Chapter XII

HEATING AND COOLING EQUIPMENT

Chapter XII.—HEATING AND COOLING EQUIPMENT

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Chapter XII

Heating and Cooling Equipment

INTRODUCTION

This chapter has two major objectives: to estimate the cost of providing space conditioning from conventional electric equipment as well as from oil- and gas-fired devices, and to analyze the performance of systems which can be coupled with solar devices. Technologies examined include electric and absorption air-conditioners, heat pumps, and conventional gas- and oil-fired boilers. Systems examined are compatible with loads varying from that of a single family residence to the requirements of a district heating system.

Much of the data needed to perform a careful study of the cost of providing heating and cooling from conventional equipment is not easily available. Some of the relevant data remains proprietary and, in a number of cases, adequate measurements of performance in realistic operating environments have never been taken. A detailed study of the performance of many heating and cooling devices is now underway at the Building Environment Division of the National Bureau of Standards. A more accurate comparison of systems will be possible when that study is completed.

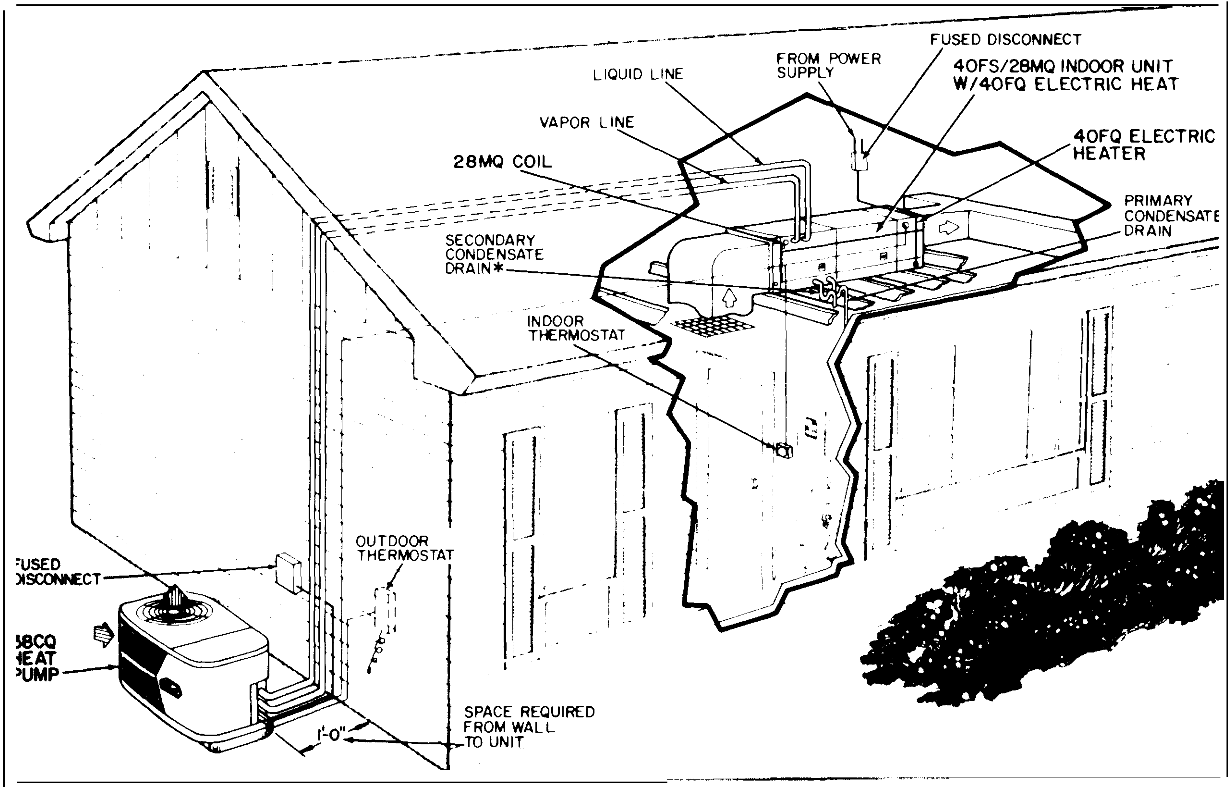
Given the uneven quality of the information utilized, no attempt should be made to use the results to judge the relative merits of different conventional approaches to space-conditioning. The object of the cost computations is simply to provide a reasonable background against which to test the economic merits of solar equipment. These computations are based on the most reliable information now available to OTA, but the lack of precision is f reel y acknowledged.

ELECTRIC AIR-CONDITIONERS AND HEAT PUMPS

A typical residential air-conditioner/heat-pump installation is illustrated in figure Xl 1-1, and a large central chiller is shown in figure Xl 1-2. Both units employ the same basic refrigeration cycle, although the smaller units usually cool and dehumidify room air directly while the larger systems typically produce chilled water which is piped to fan-coil units in various parts of the building. The cooling systems have three basic components: 1) a unit which permits a refrigerant to expand, vaporize, and absorb heat from the room air (or water system); 2) a compressor which compresses the heated vapor (increasing its temperature); and 3) a condenser located outside the building which rejects the heat absorbed from the room air into the atmosphere (condensing the compressed vapor to a liquid). In "single-package' units, all three functions are provided in the same unit and can be connected directly to the ductwork (or chilled water system) of the building. In "split-system" devices, refrigerant is sent to an air-handling unit inside the building. (This system is illustrated in figure Xl I-I.) Another distinction which is frequently made involves the technique used to compress the refrigerant vapor. Smaller units typically use a simple piston system for compression and are called "reciprocating" units. Larger units may use centrifugal pumps or screw compressors for this purpose.

Heat pumps use the same three basic components as the air-conditioners described above, but the cycle is reversed. In the heating cycle, the indoor air absorbs heat from the refrigerant and heat is acquired by the refrigerant from the outdoor

Figure XI I-I.—A Typical "Split System" Heat-Pump Installation



SOURCE. Carrier Corporation

fan unit (the "condenser" in the cooling model).

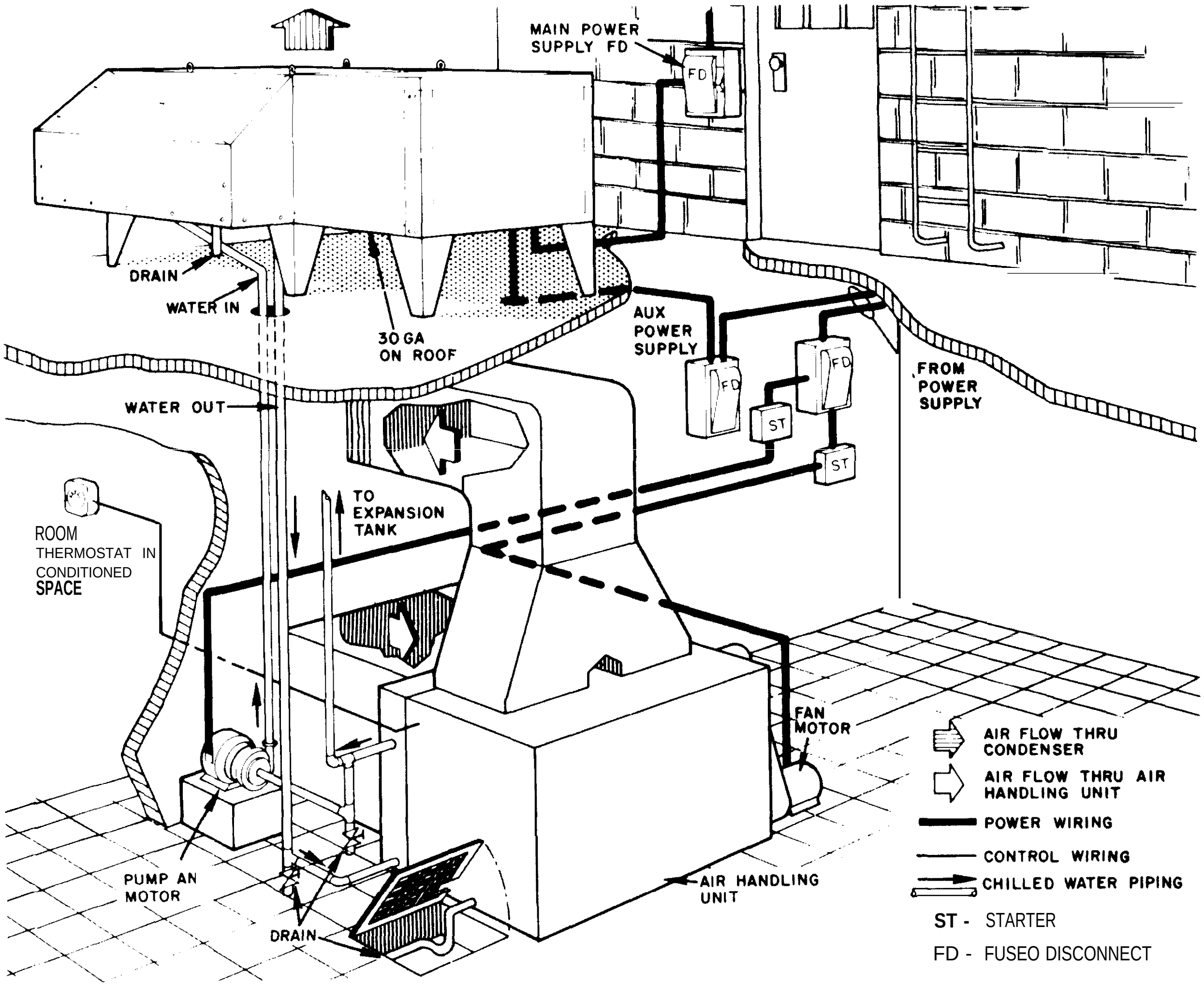
Heat pumps which can extract useful energy from outdoor air temperatures as low as 00 F are now on the market, although system performance is seriously degraded at low temperatures. The electricity used by the system can be considerably reduced if a source of heat with a temperature higher than that of the outside air can be found. Lakes or ground water, for example, are usually above ambient air temperatures during the winter and can be used to provide a source of input heat if they are available. Many buildings have sources of heat (such as lighting, mechanical equipment, rooms with large southern exposures, etc.) which can be recovered and used to heat a storage reservoir. A number of small heat pumps can be located throughout a building. Some of these pump heat from warm areas into the water reservoir, while others recover this energy and pump it into rooms requiring heating. Solar energy can also be used to provide a source of heated water. Systems which extract heat from water are called "water-te-air" heat-pump systems, while units extracting energy from the air are called "air-to-air" systems.

