1.0	-
0	0	11.4	-	1.2	-	1.1	-
+10	+10	12.1	12.0	1.3	-	1.25	-
+25	+25	-	5.3	-	0.55	-	0.5
+35	+35	-	4.3	-	0.45	-	0.4

6. Capital costs*

Output (kW)	3/4	10/12	15/20	50	100	400	>2000
Unit Cost (DM)	na	a) 3,200	est. DM 550/kW	-	-	-	-
Installed Cost (DM)	na	b) 5,700	-	-	-	-	-

* Estimated costs at 1979 price and exchange rates, without taxes; not including heat distribution or backup costs.

7. Maintenance costs: 3 percent of installed capital cost per annum

8. Service life

Source equipment, 10/15 years; heat pump, 10/15 years; drive, 10/15 years; weighted mean, 10/15 years.

9. Year of introduction: 1985

AHP SYSTEM 16

System Type: Brayton-Rankine

1. Description

Heat Pump:
Cycle: Reversed Rankine; centrifugal compressor
Working fluid: R12
Source: Ambient air
Sink: Air

Drive:
Cycle: Brayton; gas turbine
Working fluid: Air
Fuel: Natural gas

Use: Commercial space heating and cooling

2. Design data

Heat output at +7°C source temperature: 30.8 kW
Heat input (including 0.9 percent heater efficiency): 22.5 kW
Electrical input (fans, pumps, controls): 0.4 kW

3. Backup: Not necessary, designed for cooling load

4. Controls

Capacity: Modulation or on/off control of burner
Defrost: Not known
Backup: Not necessary

5. Performance

Air Temp. (°C)	Source Temp. (°C)	Heating/Cooling Output (kW)	Heating/Cooling COP	COP'
-10	-10	-	-	-
0	0	35.0	1.15	1.0
+10	+10	30.8	1.23	1.0
+25	+25	-	-	-
+35	+35	35.0	1.18	1.0

6. Capital costs*

Output (kW)	3/4	10/12	15/20	50	100	400	10,000
Unit Cost (DM)	-	-	-	16,500	-	-	-
Installed Cost (DM)	-	-	-	37,000	-	-	-

* Estimated costs at 1979 price and exchange rates, without taxes; not including heat distribution or backup costs.

7. Maintenance costs: 1 percent of installed capital cost per annum.

8. Service life

Source equipment, 15 years; heat pump, 15 years; drive, 10 years; weighted mean, 12 years.

9. Year of introduction: 1985/88

AHP SYSTEM 19

System Type: Single-Stage Absorption

1. Description

Heat Pump:

Cycle:	Single stage absorption
Working fluid:	$LiBr-H_2O$
Source:	Waste water 30-60°C
Sink:	Water, feed 60-90°C

Drive:

Cycle:	Not applicable
Working fluid:	Not applicable
Fuel:	Not applicable

Use: District heating and commercial building space and water heating

2. Design data

Heat output at source temperature:	8,750 kW
Heat input:	6,400 kW
Electrical input (fans, pumps, controls):	141 kW

3. Backup: none

4. Controls

Capacity:	Not known
Defrost:	Not necessary
Backup:	Not necessary

5. Performance

Air Temp. (°C)	Source Temp. (°C)	Heating/Cooling Output (kW)	Heating/Cooling COP	COP'
-10	50 (mean	-	-	-
0	range	8,750	1.37	1.29
+10	30-60)	-	-	-
+25	not applicable	-	-	-
+35	not applicable	-	-	-

6. Capital costs*

Output (kW)	3/4	10/12	15/20	50	100	400	8750
Unit Cost (DM)	-	-	-	-	-	-	82.5×10^6
Installed Cost (DM)	-	-	-	-	-	-	140.0×10^6

* Estimated costs at 1979 price and exchange rates, without taxes; not including heat distribution or backup costs.

7. Maintenance costs: 1 percent of installed capital cost per annum.

8. Service life

Source equipment, 15 years; heat pump, 15 years; drive, 15 years; weighted mean, 15 years.

