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MIUS TECHNOLOGY EVALUATION

PRELIMINARY SUBSYSTEM RECOMMENDATIONS for NEAR-TERM CONCEPTS

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U.S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT

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MODULAR INTEGRATED UTILITY SYSTEMS

improving community utility services / supplying electricity, heating, cooling, and water / processing liquid and solid wastes / conserving energy and natural resources / minimizing environmental impact

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CONTENTS

FOREWORD

The Department of Housing and Urban Development (HUD) is conducting the Modular Integrated Utility System (MIUS) Program, which is devoted to development and demonstration of the technical, economic, and institutional advantages of integrating the systems for providing all or several of the utility services for a community. The utility services include electric power, heating and cooling, potable water, liquid waste treatment, and solid waste management. The objective of the MIUS concept is to provide the desired utility services consistent with reduced use of critical natural resources, protection of the environment, and minimized cost. The program goal is to foster, by effective development and demonstration, early implementation of the integrated utility system concept by the organization, private or public, selected by a given community to provide its utilities.

This report represents an initial attempt to illustrate some possible combinations of the major components and subsystems that might find application in MIUS. The study was originally completed in 1973, and selections of major components, subsystems, and integration concepts reflect the status of MIUS technology evaluations at that time. The number of possible combinations which could be analyzed is very large (over 100,000 combinations), so only a few examples of complete MIUS concepts are described. These examples are not necessarily the only "prime" candidates for MIUS, but have been selected to illustrate and describe the possible variations of the concept that could be used. Final selection of the subsystems and the method of integration should be made on the basis of local conditions such as topography, geology, availability of a site for approved liquid waste effluent disposal, local effluent standards, MIUS heat balances, population density, source of potable water supply, climate, availability of fuel, etc. Future documentation, including model analysis and systems studies, will be made to further refine the MIUS concept, and to assess its resource conservation aspects and environmental impacts. Thus, this document is a brief summary of the types of technologies which might be incorporated in a MIUS and an introduction to the ways in which subsystems could be integrated.

Under HUD direction, several agencies are participating in the HUD-MIUS Program, including the Energy Research and Development Administration, the Department of Defense, the Department of Health, Education and Welfare, the Department of the Interior, the Environmental Protection Agency, the National Aeronautics and Space Administration, and the National Bureau of Standards.

Drafts of technical documents are reviewed by the agencies participating in the HUD-MIUS Program. Comments are assembled by the NBS Team, HUD-MIUS Project, into a Coordinated Technical Review. The draft of this publication received such a review and all comments were resolved with HUD.

ABSTRACT

The Modular Integrated Utility System (MIUS) Program, under the overall direction of the Department of Housing and Urban Development, is directed towards the development, demonstration, evaluation, and ultimate widespread application of a new option for providing utility services to communities. The MIUS concept is to provide developing communities with energy, water, and sanitary services from a combined onsite utility plant. A total-system approach is used to balance the requirements for environmental quality, conservation of resources, and low total cost.

The analysis reported herein is one of a series of evaluations of utility technologies applicable to MIUS. A few examples of what major components and subsystems might be incorporated into a typical MIUS are described and discussed together with possible methods of integration. Maximum effort has been made to include all possible community services; power generation, space heating and cooling, domestic hot water, potable water, fire-protection water, and liquid and solid waste treatment and disposal. In some of the examples cited complete thermal integration has not been obtained, and in certain cases integration of the liquid waste subsystem is merely the use of treated effluents for fire-protection or cooling tower makeup. The final selection of the various subsystems used in a MIUS will depend on the climate, population density, total population, consumer mix and demands, local geology and topography, and local resources such as water, natural gas, oil, and land. Schematic diagrams are provided of several MIUS configurations; however, it must be pointed out that these are not necessarily the "optimum" or "best" configurations. More detailed model studies are a part of the MIUS program and will be documented at a later date. The main purpose of this report is to illustrate how MIUS can be assembled using available technologies, and what some of the alternate possibilities are.

INTRODUCTION

The Modular Integrated Utility System (MIUS) concept consists of an onsite combined package plant, smaller than conventional plants, to provide communities of limited size with electricity, heating and air conditioning, water and waste treatment, and waste disposal. The objective of the MIUS is to provide utility services consistent with reduced use of natural resources, protection of the environment, and minimized cost. A MIUS might be sized to accommodate several hundred or a few thousand multifamily dwelling units, nearby single-family housing, and associated commercial facilities. The MIUS is modular in that it can be located near appropriate users and installed in phase with the actual demands of community development or redevelopment. The MIUS employs an integrated systems approach whereby some resource requirements of one service are met by using the effluent of another.

The selection of components and subsystems and the examples of MIUS concepts presented are based on the status of preliminary technology evaluations and model analyses[1-6] at the time of this study (1973). Although the concepts selected are for near-term application (that is, proven technologies available in 1973), a few longer term applications are discussed. The type of utilities provided, and the technologies used, will depend on many factors and must be tailored to a specific application. Some of the factors which will influence the selection of the various subsystems of a MIUS are climate, population density, total population, consumer mix or demand, local geology, and local resources such as water, natural gas, and land. It is assumed that all utilities (electricity, heating, air conditioning, potable water, fire-protection water, and solid and liquid waste collection and disposal) are provided onsite. However, it should be understood that the eventual disposal of solid waste and treated liquid waste may be offsite. Storm water treatment and communication systems are not included in the MIUS. Figure 1 is a material flowsheet for a MIUS installation.

Although economic comparisons between MIUS and more conventional utility systems will likely determine the extent of application of the MIUS concept, the purpose of this study was to describe current