While less than half of the residential units in the United States were equipped with air-conditioners in 1974, the demand for air-conditioners is growing.[1] in 1974, about 45 percent of all single family homes and 34 percent of all multifamily dwelling units were equipped with some type of air-conditioner. [2] A DOE forecast estimated that

[1] Gordian Associates, Inc , *Evacuation of the Air-to-Air Heat Pump for Residential Space Conditioning,* prepared for the Federal Energy Administration, Apr 23,1976, p. 114

[2] Ibid , p 115

Figure XII-2.– A Typical Packaged Outdoor Chiller



SOURCE Carrier Packaged Outdoor Air-Cooled Liquid Chillers Carrier Corporation 1974, Form 30GA-5P

by 1985, air-conditioning will be installed in 75 percent of all residential and commercial buildings and will require about as much energy as electric heating. [3]

Heat pumps are likely to have a far smaller impact on overall U.S. energy consumption unless some dramatic change occurs in public acceptance of the units. Less than 1 percent of U.S. homes currently have heat pumps, and only about 7 to 8 percent of the new housing starts in 197.5 used the **system.**[4] **The growth of the market has been slowed by the sensitivity of buyers and builders to the initial cost of the equipment (which is higher than conventional electric-resistance heat), and by the fact that regulated gas prices and promotional electric prices have made the cost of operating competitive heating systems artificially** low **Concerns about reliability have also been a problem. Some of the heat pumps marketed in the early 1960's were extremely unreliable, and sales of the units fell steadily be-**

[3]*National Plan* for *Energy Research Development and Demonstration, Volume I,* ERDA-48, p B 10

[4]Gordian **Associates** Inc , op cit , p v

tween 1965 and 1970. While most of the reliability problems have been resolved, a recent study showed that the problem has not vanished. The compressors examined in the study failed at a rate which varied from 3.6 percent to an astonishing 23.3 percent per years A 5-percent annual failure rate is considered tolerable for this kind of space-conditioning equipment, and apparently very few manufacturers were able to meet this standard.

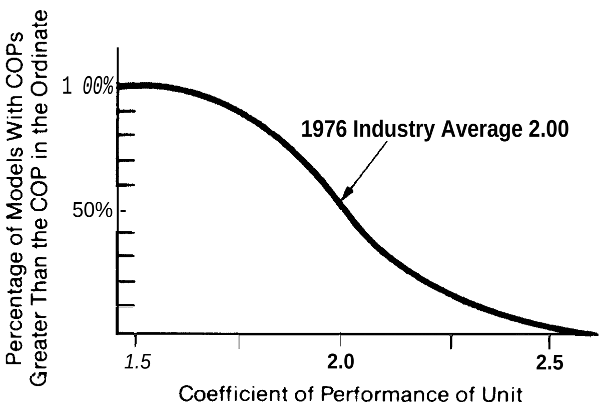
In spite of their relatively small share of the U.S. space-conditioning market, heat pumps are likely to be in direct competition with solar equipment during the next few decades. They would tend to appeal to the same category of buyers, those willing to consider life-cycle costing, and are likely to offer the lowest life-cycle cost of any non-solar space-conditioning system if the price of heating oil and natural gas increases significantly.

SYSTEM PERFORMANCE

The performance of heat pumps and air-conditioners now on the market varies greatly. Figure XI I-3 indicates the performance of air-conditioners smaller than 5½ tons now on the market. The difference in performance reflects both the quality of design and the cost of the unit. High-performance units may also result from a fortuitous combination of components. Manufacturers cannot afford to design condensers optimally suited for all compressors to which they may be attached, and some combinations of these units (in the absence of information of comparable quality about the variety of systems examined here) may therefore result in a high-efficiency system. As a result, while there are a few units on the market with very high efficiencies (figure XII-3, for example, indicated that 10 percent of the units on the market have a coefficient of performance (COP) greater than 2.5), this performance is not available in all size ranges.

[5] Ibid

Figure XII-3.— 1976 Air-Conditioning Performance of Units Smaller Than 65,000 Btu/Hour



SOURCE: OTA.

Tables XI I-I and XI I-2 give some indication of the performance which can be expected from different cooling devices, The 1976 industry average COP was 2.00.

Heat pumps were about 5 percent less efficient than the average air-conditioner, There are a variety of reasons for this. Heat pumps cannot be optimized for maximum cooling performance as somewhat more complexity is required in the coolant piping, and the valve which switches the direction of the refrigerant when the system is changed from heating to cooling introduces some inefficiencies.

Under some circumstances, small window units are capable of better performance than central air-conditioners; central units

Table XII-1 .—Cooling Coefficients of Performance for Systems Smaller Than 65,000 Btu/Hour (1976 industry averages)

	Average COP
All ARI listings	2.00
Split-system cooling	2.00
Single-package cooling	1.90
Single-package heat pumps	1.94
Split-system heat pumps	1.90

SOURCE George D Hudelson (Vice President-Engineering, Carrier Corporation), testimony before the California State Energy Resources Conservation and Development Commission, Aug 10, 1976 (Docket No 75, CON-3)

Table XII-2. — California Standards for Cooling Equipment

System type	Standard after 11/3/77*	Standard after 11/3/79*
Central Air-Conditioners		
Heat pumps (cooling mode)	1.96	2.2
Air-conditioners	2.05	2.34
Room Air-Conditioners		
All systems with capacity greater than 20,000 Btu's	2.05	—
Other heat pumps	2.08	—
Other air-conditioners	2.20	—
All systems using voltages greater than 200 v.	—	2.40
Other heat-pump systems	—	2.43
Other air-conditioners	—	2.55

"No system may be sold in the State after this date with a COP below the standard

must pump chilled air or refrigerant over significant distances, and require more energy to operate the pumps and fans needed to transport chilled air or liquids to and from the space to be cooled. The performance of large, central chilling units themselves (such as the one shown in figure XI 1-2) is better than window units, however. The larger units typically employ more efficient motors and more sophisticated designs; many units are able to achieve better performance at part loads by adjusting the flow of refrigerant (Many of these improvements could, of course, be incorporated in a smaller unit at some increase in the initial cost.) The advantages of larger systems are offset, however, by losses incurred in other parts of of the system.