9. Year of introduction: 1982

AHP SYSTEM 20

System Type: Combined Compression-Absorption

1. Description

Heat Pump:
Cycle: Stage 1, electric-reversed Rankine; Stage 2, absorption
Working fluid: R114; LiBr-H_2O
Source: Waste water: feed 30-60°C
Sink: Water: feed 100-150°C; return 40-70°C

Drive:
Cycle: Electric motor
Working fluid: -
Fuel: -

Use: District heating and commercial space and water heating

2. Design Data

Heat output at 60°C source temperature: 17,400 kW
Heat input: 0 kW
Electrical input (fans, pumps, controls): 6,200 kW

3. Backup: Not necessary

4. Controls

Capacity: Not known
Defrost: Not necessary
Back-up: Not necessary

5. Performance

Air Temp. (°C)	Source Temp. (°C)	Heating/Cooling Output (kW)	Heating/Cooling COP	Heating/Cooling COP'
-10	60	-	-	-
0	60	17,400	3.0	0.86
+10	60	-	-	-
+25	not applicable	not applicable	-	-
+35	not applicable	not applicable	-	-

6. Capital costs*

Output (kW)	3/4	10/12	15/20	50	100	400	17,400 / 200
Unit Cost (DM)	-	-	-	-	-	-	320×10^6
Installed Cost (DM)	-	-	-	-	-	-	420×10^6

* Estimated costs at 1979 price and exchange rates, without taxes; not including heat distribution or backup costs.

7. Maintenance costs: 1.5 percent of installed capital cost per annum.

8. Service life

Source equipment, 15 years; heat pump, 20 years; drive, 25 years; weighted mean, 20 years.

9. Year of introduction: 1982.

APPENDIX C

TECHNICAL APPROACH

National market study teams estimated the implementation potential for advanced heat pumps from 1980 to 2000 using a technical approach prepared by RPA. Although AHP systems will also have a significant market in commercial/industrial applications, only installations in single-family (SF) and multi-family residential buildings (MF) were considered in this study. Furthermore, national teams assumed that the entire housing stock in each country will require the following standard sizes of AHP installations:

SF and MFI	MFII
3-4 kW	50 kW
10-12 kW	100 kW
15-20 kW	400 kW
	2 MW (district heating)

The five major steps in the technical approach were:

1. Estimate H/C installations through 2000
2. Estimate energy requirements and operating costs of AHPs and conventional systems
3. Rank AHP and conventional systems according to decision criteria
4. Determine economic potential of AHP systems
5. Determine implementation potential.

These steps and the necessary data inputs required to complete them are outlined in Exhibit C.1. Each AHP system considered in the market study is described in Chapter 3, with detailed technical profiles in Appendix B.