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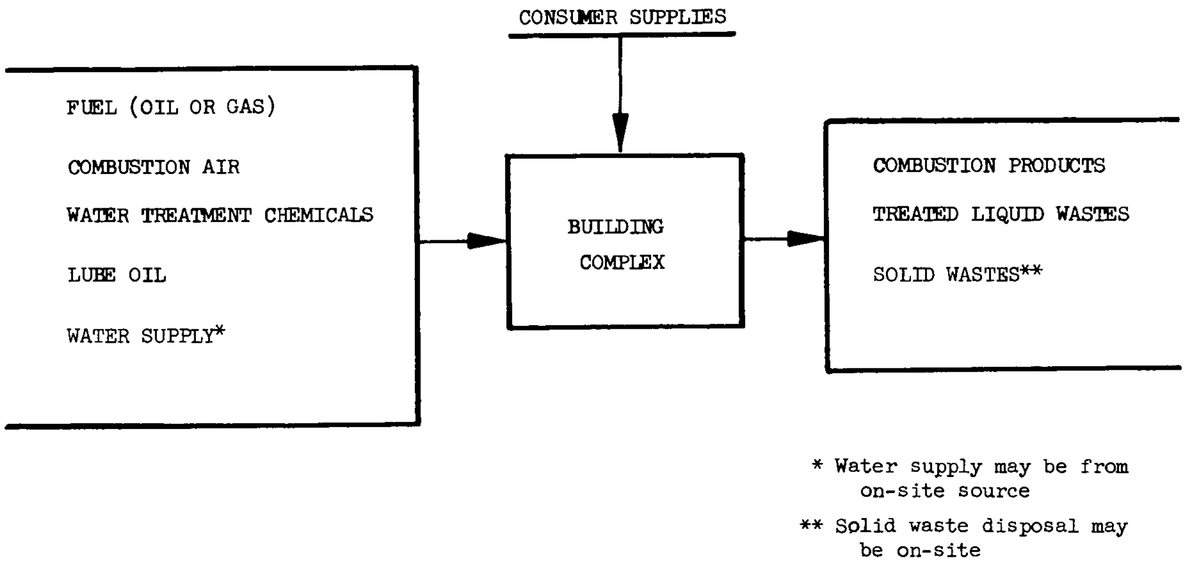

Fig. 1. Material flowsheet for MIUS installation.

technologies suitable for MIUS and to illustrate methods of integration which show promise of conserving resources, and which may now or in the near future be economically competitive with more conventional systems.

Another consideration which has an effect on the overall economic viability of the MIUS concept is the number of installations in a locality. It is implied throughout this study that the MIUS may be one of several, or many, either dispersed in an area or supplying services to sections or villages of a new community. The installations are either operated by a local utility or, at a minimum, are serviced by a local utility or service organization.

In general, sections which follow list the subsystems that may be used and discuss the effect of the various parameters (total population, population density, etc.) on the design of the subsystems. In most cases, the final selection of the various subsystems will depend on more detailed information concerning the consumers and the resources available at the selected site, and local conditions and environmental regulations.

SUBSYSTEM CONSIDERATIONS

Power Generation and Heat Recovery

The electric demand (including the plant auxiliaries required for heating and air conditioning) for a housing complex of 100 to 3000 dwelling units will range from about 300 to 6000 kW, respectively. There will also be some additional demand for any associated commercial facilities. The number and size of the prime movers used in a MIUS for such a complex will depend not only on its size, but also on such factors as the degree of reliability required, whether one has a tie-in to a local power grid, and the type and competence of the service facilities available. For an installation independent of any outside source and requiring a high degree of reliability, there should be a minimum of two spare generating units. This would allow for a malfunction of one unit while another is out of service for routine maintenance. There are several ways in which the installed capacity can be reduced. For localities with several MIUS installations serviced by one organization, it may be possible to use portable equipment as spares. Also, in new community developments, the MIUS installations could be tied together to form a local grid so that the excess capacity at each installation could be reduced. Installed MIUS generating capacity could also be reduced in installations connected to a local electric utility company grid. The type of grid connection could range from one providing only standby emergency power to one capable of handling electricity flow to or from the grid. The feasibility of grid connection depends on local utility company practices and technical and economic tradeoffs outside the scope of this analysis.

For the lower end of the complex size range, the prime movers would be about 150 to 200 kW; while for the upper end, they would be in the range of 1000 to perhaps 1500 kW. For this size equipment and for the ratio of the heat-to-electrical demand and usage typical of dwelling units, the internal combustion piston engines, either gas-fueled spark ignition or diesel or dual fueled compression ignition, are recommended. They have the best fuel economy and lowest capital cost of the equipment available in this size range and have a long history of successful operation for this application.[1] The smaller engine-generators (less than about 600 kW) would be high-speed (1200 rpm) units, while the larger engine-generators would operate at 900 rpm or perhaps 720 rpm. A more detailed technology evaluation of gas or oil fueled prime movers for MIUS applications is given in ref. 1.

The presently available internal combustion engines have emission characteristics that appear to be acceptable. The emission rate and dispersion of atmospheric pollutants from MIUS and conventional system models have been extensively investigated in Sect. 4 of ref. 7, and in ref. 8.

The primary advantage of onsite electrical power generation is the ability to use prime mover waste heat for such purposes as space heating, space cooling, domestic hot water, or other process needs. The ultimate distribution of the heat input to an engine varies from model-to-model and also depends on the engine size and operating speed. A rough breakdown is about 30% to electrical output, 30% to the jacket water, 30% to the exhaust, and 10% to the lube oil and ambient air. Most of the jacket water heat and about one-half to two-thirds of the exhaust heat can be recovered. In most "total-energy" plants built to date, the heat is recovered as steam at about 240 to 250°F from ebullient systems or 240 to 250°F water from forced convection systems.[9] Very few attempts are made to recover the heat from the lube oil or aftercooler of turbocharged units.

In the past, the design of heat-recovery equipment has been relatively straightforward; the 240 to 250°F water or steam was used in a heat exchanger to heat water for space and domestic water heating, or passed directly through an absorption chiller to produce chilled water for air conditioning.[2] The recent introduction of the two-stage or double-effect absorption chiller may complicate the heat-recovery system.[2] These new units require heat at about 350°F rather than the 240°F typical of single-stage units. The two-stage absorption machine limits the heat available for air conditioning to that recovered from engine exhaust, which is 30 to 40% of the total recovered. It would also require a dual heat recovery system (i.e., a separate water or steam loop would be required for the absorption chiller). In addition to these problems, the two-stage absorption units would reduce the amount of heat recovered from the exhaust. With single-stage machines, the engine exhaust temperature is usually cooled to 300 to 350°F. For the two-stage machine and the same size heat exchanger in the exhaust system, the exhaust gas temperature would be 400 to 450°F. The resulting loss in heat recovery will depend on the type of engine used. For example, diesel engines, because of their excess combustion air requirements, have an engine exhaust temperature of 750 to 850°F, while gas engines normally run with an exhaust temperature of 1050 to 1150°F at full load.[1] Thus, the higher temperature requirements of the two-stage absorption machine will have a larger effect on diesel engine systems than on gas engine systems.