A large number of designs are employed, and overall performance varies greatly from one installation to another. Some systems may require significant amounts of pumping energy to either move chilled liquids or air to different parts of a building or to operate a cooling tower which may be located on the roof

The performance of electric-cooling and heat-pump systems also varies as a function of the temperature and humidity of both the inside and outside air. This is due both to the fact that the theoretical capacity of a unit varies as a function of these parameters, and because most units must either be fully on or fully off. The load control achieved by "cycling" the system from full capacity to zero output requires heating or cooling large parts of the system before useful space conditioning can be performed. Using energy to heat or cool the units decreases the system's efficiency. The dependence of a typical residential heat-pump unit COP on the outdoor temperature is shown in figure XI 1-4. The fact that the heat pump's capacity to produce heat decreases as the outside temperature decreases results in a highly temperature-dependent heating mode, A system large enough to provide 100 percent of the heating load at the lowest anticipated temperature would be prohibitively expensive in most locations, and a most common compromise is to assist the heat pump with electric-resistance heat whenever its capacity falls below the heating demand. The average COP of a heat-pump system during the winter season is called the seasonal performance factor (SPF). This parameter is shown in figure XI I-5 as a function of local climate. As expected, the average COP of heat pumps is lower in northern parts of the count ry.

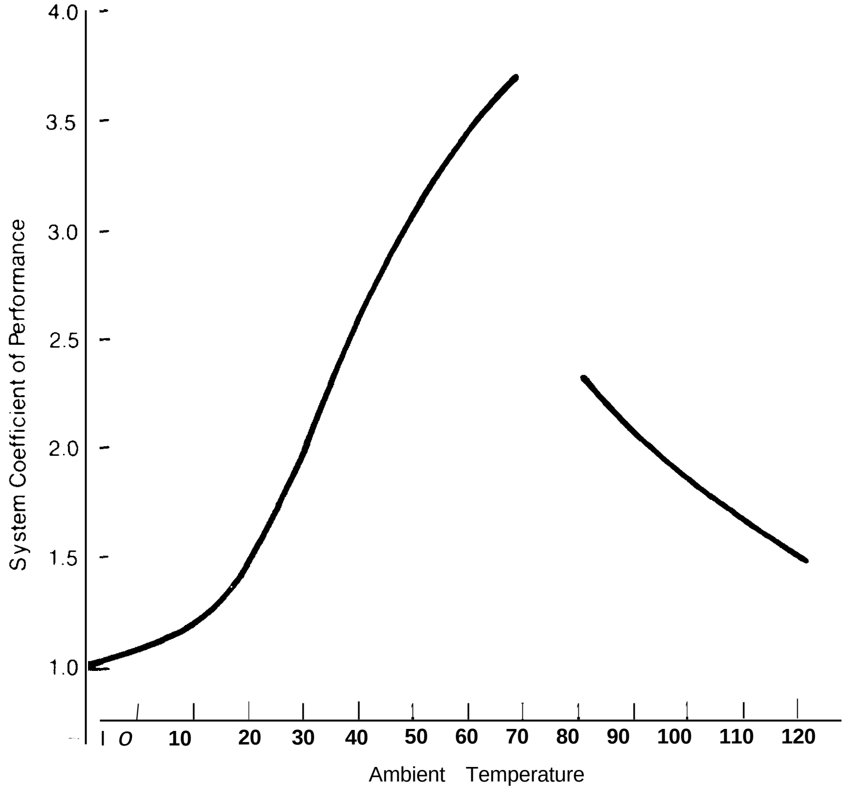
The performance of water-to-air heat-pump systems can be significantly higher than air-to-air systems if heated water is available. When 600 F water is available, most commercial units have COPS in the range of 2.5 to 3.5,[6] but units with COPS as low as 2.0 and as high as 3.7 are on the market.

Potential for Improving Performance

Research which could significantly improve the performance of these devices is currently underway in the laboratories of a number of heat-pump and air-conditioner manufacturers. Figure XI I-6 summarizes a re-

[6] *Directory of Certified Unitary Air-Conditioners, Unitary Heat Pumps, Sound-Rated Outdoor Unitary Equipment, Central System Humidifiers,* Air-Conditioning and Refrigeration Institute, 1976

Figure XII-4.– Performance of the Carrier Split-System Heat Pump

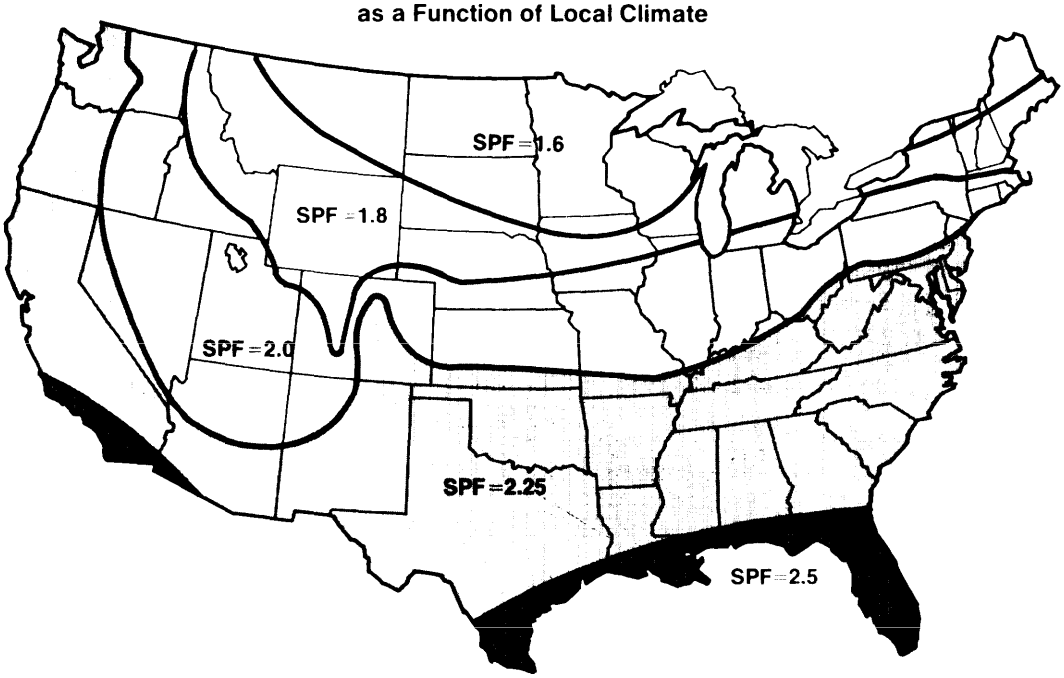


Model 38CQ020 ARI ratings:	*Heating mode* **nominal capacity 21,000 Btu/hour. COP at high temperature is 2.9, COP** at low temperature is 1.7.
	Cooling mode nominal capacity is 19,000 Btu/hour. COP is 2.1.
Assumptions used in computing system performance:	Heating mode entering indoor air is 70- F (db) heating demand in**cludes energy used for defrost balance point at 30' F.**
	Cooling mode entering indoor air is 80 F (db) and 67 F (wb). Fan power is 0.2 kW.

Energy use includes: compressor motor demands; resistance heat; the demands of indoor and outdoor fans; and the energy used in defrost cycles. The air-flow was assumed to be 700 cfm. Assumptions made about decrease in efficiency due to part load conditions were not explained in the literature.