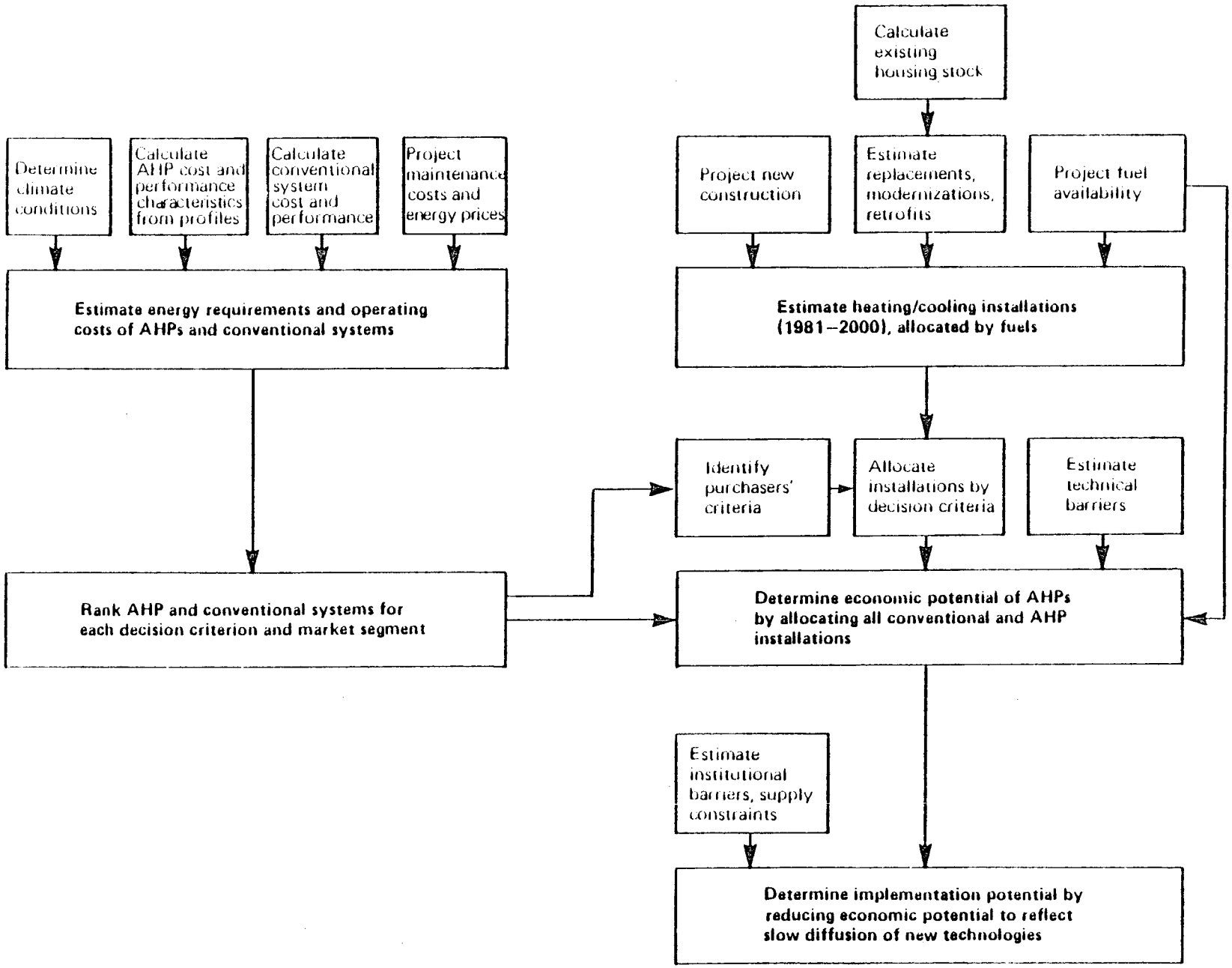
ESTIMATE H/C INSTALLATIONS THROUGH 2000

In the initial part of the study, national teams estimated the annual number of all heating and cooling installations between 1980 and 2000. These estimates indicate the size of the annual market in which AHP systems will compete with conventional systems (i.e., both conventional heat pump systems and conventional heating and cooling installations such as furnaces).

To complete the first part of the study, national teams first collected detailed inventories of existing housing stock and current installations of

Exhibit C.1

Technical Approach for AHP Market Study



types of heating and cooling systems. Such information was necessary to estimate the potential for AHP installations in existing stock. Four categories of heating systems were defined for both single- and multifamily buildings:

Central air: Central heating plant serving either the individual housing unit or the entire building, with forced-air heat distribution; the most common system in North America.

Central water: Central heating plant with heat distribution by hot water; the most common system in Europe.

Space I: Electric baseboard (or other heating built into the building structure) and ductless furnaces.

Space II: Stoves or other room heating units (i.e., units not built into building structure), common in Japan and in older buildings in Europe.

As a result of these definitions, multifamily housing stock was further categorized by types of heating systems:

Multifamily I (MFI): Apartment buildings with individual heating systems (i.e., electric heating or stoves or other room-heating units)

Multifamily II (MFII): Apartment buildings with central heating systems (i.e., central water or air)

The inventory of existing housing stock revealed that only the United States and Japan have significant demand for residential cooling systems. All cooling systems considered in this study were categorized as either central air or Space II systems in both single- and multifamily buildings.

The existing stock was also categorized by the fuel used for heating, a key factor in determining the heating system selected for replacement, modernization, and retrofit installations. Fuel types include:

- Oil/Diesel
- Natural gas
- Electricity
- Coal
- Other (district heating, block central heating).

National teams then estimated the annual amount of new construction between 1980 and 2000, classifying single- and multifamily buildings by type of heating system as for the existing stock. Teams also made assumptions about the fuels available for heating systems in new housing, particularly the availability of natural gas.

In most countries, the largest market for heating and cooling installations is not in new construction but rather in the replacement, modernization, and retrofit of systems in the existing housing stock. Each type of installation, which is defined below, implies a different set of options for system purchasers:

- Replacement: The existing heating system is worn out and must be replaced. The distribution system (i.e., central air or water) is not changed.
- Modernization: The existing heating system is replaced to upgrade living conditions. The distribution system may also be changed. Modernizations will be most common in Europe as Space II systems are replaced with central water.
- Retrofit: The existing heating system, though not worn out, is replaced with a new system for greater energy efficiency and lower operating costs.

National market teams made varying assumptions about the percentage of the existing stock that would require installations of each type in the 1980-2000 period. Most teams assumed that installations resulting from replacement, modernization, or retrofit would continue to use the same heating fuel as existing systems.

The annual number of installations was calculated as the sum of the installations derived from new construction and those derived from replacement, modernization, and retrofit.

ESTIMATE ENERGY REQUIREMENTS AND OPERATING COSTS OF AHPs AND CONVENTIONAL SYSTEMS

The next step in the analysis was to develop operating costs and capital costs for the heating and cooling systems that will compete in each market segment. Operating costs depend on the system's energy efficiency, which determines the amount of energy necessary to meet expected building heating and cooling loads. Unlike conventional systems whose efficiency is independent of climate conditions, a heat pump's efficiency (or coefficient of performance) varies with outside temperature, particularly if its heat source is outside air.

