Heat pumps in the USA*

J. M. Calm†
Consulting Mechanical Engineer, 4580 Alpine Road, Portola Valley, CA 94025, USA
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First commercially introduced in the 1930s, heat pumps are now used to heat, or heat and cool, approximately 30% of all new buildings, both residential and commercial, in the USA. Their use is considerably lower for domestic water and industrial process heating, and is still at the pioneering stage for district heating and cooling. Widespread installation of air conditioning, prevalent use of air rather than water for heat distribution, and generally lower energy prices result in major differences in heat pump acceptance compared to that in European countries. This Paper surveys the current status of heat pumps in the USA and factors influencing their future.
(Keywords: heat pumps; review; USA)

Les pompes à chaleur aux Etats-Unis

Introduites pour la première fois sur le marché vers les années 1930, les pompes à chaleur sont maintenant utilisées pour chauffer ou pour chauffer et refroidir environ 30% des immeubles neufs, résidentiels ou commerciaux, aux Etats-Unis. Leur utilisation est beaucoup moins étendue pour le chauffage de l'eau sanitaire et pour le chauffage dans les procédés industriels et elle en est encore au tout début pour le chauffage et le refroidissement urbains. L'installation générale du conditionnement d'air, l'utilisation répandue d'air plutôt que d'eau pour la distribution de chaleur et généralement des prix moins élevés de l'énergie engendrent de grandes différences d'acceptation des pompes à chaleur par rapport aux pays européens. Cet article fait le point sur l'état actuel des pompes à chaleur aux Etats-Unis ainsi sur les facteurs ayant une influence sur leur avenir.
(Mots clés: pompes à chaleur; revue; Etats-Unis)

Current heat pump technology

Electric heat pumps are available in a variety of configurations for single-family houses. The most common is the air-to-air split-system with heating capacities (at 8°C outdoor and 21°C indoor) ranging from 2 to 15 kW; supplemental resistance heaters are typically incorporated to meet peak heating and back-up demands. Such heat pumps use air as both the heat source (or sink for cooling) and the delivery medium inside the buildings. They are packaged in separate outdoor and indoor units connected by refrigerant pipes, and are usually precharged. A variation adds a third cabinet, located indoors, containing the compressor that would otherwise be part of the outdoor unit; this configuration is especially suited for colder climates. Split-system heat pumps, as differentiated from the multizone heat pumps discussed below, are generally installed as central systems using air ducts for distribution. Hydronic versions, employing hot water distribution, are also available, but are uncommon in residential sizes.

Another popular unitary heat pump (i.e. consisting of one or more units or modules designed to be used together without specific application engineering) is the single-package unit. Packaged heat pumps for residential systems include a number of air-to-air models designed for either outdoor or indoor installation, and are frequently installed in both small and mobile homes. Some discharge conditioned air directly into the occupied space, while others use air ducts for distribution. Packaged air-to-air units also include window and through-the-wall models, with typical capacities of 0.5 3.5 kW.

Split-system and packaged heat pumps are both available in water-to-air versions, with water as a heat source and cooling-mode sink; air is again used as the delivery medium. Such heat pumps can also be used to extract heat from and, for cooling, reject heat to the ground via a closed water loop; this is referred to as a ground-coupled heat pump system. Packaged heat pumps, available in both horizontal and vertical arrangements, are more common for water-source systems than are split-systems. Use of groundwater and ground-coupled heat pumps is growing, but they are still outsold by air-source heat pumps by more than 50:1.

Air-to-air, multizone split-systems (two to five indoor fan-coil units connected by refrigerant piping to a common outdoor compressor and heat exchanger) have been introduced fairly recently. Their use is increasing, particularly for retrofits as ducting is not required, but their share of the total heat pump market is still relatively small. An attractive feature is their zonal control, but installation requires higher piping skills than for conventional systems.