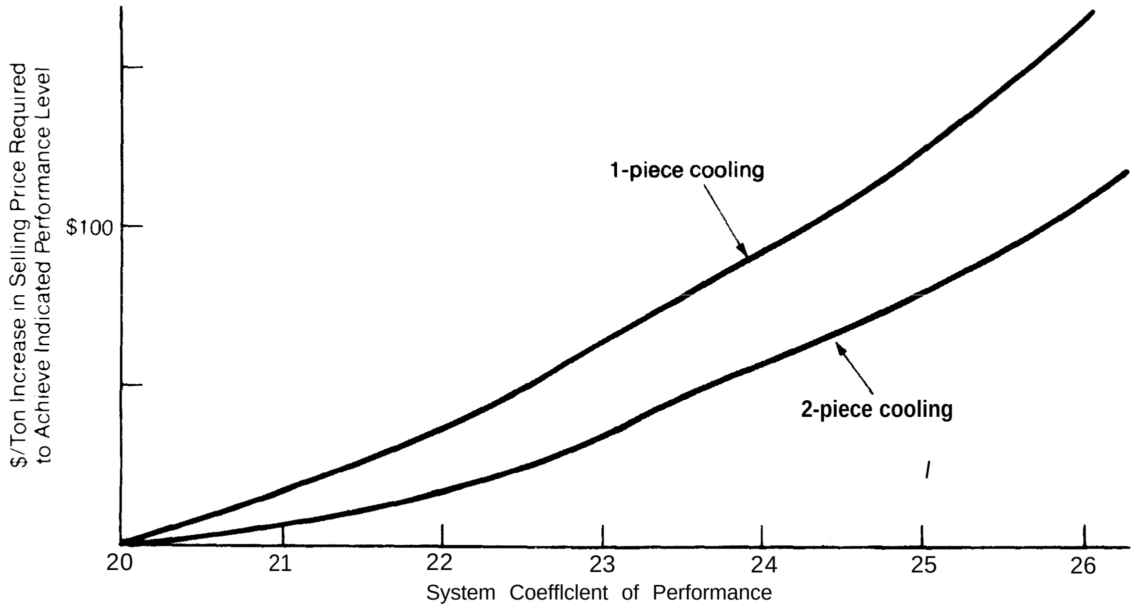
SOURCE Carrier Spilt-System Heat Pump Outdoor Sectlons Carrier Corporation 1976, Form 38CQ-1P

Figure XII-5.– The Seasonal Performance of Heat-Pump Units as a Function of Local Climate



SOURCE *What is a Single Packaged Heat Pump and How Can it Save You Money?*, Carrier Corporation, Catalog No 650.069

Figure XII-6.— Estimated Cost of Increasing the Performance of Air-Conditioners From the Industry Average COP of 2.0 to the Performance Levels Indicated (estimates assume production rates equivalent to current production rates)



SOURCE George D Hudelson (Vice President - Engineering **Carrier** Corp) presentation to the Solar Energy Resources Conservation and Development Commission of California Aug 10 1976 Docket No 75 CON 3 cent series of estimates of the increase in air-conditioning COP achievable without changing the basic design of the air-conditioning system and using a compressor unit which is currently available, and the cost of producing these new designs. Equipment incorporating these new designs could be made in the next few years. The requirements which will be imposed on air-conditioners and heat pumps sold in the State of California during the next 5 years are shown in table XI 1-2.

Looking further into the future, a number of systems have been proposed which could increase the COP of air-conditioning systems and heat pumps by as much as so percent. A series of designs being considered by the General Electric Corporation is indicated in figure XI 1-7. Researchers at G.E. believe that it would be possible to achieve an approximate 50-percent increase in the average COP of both heating and cooling for an increase in the initial cost of the unit of about *20* to 30 percent [7] It should be noted that performance can be improved by increasing low-temperature performance, high-temperature performance, or both, The speed with which these new units appear on the market will depend strongly on the company's perception of whether the public is willing to invest in equipment which can reduce their annual operating expenses over the long term. These attitudes, of course, may be influenced by legislative initiatives.

DIRECT FOSSIL-FIRED HEATING AND AIR-CONDITIONING EQUIPMENT

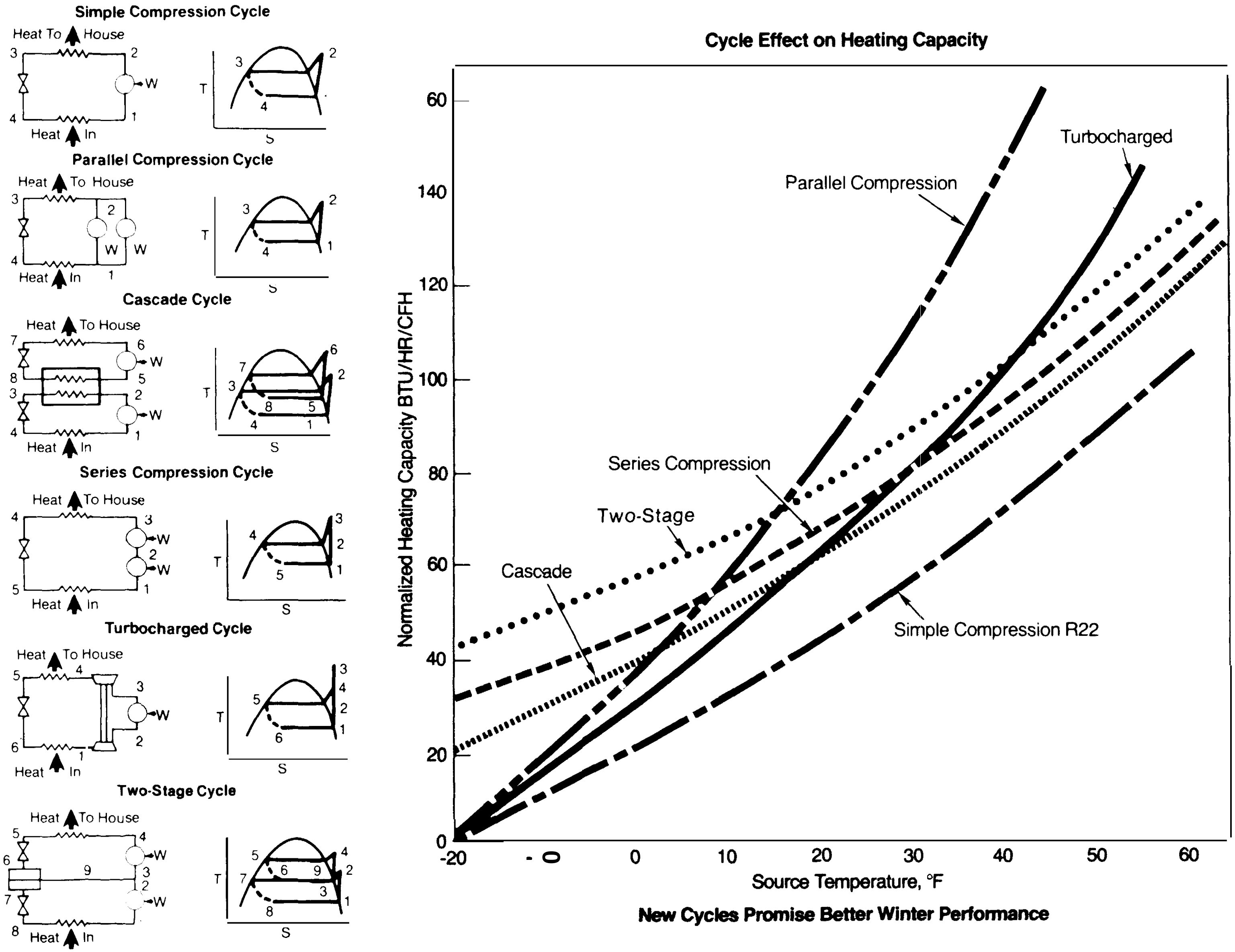
HEATING EQUIPMENT

The majority of residential and commercial buildings in the United States are heated with direct-fired oil and gas furnaces and boilers. There is considerable controversy about the typical operating efficiencies of these systems. One reason is that remarkably little is known about the performance capabilities of these systems in actual operating environments, and the literature in the area is filled with inconsistent information. Some indication of the difficulty can be seen by examining figure XI 1-8, which indicates the performance estimates made by a variety of different organizations. Performance undoubtedly varies with the age of the unit, its installation, its position in the building, and a variety of other variables which are difficult to hold constant. Another reason for the controversy is the inconsistency in the definition of efficiency. Until recently, the most common value quoted was the steady-state or full-load combustion efficiency, which is defined as the ratio of useful heat delivered to the furnace bonnet divided by the heating value of the fuel.[8] Typical values for direct-combustion furnaces are 70 to 75 percent; heat loss principally results from heated stack-gasses lost during combustion, This definition does not give a complete measure of the fuel required to heat a living space over the heating season. A more useful definition which accounts for this, and which is increasingly being used, is the seasonal performance factor or seasonal efficiency. This measure compares performances of various space-heating systems. It is defined as the ratio of the amount of useful heat delivered to the home to the heating content of the fuel the furnace used over the entire heating season. Typical gas furnaces have seasonal efficiencies in the range of 45 to 65 percent (figure XI 1-8). Seasonal efficiency accounts for all factors affecting the heating system's performance in its actual operating environ-