National teams calculated the energy requirements of heat pump systems by using aggregated climatic data for their countries (some countries, such as Canada, Japan, and the United States, performed the analysis by region). The annual hours of required heating (and/or cooling) were grouped in bins according to the prevailing outside temperatures. The coefficient of performance (COP) of the heat pump at each temperature was then taken from the specification or profile of heat pump performance and cost provided from the technical study. Analysts then calculated the energy consumption of the system for each bin of hours and added them up to derive the annual energy consumption of the heat pump system. The calculation methodology also covered estimation of the consumption of heat pump back-up systems. At the end of the calculation, analysts estimated energy consumption of the total heat pump system over the heating and cooling seasons and the seasonal performance factors. Similar calculations were made for conventional systems.

Analysts then applied estimates of expected future fuel costs to these energy consumption values to calculate energy cost; assumed maintenance and service costs were added to arrive at total annual operating costs for each system. The analysis was carried out in real money (no inflation). But, since fuel costs tend to escalate in real terms over the period, separate estimates of operating costs were made for each five year period from 1980 to 2000.

The first cost data used in the market study are in some cases uncertain and not very homogeneous, since for some systems the costs are target first costs indicated by the developers, i.e., those that they foresee as economically attractive (Rankine-Rankine, Stirling-Rankine, Diesel-Rankine, and Absorption), while others are based on present selling costs (Electric-Rankine and Otto-Rankine). In addition, German first cost estimates are often considerably higher than those from other countries.

Using capital costs in Deutschmarks taken from the heat pump profiles, national teams estimated costs for competing AHPs and conventional systems. Deutschmarks were also used to calculate the capital and maintenance costs reported in the heat pump profiles in cases when the original cost information came from a country other than Germany.

Most countries estimated heating/cooling installations by fuel type, especially for the replacement, modernization, and retrofit installations. Some countries allocated installations by fuels later in the analysis, incorporating the choice of fuel into the final selection of heating systems.

RANK AHP AND CONVENTIONAL SYSTEMS BY DECISION CRITERIA

The next step in the analysis was to introduce decision makers' criteria for selecting a heating system. National teams estimated the percentage of decision makers in each market segment that would choose among AHP profiles and competing conventional systems according to such criteria as:

- First cost
- Payback period
- Annual energy or operating cost
- Life-cycle cost.

The heating/cooling installations within a market segment were then allocated among the criteria that would apply according to these percentages.

At this point in the analysis, each national team had identified a number of market segments, characterized by:

- Number of installations in each 5-year period between 1981 and 2000
- Type of building (single-family, multifamily I, multifamily II)

- Type of installation (new construction, replacement, modernization, retrofit)
- Other distinguishing characteristics such as type of heat distribution (usually water)
- Decision criteria
- AHP and conventional systems competing in the segment.

National teams then calculated the values of the decision criteria for all the systems, both advanced heat pump and conventional, that would compete in each market segment. The systems were then ranked according to each criteria.

DETERMINE ECONOMIC POTENTIAL OF AHP SYSTEMS

The allocation of installations to competing systems, called the economic market potential, was performed in different ways in different countries. In most of the countries, all the installations in the market segment were allocated to that system (either advanced heat pump or conventional), which ranked first on the associated decision criterion. In many cases, however, technical limitations (such as natural gas availability or restrictions on ground heat sources) prevented this system from taking the entire market. Where this occurred, as many installations were given to the first-ranking system as technical limits would allow, and the rest given to the second-ranking system.

Some countries allocated all their installations to fuels before they allocated them to systems; most countries used this method for the replacement, modernization, retrofit segments. As a result, in these markets, competition for the market occurred only within fuels. Other countries allocated their installations to fuels and heating/cooling systems at the same time; often, countries allocated systems to new construction segments in this way. In these markets, competition among systems occurred across fuels, and more systems were able to compete. This more comprehensive analysis was done most often in those countries which analyzed a large number of systems and market segments.

DETERMINE IMPLEMENTATION POTENTIAL

In the last step of the technical approach, the national teams estimated the implementation potential for advanced heat pumps. The implementation potential is the economic potential reduced to reflect a host of factors that slow the introduction of a new technology, including the inherent reluctance of consumers to try a new product (a reluctance not fully captured in the decision criteria), institutional barriers, supply constraints, and the like. The technical approach specified high, low, and nominal market penetration rates taken from past experience with similar products.

One important limitation in this approach can result in the underestimation of the market potential for some technologies, and the attribution of overestimated market shares to others. Except for AHP systems with an exceptionally large market potential or very little potential, no definitive conclusion should be drawn without an analysis of the sensitivity of the results to changes in costs, performances, or other factors influencing each system's economic performance.