Two additional packaged heat pump types are available for multifamily residential applications. The

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† The author is a consulting mechanical engineer who can be contacted at Am Burgweg 8, Durlach, D-7500 Karlsruhe 41, FRG, or at 4580 Alpine Road, Portola Valley, CA 94025, USA. This Paper was prepared while the author was a Visiting Scientist at the Institut CERAC SA, Switzerland, and on an extended engagement as Technical Manager at the IEA Heat Pump Center, FRG

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first is the packaged terminal heat pump (PTHP), particularly suitable for buildings where outdoor space is limited, such as high-rise apartments. PTHPs are also used, but less commonly so, in single-family houses and room additions to the same. The PTHP is a self-contained air-to-air heat pump serving the room in which it is located and sometimes an adjacent room or two. More than one PTHP, resulting in zonal control, may be installed in a large apartment or condominium. The second type of packaged heat pump is the water-loop heat pump (WLHP), also known as the closed-loop water-source heat pump. Such devices are water-to-air heat pumps connected by piping loops, generally closed, that circulate water between different parts of a building. WLHP systems are quite commonly used for highly efficient heat recovery where some rooms, such as those in building core zones or with high internal heat gains, need cooling while others demand heating. WLHP systems frequently incorporate storage or supplemental heat sources and sinks to meet or balance thermal loads. They are also used in approximately 20% of new office buildings and especially where internal heat gains make recovery possible from core zones for perimeter heating. Very similar water-to-air heat pumps are being applied in groundwater and ground-coupled systems in small to medium size commercial buildings. Such systems are gaining acceptance in commercial buildings, but are still much less common than conventional WLHP systems.

Another option in commercial and institutional buildings, particularly for shopping centres and single-story buildings, is the roof-mounted air-to-air heat pump, a unitary single-package device. Much more common are the smaller PTHPs, described above, especially in hotels, motels and high-rise office buildings where zoning is important for energy conservation and privacy. Such systems offer low investment and both quick and unskilled installation. Split-system and other packaged configurations, with heating capacities as high as 100 kW, are also used. Packaged air-to-air and air-to-water heat pumps, having capacities up to 200 and 500 kW, respectively, are marketed for variable-air-volume (VAV) and zoned systems.

For capacities in excess of 100 kW, water-to-water heat pumps employing piston, screw and centrifugal compressors are available, the last two entering into the megawatt range. Most of these are electrically driven, but all three can be obtained with engine or turbine drives.

Retrofit use of heat pumps is increasing, with the equipment involved being similar to that described above. A popular retrofit, particularly for residential applications, is the conversion of fossil-fuel-fired furnaces to bivalent heat pump systems by substitution of air-to-air heat pumps for air conditioners when the latter are added or replaced. The furnace is left intact and controls are introduced for bivalent alternative operation. The corrosion-resistant heat exchangers in newer condensing furnaces make upstream location of heat pump heat exchangers possible. This provides more efficient bivalent parallel operation. Such a configuration is usually precluded with older furnace heat exchangers by corrosion resulting from condensation in the cooling mode. Bivalent systems are also used in new construction, but less commonly so owing to their higher cost. At present, bivalent heat pumps are still relatively uncommon and usually consist of combinations of heat pumps with furnaces or boilers, rather than unitary bivalent products. At least one manufacturer offers the latter, but they are designed more as high-efficiency furnaces than heat pumps, and offer relatively low cooling performance.

Two basic types of heat pump water heaters (HPWHs) are in use for domestic or service water heating: remote and integral. Remote units (sometimes called retrofit, without-tank or add-on) use a separate heat pump package that connects to an existing water tank. Integral units combine the heat pump and the tank into one device. Because remote units are detachable, they can be relocated if the renter moves. Water is more commonly heated by recovery of the otherwise rejected heat from air conditioning. A number of heat reclaim devices, also known as desuperheater water heaters, are sold for both new and retrofit applications. A combination of heat pump water heating and heat reclaim is available in integrated space- and water-heating heat pumps. Two such products are presently marketed, and more widespread use of this concept is expected in the future.

Community heat pump systems, sometimes thought of as small district heating or district heating and cooling networks, are beginning to emerge (such systems are often referred to as 'block centrals' in European countries). The heat pumps that provide the heating, or heating and cooling, can be centrally located with water distribution networks to individual buildings. Alternatively, the heat pumps may be located within buildings with piping networks delivering the source or sink fluid. A variety of cascaded and decentralized approaches have also been examined. Further information on such systems is available in Reference 1, but additional development is needed to fully exploit the potential of these systems.

Complementing the above systems, the following three additional types are used in industrial applications:

1. open-cycle steam-recompression (also referred to as mechanical vapour recompression or MVR) heat pumps are gaining in use, primarily with centrifugal (radial turbo) compressors. A multistage axial turbocompressor design is also marketed, but the author is unaware of any actual applications. A smaller engine-driven screw MVR is in the prototype development stage;
2. open-cycle vapour-compression heat pumps, using the process feedstock as the working fluid, have been successfully applied in a number of petrochemical refining processes; and
3. Stirling, absorption, and closed vapour-compression cycle heat pumps, the latter using methanol, water or other unconventional refrigerants, are under development and the prototypes are being tested.