Whether two-stage machines are worth the cost and complexity that they add to heat-recovery equipment will also depend on the amount of heat available for air conditioning during the summer. Because of the poor coefficient of performance of an absorption machine,[2] the first priority for the use of recovered heat is for heating needs (i.e., domestic hot water or other process needs). Only excess heat that would normally be dumped is used for the absorption units. There is also the additional problem that the heat from the engine jacket (at 240°F) may be more than that needed for heating purposes. Normally, this would be used for air conditioning; however, with the higher temperature requirements for the two-stage units, this heat may be useless and have to be dumped. It is certainly not obvious that the better efficiency of two-stage absorption machines will result in better waste heat and therefore better fuel utilization for a MIUS installation. The ultimate balance of economics and fuel use will depend on the size of the installation and the relative demand for electricity, heating, and air conditioning. These, in turn, will depend on the total population served, climate, population density, etc.

Regardless of the type of absorption system selected, it is desirable to use a package approach for the heat recovery equipment — with one heat recovery package for each engine. If single-stage absorption units are used, then a commercially available ebullient (or latent heat) type of package is recommended. If two-stage machines appear attractive for the application, then a considerable amount of detailed study will be required. With two-stage absorption chillers, an ebullient system would be required to operate at two pressure levels; engine exhaust heat recovery would be at 350°F (135 psia) and jacket water heat recovery would be at 250°F (30 psia). Any mixing of the two systems, which may result if the demand for heat exceeded that available from the jacket water, would require additional pumps and power to feed the condensate from the jacket heat recovery loop to the exhaust heat recovery loop. Although such a system has not been investigated, an alternate approach would be a forced-convection system operating at perhaps 150 psia. This would allow mixing of the two loops without additional pumps and would simplify the operation and control of heat recovery equipment. However, this would require an engine jacket that would withstand the higher pressure and might also lead to hot spot problems.

In summary, internal combustion piston engines are recommended for the prime movers. Although further considerations should be given to various heat-recovery systems, a 240 to 250°F ebullient system, suitable only for the single-stage absorption chillers, now appears to be the better selection. A schematic diagram of an engine and ebullient heat recovery-package is shown in Fig. 2, and a typical flow diagram for a MIUS power plant is shown in Fig. 3.

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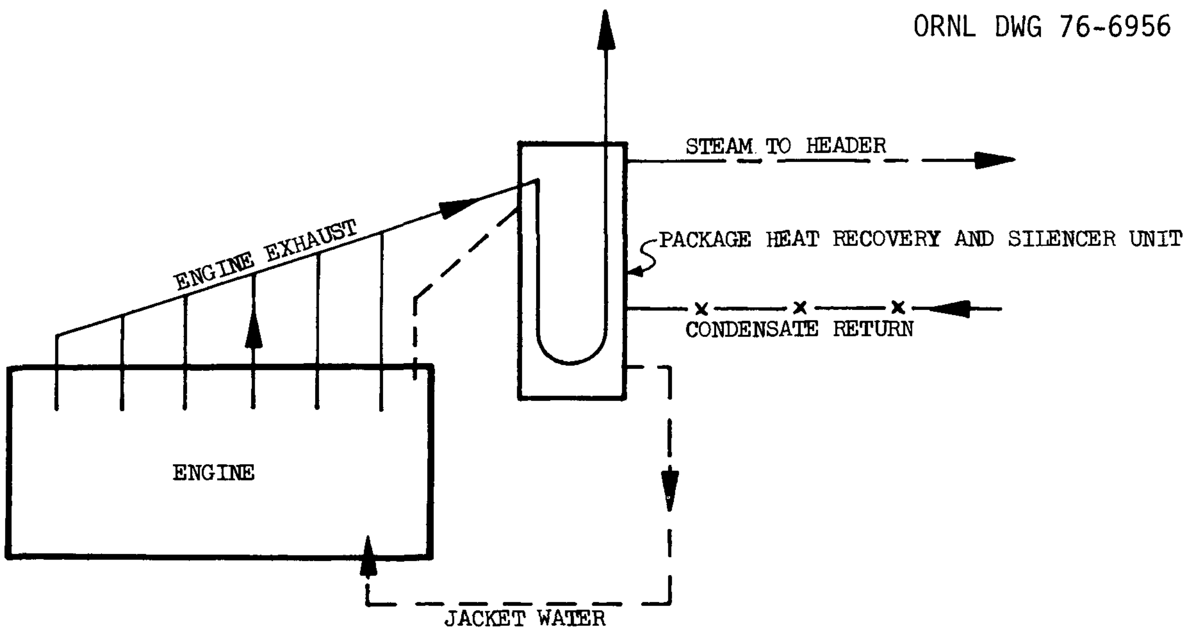

Fig. 2. Schematic diagram of engine and ebullient heat-recovery package.

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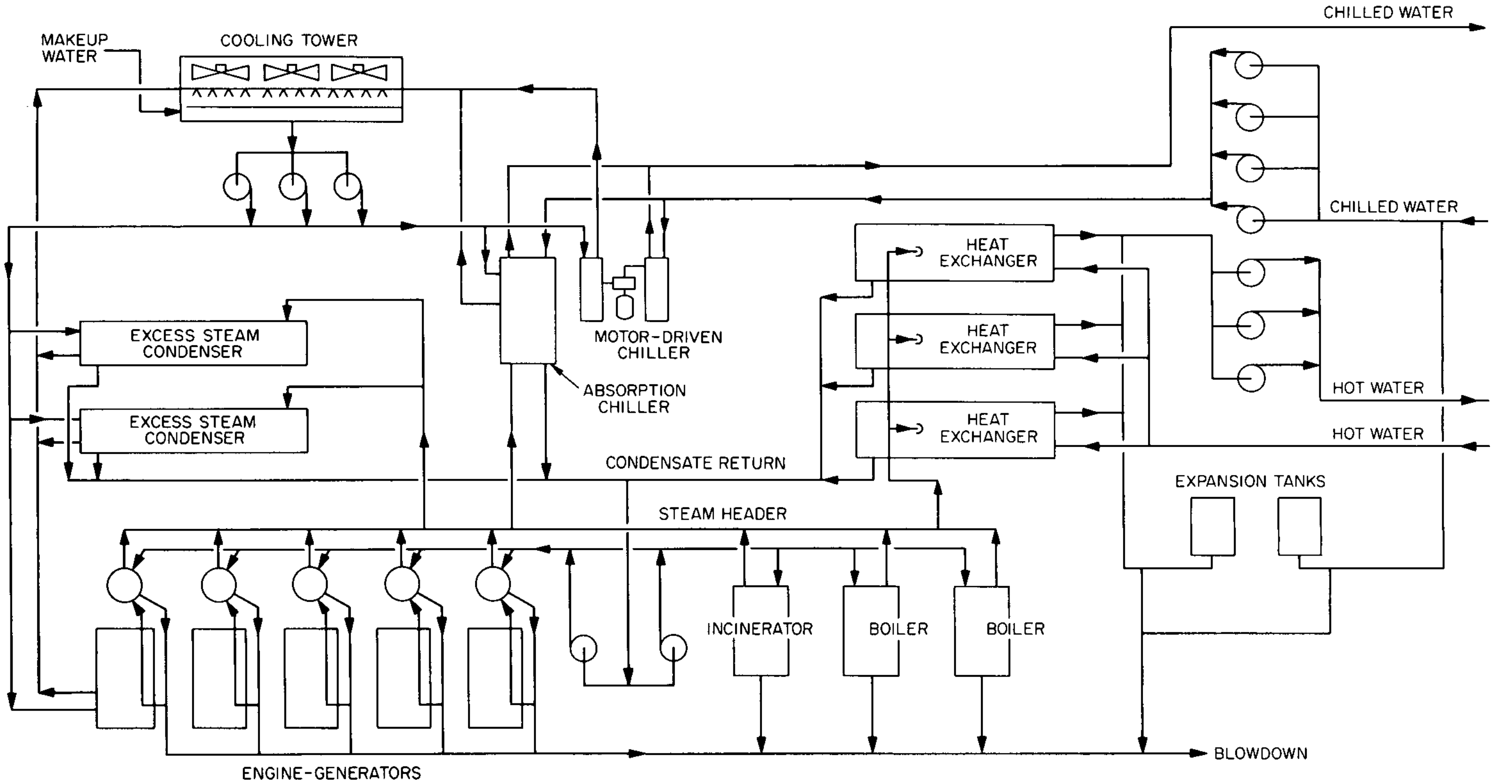