[7] Conley, General Electr c Corp , private communication, 1977

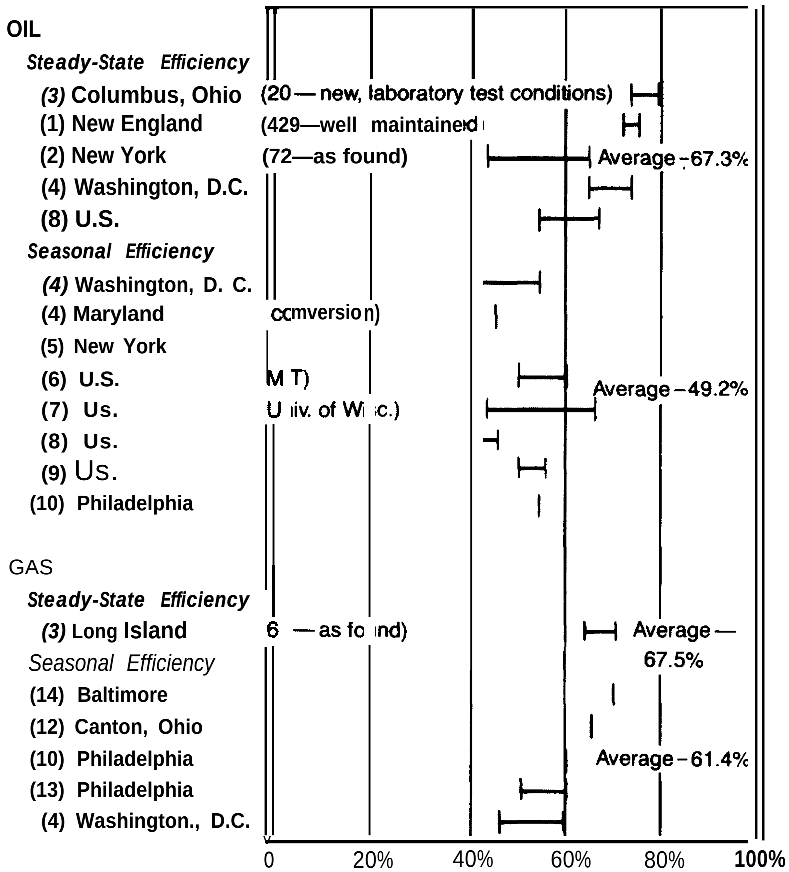
[8] Hise and Holman, op cit

Figure XII-7.—Some Examples of Proposed Advanced Heat-Pump Cycles



SOURCE: J. B Comly, et al., "Heat Pumps—Limitations and Potential," General Electric Company, Technical Information Series, Report No. 75CRD185, September 1975.

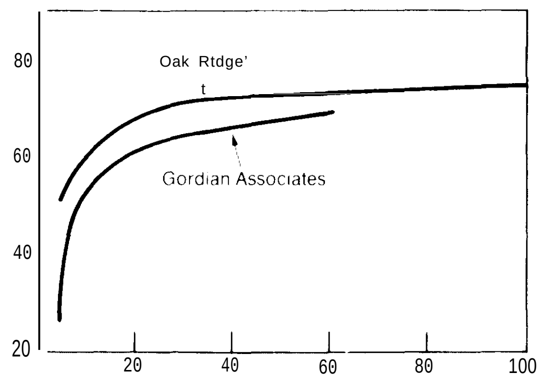
Figure XII-8. – Residential Heating Systems



SOURCE: J. H. Leggoe, "Seasonal Efficiency of Home Fuel 011 Furnaces" Philadelphia Electric Company Paper, Aug. 26, 1976.

ment. In addition to stack gas losses (the largest contributor) these factors include loss of heated room air through the chimney while the furnace is off, cycling losses, pilot light (gas furnaces only), and heat losses through the air distribution ducts when in unheated spaces.[9] Cycling losses are a result of operation at part loads, which causes heat to be lost in raising the temperature of the furnace before useful heat can be delivered to the living space. A recent measurement of this part-load performance is indicated in figure XI 1-9. The seasonal efficiency of many installations is reduced by

Figure XII-9.— Efficiency of Gas Furnaces



'G Samuels, et al , *MIUS Systems Analysis—Initial Comparisons of Modular-Sized Integrated Utility Systems and Convention/ Systems,* ORNL/H UD/MI US-6, June 1976, p 24.

installing units which are larger than necessary, meaning that the systems are always operating at relatively inefficient part-load conditions.[10]

In addition to the fossil fuel required for the burner, gas and oil furnaces and boilers require electric energy to operate fans and pumps. A typical small gas furnace will require about 13 watts per 1,000 Btu/hour capacity,[11] A large central boiler and hot-water distribution system will also require about 13 watts per 1,000 Btu/hour of heating capacity to pump heated water.[12]

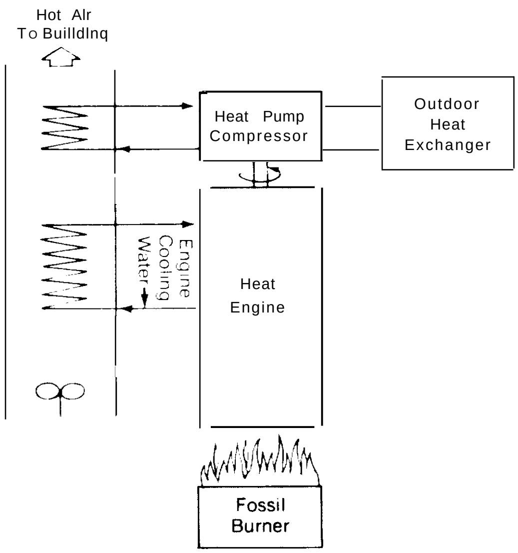
Potential for Improving Performance

The performance of gas furnaces can be increased by improving fan controls, using systems which preheat the air entering the furnace with the heat in the chimney, installing an electric ignition system to replace the pilot, and a variety of other rather straightforward changes in design, A recent study conducted by the Oak Ridge National Laboratory estimated that full-load combustion efficiencies of gas furnaces could be increased from 75 to 82 percent if these changes were implemented.[13] The combustion efficiency of oil-burning furnaces can also be improved by using improved burner heads and by ensuring that the burners are well maintained

An entirely different approach to the problem, using fossil fuels to operate a heat pump, has been under investigation for some time under the sponsorship of the American Gas Association. These designs burn fuel to operate a small onsite heat engine, which in turn drives the heat-pump compressor.

An advanced fossil fuel heating concept involves using the fuel to power a small heat engine directly coupled to the compressor or a heat pump (figure XI I-I O). The heat rejected by this engine can be used to maintain a source of heated water, which can then provide the heat pump with a source of thermal energy at a temperature higher than the ambient air. Studies of this approach

Figure XII-10.—A **Fossil-Fired Heat-Pump System**



SOURCE OTA

have been underway for some time in industrial laboratories and a number of projects in this area have been supported by the American Gas Association.

A variety of different heat-engine designs have been considered. Designs employing Stirling and Ericsson cycles are being examined by RCA, the N.V. Philips Corporation, Sun Power, Inc., Energy Research and Generation, Inc., and by the University of Washington.[14 15 16] A number of working systems have been designed and tested.

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[10] Hise and Holman, op cit

[11] Sears Fall-Winter Catalog, 1976, p 955

[12] Ibid

[13] Hise and Holman, op cit , p 3

[14] W Beale (Sun Power, Inc.), private communication, June 1976

[15] G Benson (Energy Research and Generation, Inc), *Thermal Oscillations*, presented at 8th I ECEC meeting, Aug 14, 1973

[16] W R Martini, *Developments in Stirling Engines*, presented to the Annual Winter Meeting of the American Society of Mechanical E ngineers, New York, N.Y , Nov 26-30, 1972

A number of advanced, gas-fired, heat-pump systems are being examined by the industry, with the support of DOE and the American Gas Association:* **

- An absorption system capable of producing both heating and cooling is being developed by the Allied Chemical Corporation and the Phillips Engineering Co.
- A concept which uses a subatmospheric gas turbine is being developed by the Garrett Air Research Corporation.
- A free-piston Stirling engine is being developed by the General Electric Corporation (the project received about $1 million from the American Gas Association and about $2 million from DOE in 1 977).
- Systems based on diesel engines and Rankine-cycle devices are also being examined.

The technology of the engines used to drive the compressors was discussed in greater detail in the previous chapter. An interesting feature of the heat-fired, heat-pump systems is that their performance does not decrease with temperature as fast as the performance of conventional heat pumps.

While working systems have been designed, commercial production is unlikely to begin for the next 5 to 10 years.

The performance of the engines being considered for use with fossil-fired heat pumps is discussed in greater detail in the section on *Solar Heat Engines* in this chapter.