Most compressors of <25 kW thermal capacity are of the hermetic variety; semi-hermetic designs are common up to 500 kW, and open-drives dominate the largest sizes. Fixed-vane rotary (rolling piston) compressors compete with piston (reciprocating) compressors up to 15 kW heating output, although the former are frequently used only in very small units. Piston machines dominate up to approximately 300 kW, and screw compressors are used between 100 kW and 6 MW. Centrifugal compressors are common in sizes >500 kW and dominate above 4 MW. Note that there is considerable overlap in these ranges and that piston, mono- and twin-

Table 1 Product groups and typical use
Tableau 1 *Groupes de produits et utilisations caractéristiques*

Product group / Market sector	Domestic water heaters	Consumer appliance	Space (and process) heating: Unitary	Space (and process) heating: Applied package	Space (and process) heating: Field engineered (large, built-up)
Residential:					
Single-family and multifamily low-rise	HPWH (remote and integral)	Window	Split-system, single-package	GSHP, WSHP	
Multifamily high-rise	HPWH	–		PTHP, WLHP	a-w, w-w[a]
Commercial and institutional:					
Light/small	HPWH	Window, through-the-wall	Single-package, split-system	GSHP, WSHP	
Heavy/large	–	–		PTHP, WLHP	w-w, a-w[a]
Industrial					Various
1985 US sales ($\times 10^3$)	12	≈45	821	257	≈5

[a] a-w = air-to-water; w-w = water-to-water

screw and centrifugal compressors are all used in thermal capacities of 500–750 kW. Scroll compressors with capacities up to 50 kW, are just entering the market. R22 (chlorodifluoromethane) is the most commonly used refrigerant, followed by R12 (dichlorodifluoromethane) and, less commonly, by R114, R500, R502, R11, R12B1 and R717 (ammonia).

All of the heat pumps described above are typically applied with single-speed electric motors. Adjustable speed drives, primarily based on pulse width modulated (PWM) and six-step voltage-source square wave inverters (VSI), are gaining in application, particularly for larger equipment but also in unitary equipment.

Although extensive research and development is underway to develop them, gas-fired heat pumps are not currently marketed for residential use in the USA. A few prototypes are being tested, but their commercialization remains to be determined. Gas-fired ammonia–water absorption chillers are sold for residential air conditioning by a single manufacturer and account for fewer than 6000 sold per year in contrast to 3.3 million unitary electric air conditioners and heat pumps. Heat pumps and chillers driven by engines, as well as both combustion and steam turbines, are available for commercial space conditioning and industrial applications, but are less commonly used than those driven by electric motors. At least one manufacturer offers a heat transformer (sometimes referred to as a type II absorption heat pump) for industrial use, but no such installations in the USA, other than experimental, are known to this author.

The heat pumps described and their common uses are summarized in *Table 1*. For further information on heat pump equipment and applications see References 2–8.

Typical installation costs

The wide range of climates found in the USA results in considerable variation in heating demands and, therefore, equipment capacities and installation costs. The most common residential sizes, 6–12 kW plus up to 15 kW supplemental resistance heating, cost between \$1800* and \$3500 in new construction. High-efficiency models, often equipped with programmable thermostats for temperature setback, cost \$300–700 more. These prices represent fully installed systems, including ductwork and thermostats, providing both heating and air conditioning. Heating-only heat pumps would cost nearly the same and are, therefore, very uncommon except for hydronic heat pumps. Since central air conditioning is installed in more than 70% of new single-family detached and 88% of new multifamily residences, cost comparisons against combinations of gas furnaces and electric air conditioners are more realistic than against furnaces alone. Although the equipment prices for residential heat pumps are typically higher, the fully installed costs, including electric and gas distribution, combustion air provisions, flue venting and chases, and roof penetration, result in a lower initial cost for many heat pump installations, particularly for small capacities. Furthermore, the incremental costs associated with new high-efficiency and condensing furnaces usually exceed the premiums for high-efficiency heat pumps.

Commercial water-to-water heat pumps cost approximately \$150 per kW of heating output in capacities of 100 kW, and decrease to \$50 per kW in capacities of the order of 5 MW. Such prices reflect the fully installed heat pumps, exclusive of either the structure in which they are located or pumps and piping for their source and distribution fluids. Installed remote and integral HPWHs cost \$600–1100 and \$1100–2000, respectively, for residential sizes.