Fig. 3. Typical flow diagram for MIUS power plant.

Space Heating, Space Cooling, and Domestic Hot Water

The type of space heating, space cooling, and provisions for domestic hot water for the building complex is very dependent on the type and density of the residences, the type of commercial facilities serviced, climate, and local topography and geology. In fact, the feasibility of the "total energy" aspect of the MIUS depends on being able to distribute the heat (or services derived from the heat) recovered from the prime movers in an economical manner. Assuming a demand for heat, then the basic question is one of density of heat utilization. The integrated utilities concept adds another dimension to the total energy system approach in that one can consider multiple use of utility equipment or systems. This feature is discussed in more detail in following sections.

In order to illustrate both the problems and possibilities of the MIUS, let us assume a consumer mix typical of a section or village of a new community. The village concept is usually built around a central commercial and high-density residential (high-rise and garden apartment) area. Surrounding the central core is an area of medium density residences with apartments and townhouses. The outer area of the village has a low-population density consisting of townhouses and single-family homes. Thus, the manner in which services are provided will probably be some combination of the systems normally used.

There are many ways in which space heating and cooling and heat for domestic hot water may be provided. Those methods considered in this study for apartments, townhouses, individual homes, and commercial buildings are listed in Table 1. It should be emphasized that the systems listed in Table 1 are based on the premise that both space heating and cooling are provided to the apartments simultaneously (i.e., some apartments can be heated while others are being cooled).

Figures 4 through 8 show schematic flow diagrams for several of these systems. Figure 4 shows a simplified flow diagram of a four-pipe district heating and cooling system for a building. Figures 5, 6, and 7 show various heat pump cycles applicable to a MIUS installation. Figure 5 is for an air-to-air unit, while Fig. 6 is for a water-to-air unit. Both of

Table 1. Methods for Providing Space Heating and Cooling and Domestic Hot Water

Space Heating	Space Cooling	Domestic Hot Water
1) Central plant with two-pipe hot water distribution system. 2) Some space heating may be as follows: a) Apartment building heaters using gas, oil, or electricity. b) Apartment building heat pumps (air-to-water or water-to-water) with supplemental heat from gas, oil, or electricity. c) Individual apartment or home heaters using gas, oil, or electricity. d) Individual apartment or home heat pumps (air-to-air or water-to-air) with supplemental electric heat.	1) Central plant with two-pipe chilled water distribution system. 2) Some space cooling may be as follows: a) Apartment building compressive air-conditioning system. b) Apartment building heat pumps (air-to-water or water-to-water). c) Individual apartment or home compressive air conditioning units. d) Individual apartment or home heat pumps (air-to-air or water-to-air).	1) Heat supplied from central plant through a two-pipe hot water system. 2) Building hot water heater using gas, oil, or electricity. 3) Building hot water heater with preheating from heat pump compressor discharge and supplemental heat by gas, oil, or electricity. 4) Individual apartment or home hot water heaters using gas or electricity. 5) Individual apartment or home hot water heater with preheating from heat pump compressor discharge and supplemental heat by gas or electricity.

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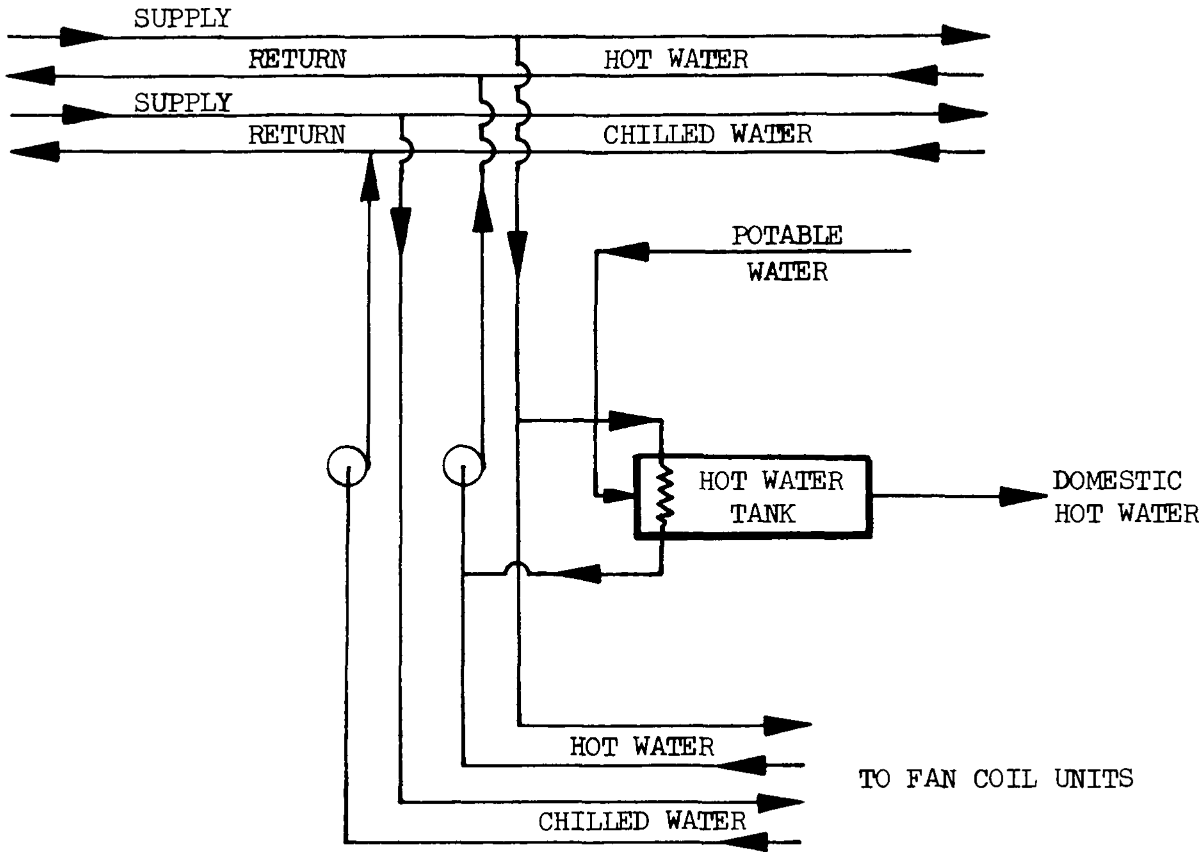