Stirling and Ericsson cycle, free-piston devices may be able to achieve efficiencies in the order of 60 to 90 percent of ideal Carnot efficiency.[17] An engine operating between 1,4000 and 1000 F could therefore achieve a cycle efficiency of 40 to 63 percent. (ERG has reported a measured indicated efficiency which represents 90 percent of Carnot in a free-piston device operating i n roughly this temperature region.)[18] The Garrett Corporation has reportedly achieved a cycle efficiency of 38 percent, using a small regenerated gas turbine.

If it is assumed that seasonal performance factors for heat pumps can be in the range of 2.5 to 3.0, the overall system COP (or ratio of heat energy delivered to the living space to the heating value of the fuel consumed) of a heat pump combined with a heat engine which is 38 to 60 percent efficient can be in the range of 0.95 to 1.8, If waste heat from the engine is used, the effective COP can be as high as 2.2.

A 38- to 60-percent efficient engine combined with an air-conditioning cycle with a COP of 2.5 could achieve system COPS of 0.95 to 1.5. These coefficients cannot be compared directly with COPS of electric heat pumps. In order to obtain comparable "system efficiency" for an electric system, the electric COPS must be reduced by the efficiency of converting primary fuels to electricity and transmitting this energy to a heat-pump system. The average generating efficiency in U.S. utilities is approximately 29 percent, the average transmission losses, approximately 9 percent. Under these assumptions, an electric heat pump with a heating COP of 3.0 and a cooling COP of 2.5 would have an effective "system" COP of 0.79 for heating and 0.66 for cooling. There are a number of questions about the system's performance as an integrated unit, its reliability, safety, noise, ease of maintenance, etc., which can only be resolved after much more experience has been obtained.

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*"Advanced Gas-Fired Heat Pumps Seen Cutting Heating Bills in Half, " *Energy Users Report* #188, Mar 17, 1977, p 25

* * Paul F Swenson, "Competition Coming in Heat Pumps Gas-Fired May Be Best in Cold Climate, " *Energy* Research Reports, Vol 3, No 5, Mar 7, 1977, p 2

[17] Benson, 011 cit

[18] Ibid

"Patrick G Stone (Garrett Corporation), private communication, December 1976.

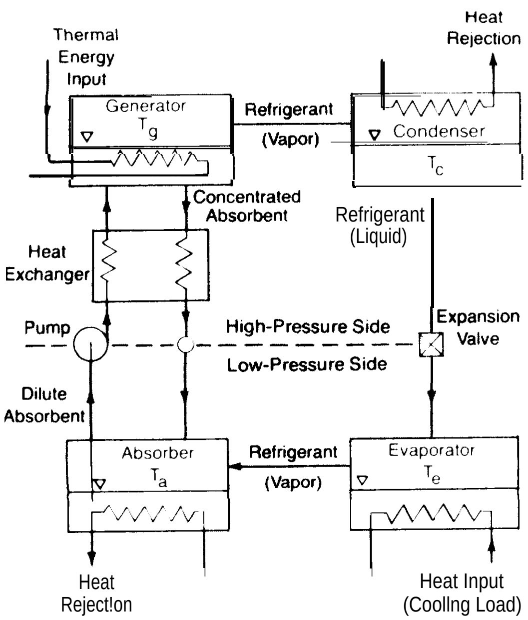
The devices do offer the prospect of a much more efficient approach to converting fossil fuels to useful space-conditioning,

A major question concerning any onsite system requiring oil or gas is whether these fuels will continue to be available at acceptable prices, or whether they will be available at al 1. The heat-engine devices just discussed could, at least in principle, be used in connection with a coal-burning, fluidized-bed boiler or other system, and thus might present a promising long-term alternative. One advantage of electric systems is that they may be able to use a greater variety of primary fuels than onsite systems.

ABSORPTION AIR= CONDITIONING

An "absorption-cycle" device for using direct thermal energy to operate air-conditioning systems has been available for some time. A standard cycle is illustrated in figure XI 1-11. The refrigeration cycle is very similar to cycles used in other types of air-conditioning systems (vapor-compression). A chilled liquid (usually water instead of a refrigerant) is permitted to expand and cool air. This water is then recompressed and the absorbed heat rejected into the atmosphere (this cycle is on the right side of figure XI 1-11). The absorption cycle accomplishes this recompression by absorbing the low-pressure water vapor in a concentrated salt solution. This concentrated solution is continuously produced in a distilling unit which is driven by the heat from the fuel.

Figure XII-11.—Basic Single-Effect Absorption Refrigeration Cycle



SOURCE: National Science Foundation.

The cooling performed by the absorption system can be separated into two distinct phases, and it would therefore be possible to store the concentrated salt solution for use when required by the cooling load. This concept is discussed further in chapter XI, Energy Storage. The major limitation to such a procedure at present is the cost of the working fluids,

An enormous amount of time and money has been invested in the search for better working fluids. Lithium bromide/water solutions are used most frequently at present. Ammonia/water solutions are also used.

Absorption units are inherently more expensive than electric systems 1) because of the larger number of heat exchangers required, and 2) because the unit's cooling towers must be large enough to reject both heat from the combustion process and heat removed from the space which was cooled. (In electric systems, the heat from generation is rejected at the electric generator site)

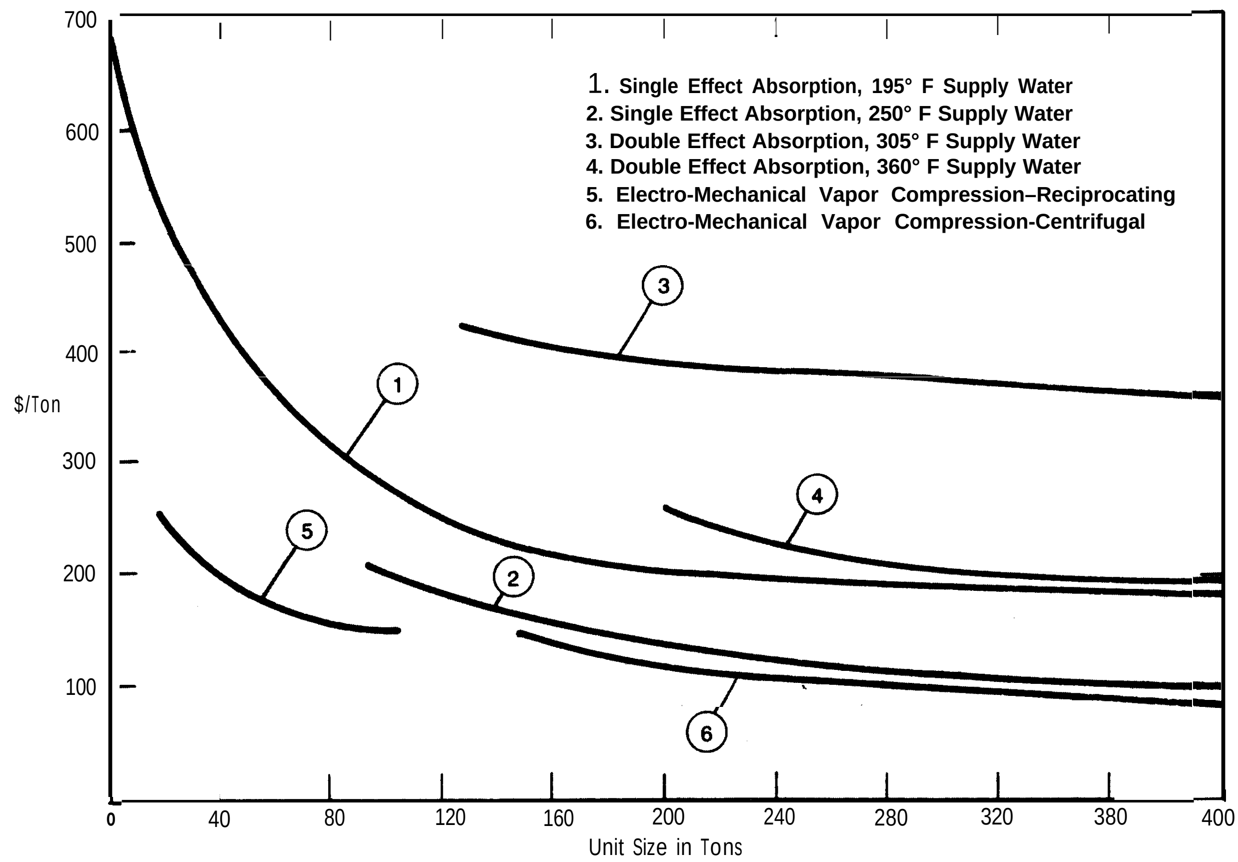
Double-effect units are also more expensive than single-effect devices because even smaller numbers are produced An analysis of the components required indicates that double-effect machines could cost about 20 percent more than single-effect units in the same capacity range. The prices shown in figure XII-12 indicate that double-effect units operating at 3050 F instead of 3600 F would cost nearly twice as much because capacity would be decreased. Little work has been done to produce an optimum design for low-temperature systems, and DOE is currently funding several projects in this area.