* All prices quoted are in US\$

Government and utility promotion

Governmental promotion of heat pumps is virtually non-existent at the federal level. Current laws, rules and interpretations specifically exclude heat pumps, with a few very restrictive exceptions, from existing conservation, solar and geothermal tax credits. The rationale offered is that the credits are intended to stimulate initial use of conservation approaches that would not otherwise be implemented. Advancing arguments that such credits would broaden both new and proven conservation approaches, legislation has been proposed repeatedly to entitle heat pump users to federal solar and geothermal tax credits; the author does not anticipate passage of this legislation.

Despite the above, the federal government has a major, albeit indirect, influence on heat pump use. Federal agencies prescribe minimum building standards for government financed and subsidized construction. Such standards are frequently adopted voluntarily by private lending institutions. Recent trends in such standards have been away from prescriptive rules and towards performance specifications. By setting relatively lax or severe standards for heat pumps as compared to competing systems, notably gas furnaces, the government influences system costs and, therefore, selection for such buildings. Similarly, under federal laws adopted in 1978, the government was charged with setting minimum efficiency standards for a number of appliances, including heat pumps. The Department of Energy first proposed a highly controversial set of standards and then determined, as allowed by the cited laws, that such standards were unjustified. Many state governments petitioned for non-preemption of their own standards in light of this determination. Moreover, several states and a number of organizations successfully took the issue to the courts seeking reversal of the determination. The issue may be resolved by a recent legislative proposal, which is expected to be enacted, that would set minimum efficiency standards.

Promotion by state governments varies considerably. A number of states currently provide limited credits or incentives for specific classes of heat pumps, among them groundwater, ground-coupled and solar-assisted heat pumps. Perhaps the greatest promotional impact is that of the electric and gas utilities. With more than 6000 such utilities operating in different climates and population densities and having differing energy supply and financial circumstances, wide variation results in their position regarding heat pumps. However, as evidenced by multimillion dollar annual support levels for heat pump research by the Electric Power Research Institute (EPRI) and the Gas Research Institute (GRI), both the electric and gas industries are committed to advancement of their respective heat pump technologies. No comparable programme exists for diesel-powered heat pumps by the petroleum industry.

With a few exceptions, electric utilities generally support increased use of heat pumps as a means of balancing summer and winter loads and to increase the value of service as an alternative to central electric resistance heating. Note that approximately 70% of electric utilities in the USA are summer peaking, and this fraction is increasing. Since nearly all residential and more than 95% of commercial and institutional air conditioning is powered by electricity, use of the dual-mode (heating and cooling) heat pump offers an attractive load management option. The utility promotion ranges from advertisements on television, radio, newspapers and other media, to offering special rates for heat pump users. Regulatory practice in the USA generally limits the latter to rates reflecting verifiable reductions in costs of service for space conditioning. Some electric utilities also offer consumer rebates to encourage the use of high-efficiency equipment as well as peak-limiting or interruptible systems. In addition, some utilities publish recommended installation standards and a few conduct assured service programmes to foster improved quality in product selection and installation. The latter programmes amount to equipment service contracts with utility monitoring and certification of the products, dealers and contractors involved.

Gas utilities generally oppose residential heat pump use since current products (i.e. electric heat pumps) result in lower gas sales. Furthermore, water heaters, stoves, laundry dryers and other appliances often use the same fuel as selected for heating because the installation of a gas supply into buildings is usually impractical unless used for heating. The opposition is manifested in aggressive advertising campaigns attacking heat pump costs, reliability and comfort. Gas utilities have reacted strongly to retrofit conversion to bivalent systems for similar reasons; rate surcharges have been attempted, although public pressure and regulatory actions have largely curtailed such attempts. Moreover, bivalent systems have gained in popularity even where such surcharges have been imposed. A few gas utilities have offered financial incentives for the use of high-efficiency furnaces to promote conservation and increase their competitiveness against high-performance heat pumps.

Strong gas industry promotion of gas-fired heat pumps will probably surface as suitable products become available. The single firm still manufacturing residential gas-fired chillers was, until recently, owned by a gas utility company. Similarly, efforts to commercialize gas-fired chillers in the late 1970s, and continuing at present, were led by a gas utility subsidiary importing a series of Japanese products.