Fig. 4. Simplified flow diagram of a district heating and cooling four-pipe system for a building.

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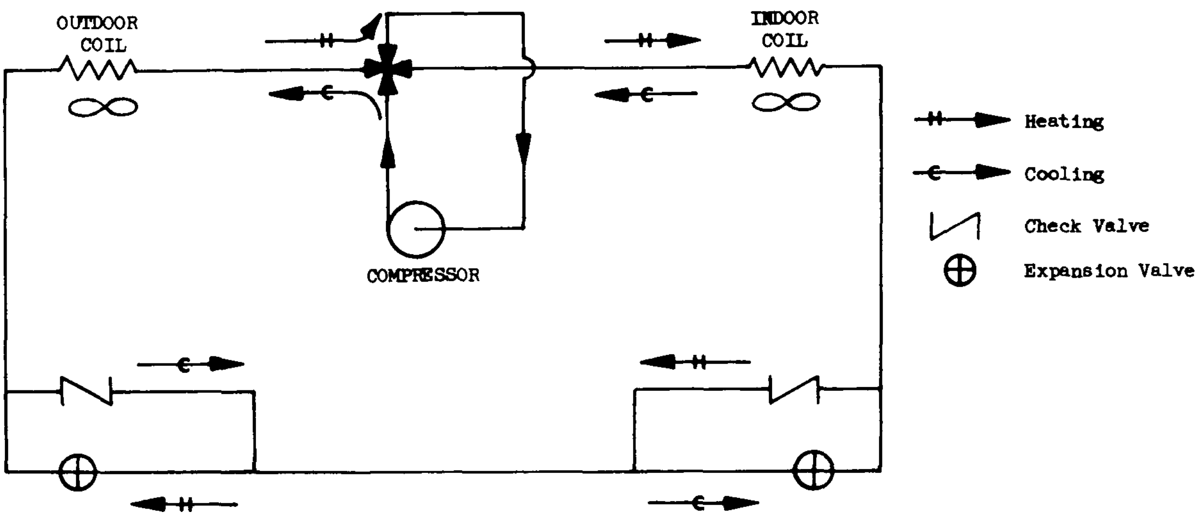

Fig. 5. Air-to-air heat pump flow diagram with refrigerant reversing valve.

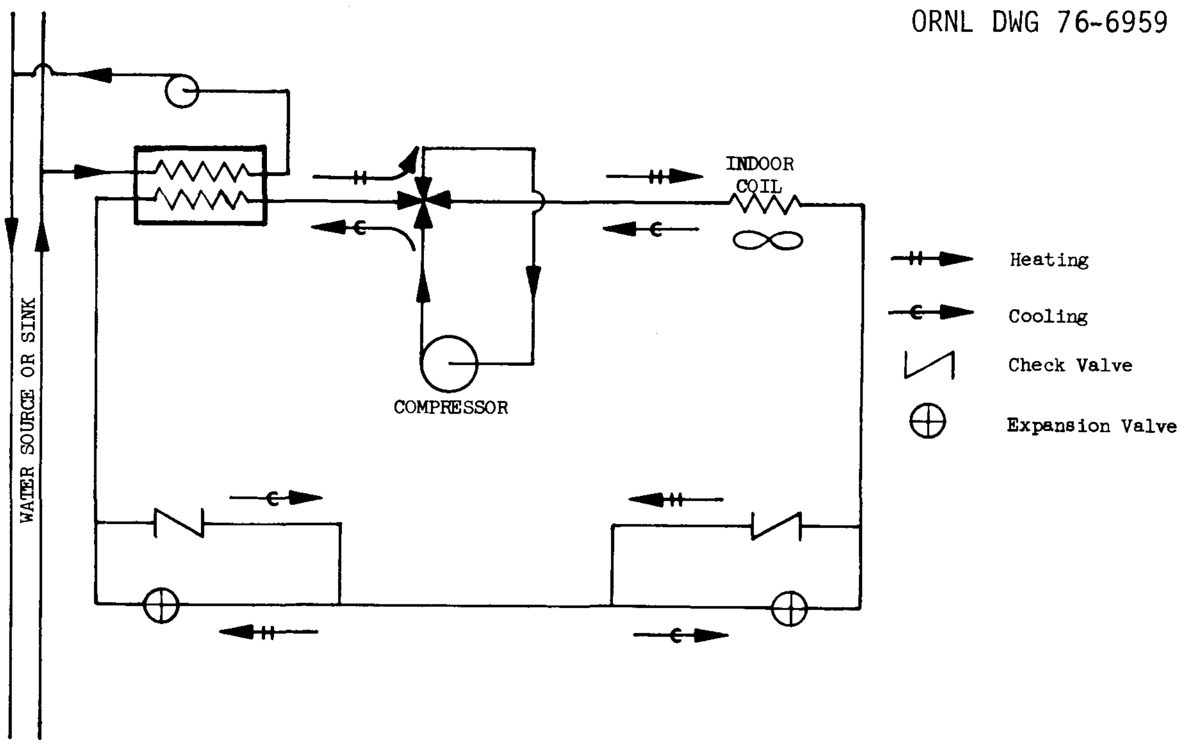

Fig. 6. Water-to-air heat pump flow diagram with refrigerant reversing valve.