The only small absorption units now on the market are the Arkla single-effect devices, manufactured in 3- and 25-ton sizes. There are currently no small double-effect machines on the market. In the early 1960's, the Iron Fireman Webster Division of the Electronic Specialties Corporation briefly marketed a small (1 5-ton) lithium bromide, double-effect, absorption machine. The design was taken from work supported in part by the American Gas Association, and was apparently capable of achieving very high efficiencies. It was removed from the market after only a few hundred were sold, apparently because the company felt that it could not overcome problems with the system's reliability at a reasonable cost. The unit was sufficiently different from single-effect units that gas company maintenance personnel had difficulty repairing the devices. The unit at least demonstrated the feasibility of small double-effect units.

System Performance

The coefficient of performance (COP) of contemporary absorption air-conditioners is

Figure XII-12.— Estimated Refrigeration Unit Cost Per Ton, 12,000 Btu/hr(contractor's cost)*



*Industry Average- 1976 Costs

NOTE Prices do not include installation or subcontractor O&P costs

SOURCE prepared for OTA by H Corbyn Rooks April 1976 shown in figure XI 1-13. A typical single-effect device has a COP of 0.65 and double-effect units can have COPS of 1.1. These COPS must, however, be carefully qualified. (As in the case of fossil-fired heat pumps, these COPS should be compared with the "system" COPs of electric system s.)

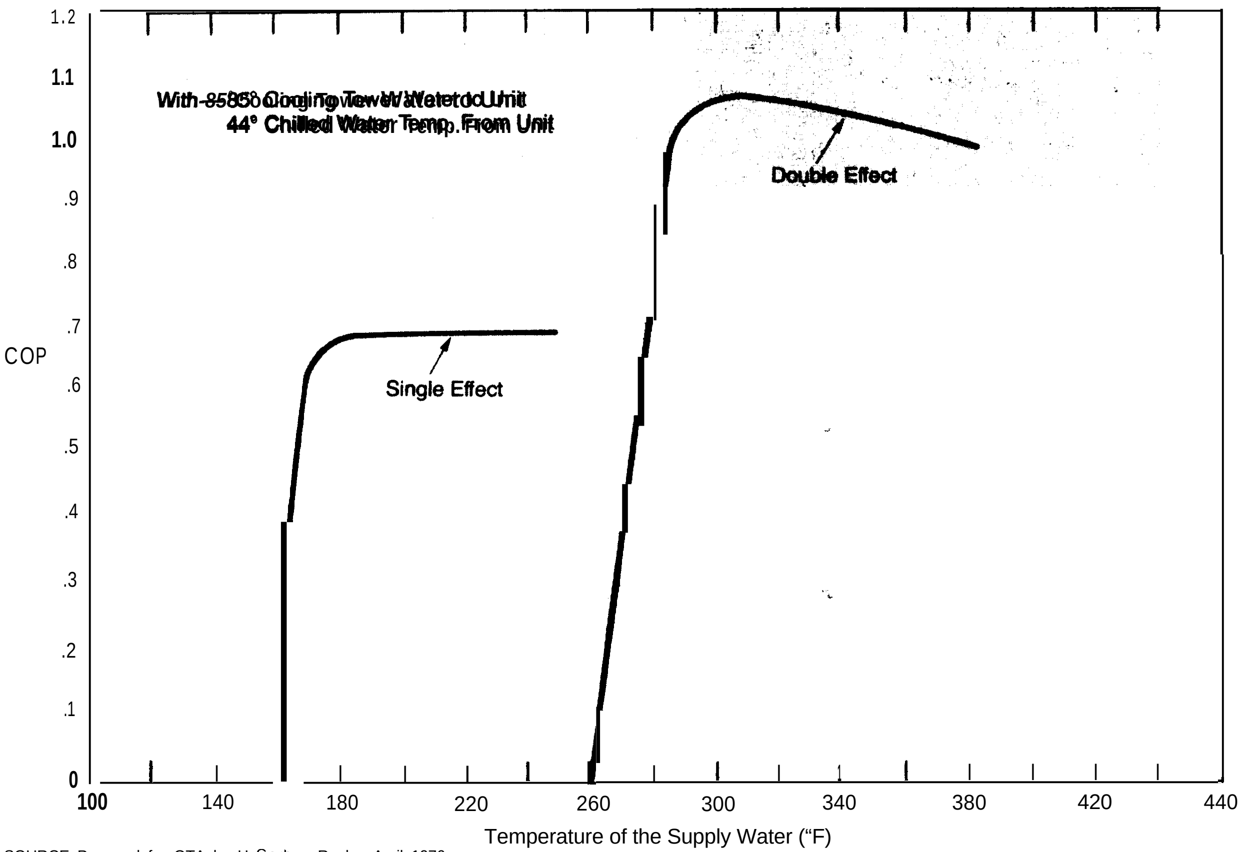
The COPS shown in figure XI 1-13 include neither the electric energy required to operate pumps which move chilled water to the building loads and cooling water to and from the cooling tower, nor the electricity required to operate the fan in the cooling tower. These ancillary units require about 0.14 kW per ton of cooling in a typical installation.[20]

[20] Samuels, et al , op cit , p 20

The COPS also do not include the inefficiency of the boiler which must be used when the absorption units are used with fossil fuels. Typical boilers used in such applications lose about 20 to 22 percent of the heating value of the fuel burned in hot gasses escaping up the chimney. The COPS shown in the figure would apply to units operated from solar-heated fluids or by steam generated by a waste-heat boiler connected to a direct or other heat engine. They must be reduced by 20 to 22 percent when used to represent the performance of direct-fired devices.

It is reasonable to expect that improvements in current designs could lead to significant improvements in performance. A new series of absorption units, soon to be marketed by Arkla, will probably achieve a COP greater than 0.7 for a single-effect de-

Figure XII-13.—Coefficient of Performance Versus Supply Water Temperature



SOURCE Prepared for OTA by H Corbyn Rooks, April 1976 vice with no substantial increase in price. An experimental machine, which was a modified version of the single-effect Arkla device, has been tested with a COP greater than 0.8.[21]

The Iron-Firemen double-effect device discussed previously was able to achieve a COP of 1.2 (not including boiler losses and electric energy requirements).[22] Some engineers believe that it would be possible to construct double-effect absorption devices with COPS in the range of 1.35.[23]

Absorption units have good performance at partial loads because their effective capacity can be varied by simply changing the rate at which the salt solutions are pumped through the systems. This type of control works until the load falls to about 35 percent of the peak load, at which point substantial inefficiencies are experienced.

CONVENTIONAL GAS AND ELECTRIC WATER HEATERS

Residential hot water heaters are very inefficient.[24] A gas water heater has a COP of about 0.50, and an electric water heater a COP of about 0.75.[25,26,27] Better insulation and other improvements could increase the COPS of future electric units to 0.85 and the COPS of gas units to 0.80.

The efficiency of water heaters varies somewhat as a function of loads, but for simplicity it is assumed that water heaters have a constant "average" efficiency.

OPERATING COSTS

The costs of operating conventional heating and cooling equipment (exclusive of fuel costs) are not well documented, and no extensive study has been conducted on the subject. The estimates used in later analyses are shown in tables XI I-3 and XI 1-4. The costs used in this study were taken from the costs of purchasing a service and maintenance contract for equipment installed in the Washington, D. C., area. The actual costs will vary as a function of geographic location, quality of the equipment, location of the equipment in the building, design of the systems, etc. The costs must be considered conservative since the sellers of maintenance contracts must increase the actual maintenance costs by a margin sufficient to cover overhead and profit requirements.