An additional role worth noting lies in both gas and electric utility efforts with developers. Since it is the latter, rather than the ultimate building owner, that selects heating systems for most new homes or office buildings, utilities work with such developers, as well as the engineering and architectural firms involved, and try to influence their decisions. By offering technical assistance and bargaining with the cost of electric and gas distribution systems, utilities further promote the selection of heating fuel and, therefore, the ultimate use of heat pumps.

Approximately one-quarter of investor-owned utilities and most municipal utilities either operate as dual utilities, providing both electricity and gas, or are owned or controlled by the same body that operates the counterpart utility. Public utilities frequently offer other services (e.g. water supply) as well. Again with exceptions, usually based on the financial advantage of gas over electricity sales, such utilities generally support broader use of heat pumps for the same reasons as discussed above.

Energy prices and economics

Electricity prices in the USA in 1985 averaged $0.0782 per kWh for residential customers and $0.0519 per kWh for industrial customers; the corresponding averages were $0.0214 per kWh and $0.0131 per kWh for gas, and $0.0270 per kWh and $0.0218 per kWh for oil. The typical price ratio for electricity compared to natural gas, both expressed in equivalent thermal units, was 3.4–4.1 and for electricity to light oil (no. 2 distillate) was 2.3–3.0. Such ratios, however, obscure the differences between peak-season (summer) and peak-time (day) rates compared to those off-peak. With off-peak rates, or excluding demand components for commercial and industrial customers, the price ratios are considerably more favourable for electric heating. Such average ratios also hide local and regional variations; the ratio of residential electricity to gas prices, for example, ranges from 1.1 to 8.0. *Figure 1* shows the historical averages for electric to gas price ratios; Reference 9 discusses the relation of such ratios to heat pump acceptance.

The governing criterion for developer selection (approximately 75% of the total) in single-family detached dwellings is neither payback nor life cycle cost, but a variation on cash flow, namely which system will hold down outlays and contribute to quickest turnover in sales. The result is generally selection of systems having local acceptance constrained by short payback periods of less than six years. For owner-built homes, the criteria are similar with acceptance of a somewhat shorter payback period, perhaps up to five years. The unfortunate reality is that most home buyers in the USA give insufficient attention to the specific heating system used in selecting a new home. For commercial and industrial heat pump decisions, significantly shorter payback criteria, usually less than three years, are typically cited.

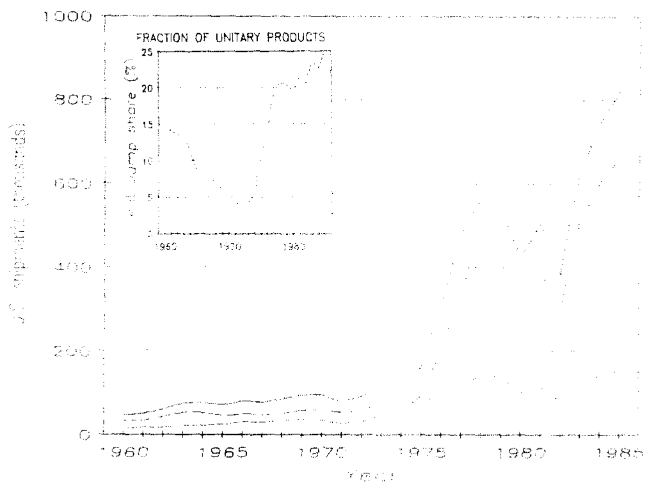

Figure 2 Heat pump use, unitary products only, excluding window and applied systems (based on ARI statistics). Heat pump type: ——, total; - - - - -, split system; ·····, single package

Figure 2 *Utilisation de la pompe à chaleur, uniquement groupes individuels mis à part les systèmes de type fenêtre en en applique (d'après les statistiques de l'ARI). Type de pompe à chaleur: ——, total; - - - - -, système à deux ou trois blocs préfabriqués; ·····, monobloc*

Market development

Based on statistics from Reference 10, heat pump sales in the USA set a historical record in 1985 with shipments of 820623 unitary heat pumps, 11% more than in 1984. Statistics up to August 1986 indicate a similar further increase in the current year. *Figure 2* shows the growth in unitary (primarily residential) heat pump sales in the USA. Five large manufacturers account for more than 80% of such products, although there are more than 60 manufacturers of heat pumps. Adding in domestic water heating, window and applied heat pumps (e.g. packaged terminal, water-loop, central water-to-water and industrial), the total for 1985 exceeded 1.1 million new heat pumps and seven million if cooling-only devices are also counted. These statistics are summarized in *Table 1*. Further discussion of the factors influencing these statistics can be found elsewhere[11-13]. The insert in *Figure 2* compares unitary heat pump shipments with the total for unitary air conditioners and heat pumps. This comparison clearly shows, contrary to some claims, that heat pump sales are not directly linked to those of air conditioners. Between 40 and 45% of the quantities cited are for replacement or retrofit use.