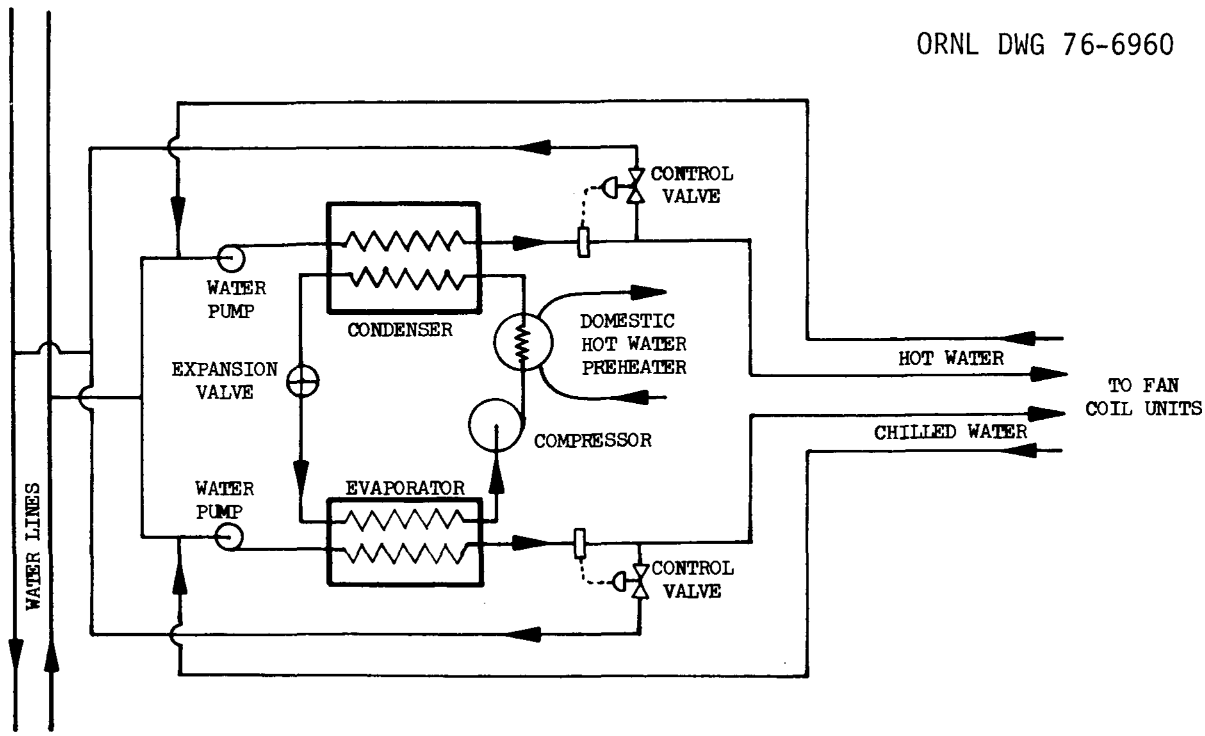

Fig. 7. Water-to-water heat pump cycle providing simultaneous heating and cooling.

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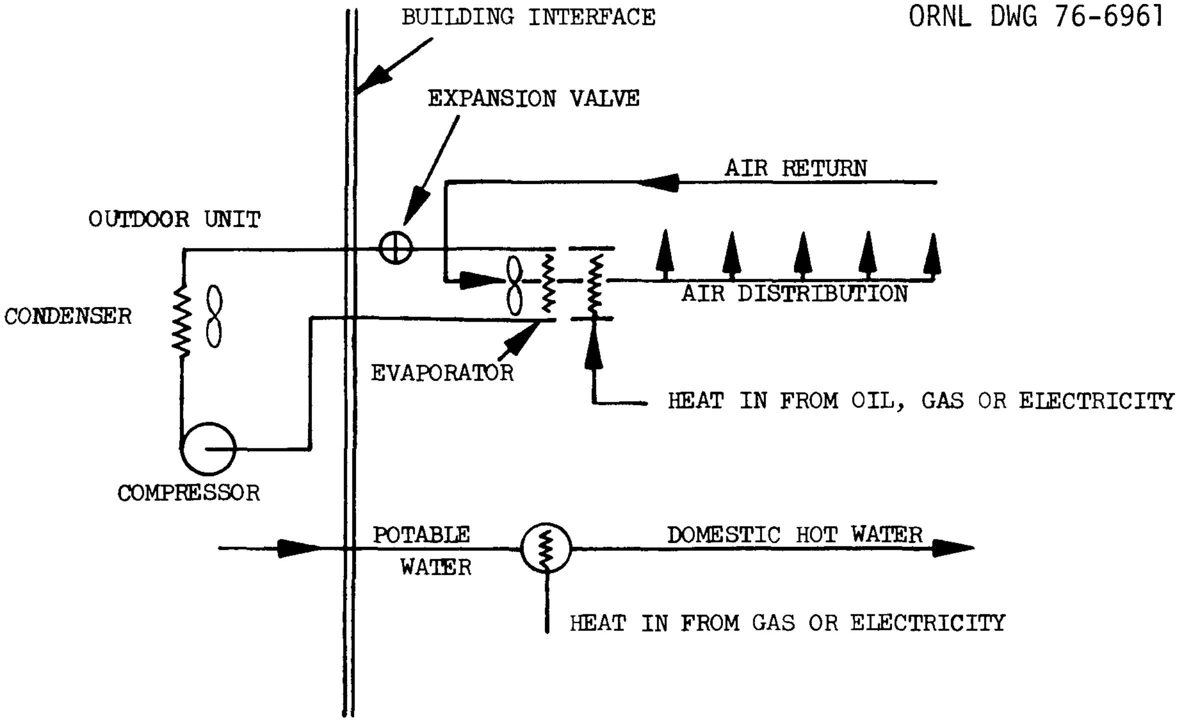

Fig. 8. Flow diagram for individual dwelling unit with split air conditioning system and gas, oil, or electrical heating.

these are the refrigerant reversing type and would be of interest for single-dwelling units. Figure 7 shows a water-to-water cycle capable of providing heating and cooling simultaneously. This figure also shows the system being used to preheat domestic hot water. This type of system would be applicable to apartment houses or office buildings rather than individual dwellings. Figure 8 is a flow diagram for an individual dwelling unit with a split air-conditioning unit and gas, oil, or electrical heating. Domestic hot water is provided by gas or electricity.