Table XII-3. — Average Cost of Maintenance Contracts for Residential Heating and Cooling Equipment

	Annual cost
Gas furnace and eleotric air-conditioning	$60
Air-to-air heat pump	$50
Baseboard electric heat and window air-oonditioners	$30

SOURCE Gordian Associates, Inc Evaluation of the Air-to-Air Heat Pump for Residential Space-Conditioning. April 1976

[21] Joseph Murray, Chief Engineer of Applied Systems, Airtemp Corporation, private communication, Sept 23,1976

[22] Joseph Murray, private communication, 1977

[23] G.C Vliet, et al , A Thermodynamic *Approach to the Developments of a More Efficient Absorption Air-Conditioning System*, University of Texas at Austin – Center for Energy Studies

[24] Gillman, op cit

[25] APS, *Efficient Use of Energy*, p 83.

[26] J. J. Mutch, Residential *Water Heating, Fuel Conservation Economics and Public Policy*, pp. 8 and 55

[27] Arthur D Little Co., Study of Energy-Savings Options for Refrigerators *and Water Heaters*, draft, pp S-12,1 3,14

Table XII-4. —Cost of Maintaining Commercial Heating and Cooling Equipment* (Parts and Labor)

	Dollars per year	Dollars per year per 10^6 Btu/hr. capacity
Low Rise		
Heating (10^6 Btu/hour)		
Gas	$1,000	$1,000
Oil	1,250	1,250
Electric	1,000	1,000
Cooing (50 tons)		
Gas	3,8OO-4,5OO	6,300-7,500
Electric	3,000-3,6OO	5,000-6,000
High Rise		
Heating (2 units@ $2x10^6$ Btu/hour)		
Gas	2,000	500
oil	2,500	625
Electric	2,000	500
Cooling(200tons)		
Gas	5,000-6,000	2,000-2,500
Electric	4,000-5,000	1,700-2,000
Shopping Center		
Heating (2 units@ $8x10^6$ Btu/hour)		
Gas	2,500	150
Oil	3,000	190
Electric	2,500	150
Cooling(2000tons)		
Gas	19,000	800
Electric	15,000	600

*Actual costs will vary greatly as a function of equipment quality, installation, building features, etc Costs based on "very rough" estimates of Robert Noyes of R E Donovan Co, Inc a service company in the Wasthington DC area Sept 23 1976

ADAPTATION OF CONVENTIONAL EQUIPMENT TO SOLAR POWER

Conventional heating and cooling equipment can be integrated with solar energy **in two basic ways: 1) electricity or mechanical energy generated by solar energy devices can be used to supplement electricity purchased from a utility, and 2) direct use of thermal energy generated by solar devices can provide a source of thermal energy for liquid and air-heat pumps, for absorption air-conditioning, forced-air heating, and to heat domestic hot water.**

The direct **use of solar-heated fluids for space heating or for the heating of hot water**

requires no sophisticated equipment, and the problems of designing these systems are discussed elsewhere.

SOLAR HEAT ENGINES

Direct use of solar-heated fluids can operate heat engines such as Rankine cycle turbines or Stirling engine devices which are coupled mechanically to heat pumps and air-conditioners. The direct-drive systems have a substantial theoretical advantage over systems operating from solar-generated electricity in that the losses associated with a motor and generator can be avoided. This can be a substantial gain, since typical efficiencies of small motors and generators are in the range of 80 to 90 percent and combined losses can amount to 30 percent. Total energy systems, which use the solar-powered engine to drive both a generator and a heat pump, could be driven directly from utility electricity when solar energy is not available by using the electric generator as a motor to drive the compressor. Direct-drive systems have a potential disadvantage if they cannot be designed as a single-sealed unit, since seals on rotating shafts could reduce overall system reliability. It may be possible to develop completely sealed engine-compressor units, but this will require a lengthy development program,

All of the heat engine alternatives are discussed in detail in the chapter discussing the conversion of solar energy into electricity. The operating characteristics of conventional heat pumps and air-conditioners integrated into solar energy designs using direct-drive connections will need adjustment to eliminate the inefficiency of the motors used in conventional systems. For the purposes of the calculations which follow, it is assumed that the motors used on conventional systems are 80 percent efficient. Systems connected electrically are assumed to be identical to conventional equipment, and conventional performance characteristics are assumed.

SOLAR ABSORPTION EQUIPMENT

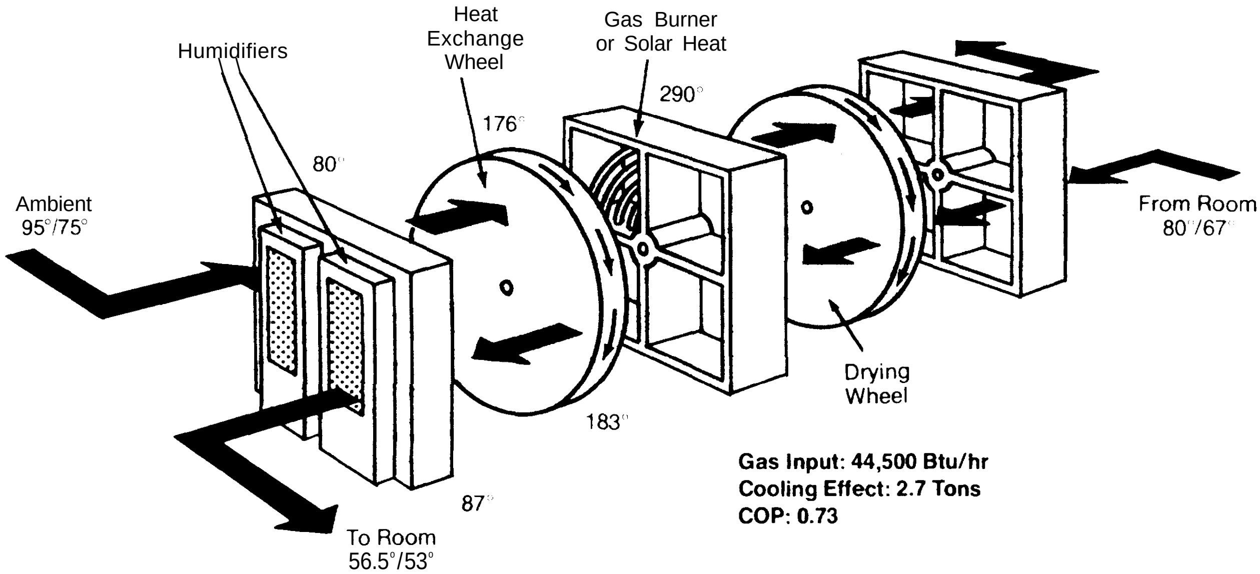
Absorption cooling equipment can be easily converted for use with solar-heated fluids, and the modifications being suggested for high-performance solar applications should not require major design changes. As a result, absorption equipment will probably represent the majority of units used in solar air-conditioning systems in the near future. The water sent to the absorption generator can be heated either from a conventional boiler or from a solar collector. The coefficients of performance used for solar absorption equipment will be the same as those used for the steam-driven absorption equipment, since no boiler losses are involved.

The Adsorption Cycle System

The adsorption cycle was originally developed by Carl Munters of Stockholm, and is often known as the Munters system. The system is basically a desiccant system, drying the air with various kinds of salt crystals, silica gels, or zeolite. Heat and moisture are typically exchanged between an exhaust airstream and a supply airstream using a heat exchange wheel and a drying wheel as shown in figure XI 1-14. The air is taken from the room and passed over the drying wheel which contains the desiccant. In passing through this wheel, the air is dried and heated to about 180°F. It then passes through the heat exchange wheel, where it cools to near room temperature. The air is finally passed through a humidifier, where it picks up moisture and cools to 550 to 600 F. The exhaust airstream takes ambient air and humidifies and cools it slightly to keep the heat exchange wheel as cool as possible. After passing through the heat exchange wheel, the air is still not hot enough to drive the moisture out of the drying wheel, so additional heat from a solar or gas source is added. This hot air then passes through the drying wheel, where it evaporates moisture from the desiccant, and the moist, heated air is exhausted to the atmosphere,

Its advantage is that it takes no refrigeration unit, but the wheels are large and require power to drive. After years of development, problems still exist with desiccant systems, including the desiccant, the seals between the supply and discharge airstream on the rotating wheels, and the wet pads. Variations of this adsorbent system are being properly supported by DOE. It has advantages, but still requires development prior to demonstration.

Figure XII-14.—An Adsorption Chiller



SOURCE Based on a drawing by W F Rush, statement relative to H R 10952 (Institute of Gas Technology, Illinois Institute of Technology, Chicago, Ill) Nov 14, 1973

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