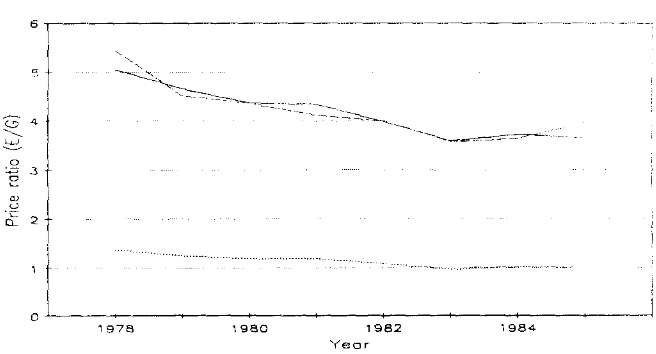

Figure 1 Electricity:gas price ratios for national averages for thermally equivalent units (based on OEDC/IEA data). See text regarding variations. – – –, Industrial; ——, residential; · · · · ·, delivered heat with typical heat pumps and furnaces

Figure 1 *Rapports du prix de l'électricité et du gaz pour les moyennes nationales d'unités thermiques équivalents (d'après les renseignements de l'OCDE/AIE). Voir le texte, pour les variations. – – –, Secteur industriel; ——, secteur résidentiel; · · · · ·, chaleur produite avec des pompes à chaleur typiques et des chaudières*

Heat pump water heaters (HPWHs) for heating of domestic or service hot water are marketed by 14 manufacturers, although this number is declining, for heating of domestic or service water. These devices offer energy savings exceeding 50% compared to electric resistance water heaters. Water heating accounts for 16–18% of the energy used in a typical home in the USA, with 53% of in-place water heaters using natural gas, and 45% using electric resistance heating. Propane, oil and solar units account for most of the remaining 2%, along with HPWHs of which > 12 000 were sold in 1984; sales have declined somewhat in 1986. Similar products are available for heating swimming pools, spas and hot tubs.

Influencing factors

The most commonly cited factors influencing broader heat pump use are installed costs and energy prices; without minimizing their relevance, there are also a number of additional factors. Reliable performance is a vital criterion for acceptance, whether by home-owners, building operators, or plant engineers. Simply stated, competing systems exist with established recognition of reliability and, although no longer justified, incidents of the 1950s continue to haunt the heat pump image. Expanded use places the heat pump in the challenger's role with the implicit burden of offering better value, an unachievable goal unless reliable service is assured. Market opponents continue to stress this issue. Manufacturers could increase heat pump sales by offering warranties longer than the typical one year (five for hermetic compressors in unitary products), thereby demonstrating greater confidence in their products. At least one manufacturer has introduced a 10 year warranty for some of its products. Equally important are the installation and repair practices, since they can defeat even the best designs. Manufacturers and contractor trade associations share a responsibility to train and retrain technicians in proven approaches. Utility and contractor associations can play important roles in

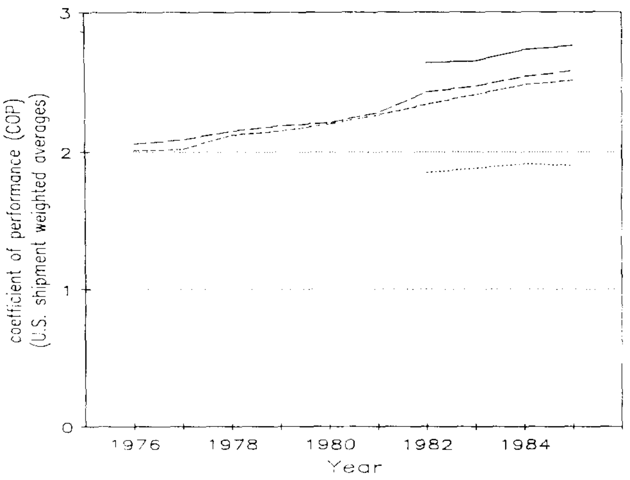

Figure 3 Average efficiencies for new air-source unitary air conditioners and heat pumps (based on ARI statistics). – –, AC cooling; -----, HP cooling; —— —, HP heating 8°C; ·····, HP heating −8°C. Efficiences are EERs up to and including 1980 and SEERs from 1981 onwards