An economical site layout for a MIUS installation is one with the central equipment building located in the center of a building complex with a high-population density. In such a layout, space heating and heat for domestic hot water would be supplied through a two-pipe hot water distribution system with space cooling provided by a separate two-pipe chilled water distribution system. Although the feasibility of the MIUS concept does not require this ideal arrangement, it is necessary for part of the site to be sufficiently compact or have a high localized heat demand to economically justify distributing the heat (or chilled water generated from the heat) recovered from the engines. The basic parameter in any analysis of the system is the ratio of the electrical demand and usage to the amount of heat that can be used. Once the electrical consumption characteristics of the complex are determined, then the amount of heat that can be recovered is fixed. It is then necessary to be able to utilize a reasonable amount of this heat.

Absorption chillers represent a poor method of heat utilization because of their low coefficient of performance (COP). Wherever possible, heat from the engines should be used for heating rather than cooling purposes. Space cooling demand beyond that available from the balance of waste heat should be supplied by compression machines. Even if all of the heat recovered from the engines during the cooling season can be used for heating purposes, there are still advantages in using a chilled water distribution system. The large central-plant type of compression machines are more efficient than the smaller individual home or apartment units and are more rugged, reliable, and have a longer life. Also, the diversity factor of a community system reduces the peak demand on the system and thus the total installed capacity that is required. It should be noted that part, if not most, of the difference between the efficiency of large compressive equipment and of smaller individual home units is due to emphasis on minimizing the "first cost" for the smaller units. For a relatively small increase in cost, the efficiency of these units can be improved, and at least one manufacturer does produce efficient small units. These units are now sold in the southern part of the United States where the longer cooling season and the better efficiency pays for the increased first cost.

Heat pumps offer the potential for energy conservation in the low-density sections of a MIUS-served development by virtue of their operation at COPs greater than one. The following three types of unitary heat pumps are in general use:

1. The air-to-air heat pump is the most common unitary type because of its universally available heat source and its simple application to smaller structures. The air-to-air heat pump

could be used to heat and cool individual dwelling units in the low-population density areas of MIUS, and the heat recovered as a result of generation of electricity for these heat pumps could be used in the district heating and cooling system for the high-density population areas.

2. The water-to-air heat pumps use water (normally well water) as their heat source and sink. Air is used to transmit heat to and from the conditioned space. These units are proposed in MIUS to space condition the larger buildings in the low-population density areas.
3. Water-to-water heat pumps are also proposed for low- and medium-population density areas. This application requires a two-pipe water loop which serves as both a heat source and heat dump. The water source or sink improves the COP for both heating and cooling, and during the spring and fall when both heating and cooling is needed, the heat rejected from those units supplying air conditioning can be used as the source for space heaters. During extended cold periods, heat would be added to the loop by a gas- or oil-fired boiler.

The performance characteristics of a typical heat pump are shown in Fig. 9. The capacity, power input, and COP characteristics can vary appreciably with equipment size and design. In residential sizes, an annual COP of ∿2 may be realized under typical cooling and heating operations. Specification data published for several hundred air-to-air heat pump models having cooling capacities from 20,000 to 150,000 Btu/hr and above show COPs in cooling typically within the range of from 1.8 to 2.8 at rating conditions of 80°F dry bulb, 67°F wet bulb indoors, and 95°F outdoors. Generally, the larger sizes have higher COPs. The temperature at which the heat pump capacity and the building heat requirements are equal is referred to as the balance point. If the balance point is above the heating design temperature, supplemental heat will be required as denoted by the shaded area in Fig. 9.

It can be shown that a properly designed heat pump system is competitive with oil- and gas-fired systems from the standpoint of fuel

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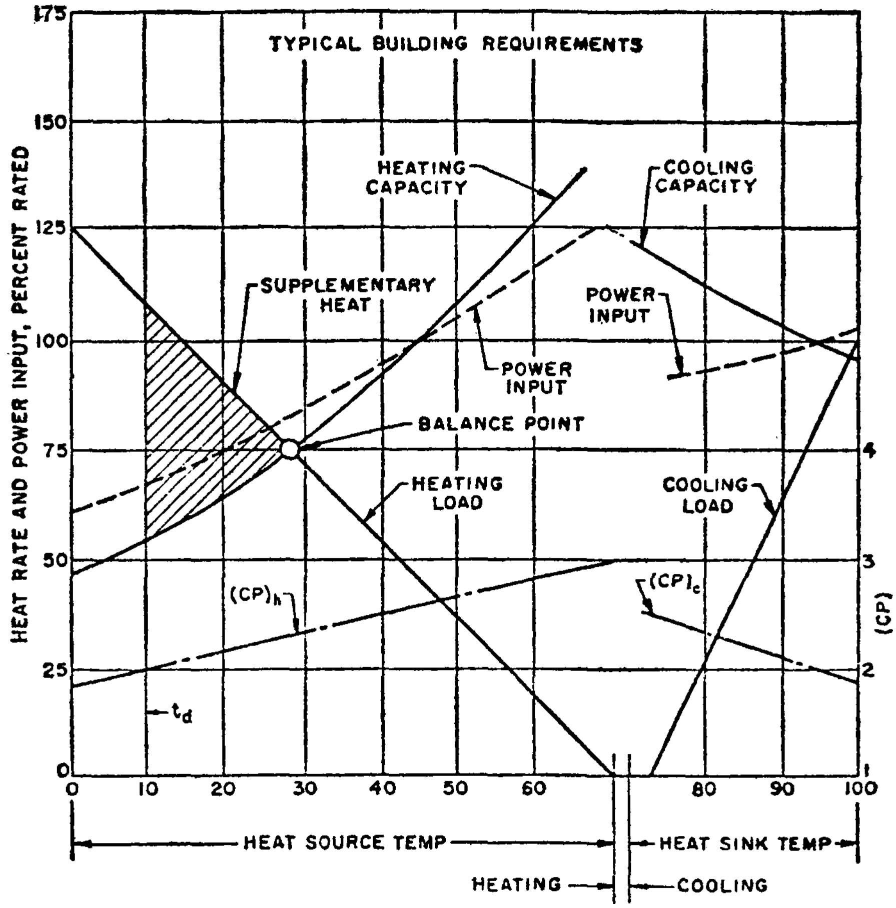

Fig. 9. Operating characteristics of single-stage unmodulated heat pump. Source: With permission from American Society of Heating, Refrigerating, and Air-Conditioning Engineers, New York, *ASHRAE Guide and Data Book, Equipment Volume*, 1972.

conservation.[10] A typical heat pump delivers about two units of heat energy for each unit of electric energy that it consumes. The average efficiency of electric power plants in the United States is about 33%, and the transmission and distribution efficiency of delivering electric power to the consumer is about 91% — giving an overall conversion efficiency of about 30%. Therefore, only 1.7 units of fuel energy would be required at the power plant for each unit of heat delivered by the heat pump. The end-use efficiency of oil- or gas-burning home heating systems is ∿60% (claimed values range from 40 to 80%), meaning that 1.7 units of heat must be supplied by fuel for each unit delivered to the conditioned space.