Figure 3 *Rendements moyens pour les nouveaux conditionneurs d'air et pompes à chaleur à source d'air (d'après les statistiques de l'ARI). – – , AC refroidissement: -----, HP refroidissement: ———, HP chauffage par 8°C; ·····, HP chauffage par −8°C. Les rendements sont les coefficients de rendement énergétique (SEERS) jusqu'à 1980 inclus et SEERS à partir de 1981*

enforcing quality installations and repairs to insure their competent performance on the first visit.

Awareness is a second factor; few products that succeed in the market-place do so without continuous promotion to their buyers. Unfortunately, too few consumers understand the economic, environmental and comfort- or process-quality benefits of heat pumps. Manufacturers, dealers, contractors, utilities and governments can have critical roles here.

Development of lower-cost, higher-performance and quieter heat pumps will have an impact on both economics and consumer preferences. Manufacturers are developing improved heat pumps in response to market influences, utility incentives, building regulations and competitive interests. The average efficiency of residential heat pumps sold in the USA has increased at a rate of 2.5% per year since 1976[10], as shown in *Figure 3*. Major research programmes in heat pump technologies, beyond those by manufacturers, are sponsored by the Electric Power Research Institute, Gas Research Institute, US Department of Energy, utilities, state energy agencies and other organizations. The resulting improvements can be expected to continue current efficiency gains. Seasonal performance improvements for residential heat pumps in excess of 30% are believed to be attainable within the next 10 years. The outlook and implications of advanced heat pump development are discussed elsewhere[2–8]. Research, development and demonstration of community heat pump systems has virtually ceased in the USA implying slower future adoption rates than in other countries.

Parallel with heat pump improvements will be improvements and cost reductions in competing systems, although performance improvements in combustion systems will be more limited since their efficiencies are already much closer to theoretical limits.

Government subsidies for heat pumps, or competing technologies, can have as much adverse as beneficial impact. Because subsidies are usually abruptly introduced and terminated, they result in artificial surges and curtailments of demand. Inferior products and installations (witness the US experience in the 1950s) result from the former, and stagnation from the latter. The author recognizes that many of his colleagues in the USA hold an opposing view and encourage government subsidies for heat pumps based on the latter's proven abilities to conserve energy, avoid dependence on imported fuels and reduce undesirable environmental effects.

Future heat pump sales will be influenced to a greater extent than in the past, during their introduction, by the cyclical rise and fall of building construction rates. Similarly, sales for the replacement and retrofit markets will cycle with the economy as a whole.

With regard to energy prices, declines in oil prices will reduce the attractiveness of heat pumps in commercial, institutional and industrial applications, and will similarly affect the residential market for the north-east and the north-west. More significantly, falling oil prices will also force reductions in gas prices, again adversely affecting heat pump sales. Where generation is based on oil or oil-fired peaking, resulting changes to electricity prices will also favour heat pump use. Conversely, rising electricity rates, which might result from further nuclear mishaps or regulatory uncertainty, would do the opposite. Unstable energy prices and possible, but unpredictable, supply interruptions due to catastrophic incidents (e.g. nuclear accidents, Middle East oil embargoes, gas pipeline explosions) erode confidence in sales forecasts.

Conclusions

More than one-quarter of the residences built in the USA during the last decade have used electric heat pumps for heating and cooling. In new construction, this rate is nearly one in three, and is almost the same for non-residential construction. A variety of heat pump configurations for zonal and central space conditioning, using both air- and water-source heat pumps, are commercially available with thermal capacities ranging from hundreds to millions of watts. Such heat pumps have established economic viability as reflected in sales of more than 1.1 million heat pumps in 1985, a record year. More significantly, heat pump sales have been increasing in recent years and this trend is expected to continue. Gas-fired heat pumps are under development, but are not yet sold for residential use. Large heat pumps, both open- and closed-cycle are used in industrial systems powered by electricity, gas, steam and oil. Energy price and other uncertainties make prediction of future heat pump penetration unreliable, but technical advances and increasing recognition of their conservation and environmental benefits will favour broader heat pump use.

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