When using heat pumps with MIUS, an energy balance depends on many specific system and site characteristics. However, for the sake of comparison, an assumed engine-generator efficiency of 30% and heat recovery rate of 45% (of fuel input) gives only about 0.95 units of fuel energy input per unit utilized. Another advantage of using heat pumps with MIUS is that their power consumption increases with decreasing temperature in a manner similar to the demand for heat on the entire system. Thus, heat available from engines supplying power to the heat pumps could likely be used for that part of the complex served by the hot water distribution system. The major disadvantage of heat pumps is the dependence on auxiliary electric resistance heaters at temperatures in the range of 0 to 10°F. This leads to a very high peak electrical demand which may increase the installed generating capacity required. The number of air-to-air heat pumps that one has in a MIUS should be limited by two considerations. The increased electrical demand during the winter should not exceed the peak summer demand, and the increased amount of heat recovered during the peak winter electrical demand should be usable by that part of the complex on the district heating system.

The low-density section may also be heated by gas or oil heaters or by electric resistance heaters. Although electric heating is generally considered very poor from the standpoint of energy conservation, the overall fuel utilization in a MIUS is about 75% if the heat recovered from the engines can be fully utilized. This is better than the efficiency of most small individual home furnaces.

Space cooling for the low-density section may be provided by heat pumps or by individual single package units or split systems.

The medium-density section may be supplied with space heating and cooling by the methods previously discussed for the high- and low-density areas. In fact, the method of serving the medium-density area can be split in a manner to match heat requirements to waste heat availability. There are two other methods that should be considered. This section could be supplied with heat from a hot water distribution system and cooled by individual apartment or apartment building air-conditioning units. The second method is to use water-to-water or water-to-air heat pumps, as shown in Fig. 6 and 7 and described as item 3 above. In those parts of the country with mild winters, but large diurnal temperature variations or short periods of cold weather, a small lake or pond could be used as a heat source. This system has the advantage that it does not cause a high electrical demand on the power generating or distribution systems during short periods of cold weather. The main disadvantage of the system is the cost of the piping. Also, this system may require more fuel than an air-to-air system unless it is held to a size compatible with that of its water supply.

Heat for domestic hot water would be supplied from the district hot water system in the high-density areas. The other areas would use gas, oil, or electric hot water heaters. The amount of energy required for the hot water heaters could be reduced by preheating the water with the high temperature discharge from the heat pump or air-conditioning compressor. This feature would require the redesign of small package units and is considered for future rather than near-term applications. However, larger built-up systems for apartment buildings could incorporate this feature with relatively few modifications.

In summary, space heating and cooling and domestic water heating should be provided to high-density areas by a four-pipe hot and chilled water district system. Heating and cooling in the low-density areas may be provided by heat pumps or by individual cooling units with heat supplied by oil, gas, or electricity. Domestic hot water in the low-density areas would be supplied by gas, oil, or electric hot water heaters. The medium-density areas could be served by any combination of the above methods or by a heat pump system using a water source. The final selection will probably be based on obtaining a good balance or match between the heat available from the engines and the heat demand on the district system.

Two-pipe rather than four-pipe systems are possible alternate subsystems. This leads to several possible variations, such as: (1) the elimination of chilled water distribution with space cooling provided by chiller units at the consumption point or (2) dual use of the two-pipe system for heating or cooling, with domestic hot water supplied by either a separate line or by electric or gas heat. Two-pipe systems have not been studied in adequate detail to determine their merits relative to the four-pipe systems.

Solar Energy

There have been a number of solar energy devices and systems built or proposed; however, most practical applications to date have been limited to heating and storing water at 120 to 150°F for domestic hot water or space heat and to small distillation processes producing potable water. The use of solar energy is limited by cost rather than technology. Considering the present upward trend in power costs and possible reductions in solar equipment capital cost, the use of solar energy for domestic hot water should be considered for areas in which natural gas is unavailable.

Solar water heaters have a demonstrated performance of 25 years in Florida,[11] and even with cracks in the glass collectors, they have functioned adequately. Operating and maintenance costs can be considered minimal.[12] Costs for a typical Florida-type solar water heater in 1964 were given in ref. 13 as $4.50 per ft^2 of collector, including 1.5 gallons of water storage per ft^2 of collector. Tybout[12] gives a cost (1971) of $4 per ft^2 of collector. Daniels[14] reports costs of $250 to $400 for well tested units exported from Israel.

In some areas of the country, solar energy can be used with a small lake or pond which serves as a water source for a heat pump system, as discussed in the previous section. The pond used to collect solar energy would probably be available because of other needs for a pond. For example, it may be used as the heat dump for the entire complex, a source of water for the fire protection system, and hold up storage for storm water runoff.

Thermal Energy Storage

The objective of thermal energy storage for a MIUS is to store energy during periods in which all of the recoverable heat from engines cannot be used for use during periods when the demand is greater than that available from the engines. A previous study[3] of thermal energy storage systems indicated that, even for the largest size installation considered (3000 dwellings) and some rather optimistic assumptions, the cost of fuel would have to be well over $2 per million Btu to pay for the equipment. This study was limited to storage of water for a hot or chilled water district system in which the ΔT of the hot water was 40°F and for the cold water was 15°F.

An alternate method that may have merit is to use one end or perhaps a protected section of the pond discussed in the previous section. During periods when excess heat is available, the heat is dumped into the pond and later used in a water source heat pump system. This approach again makes multiple use of the components of the system and would add very little, if any, cost to the system. Because of the low temperature of the stored heat, this method would be limited to installations having part of the complex served by a water source heat pump system.

It should be noted that all piping systems can be used for thermal energy storage. For example, with a chilled water system operating with a ΔT of 15°F to 20°F, the temperature of the return loop and possibly the entire system can be cooled below its normal operating point during periods of low demand. The reverse can also be done with the hot water system.

Multiple Use of Components and Resources

The MIUS concept makes possible the consideration of multiple use of components and resources and the use of components and resources in somewhat unconventional ways. One of the more obvious components that can serve several functions is a small lake or pond. Many housing developments and new communities have lakes on the property. Furthermore, the cost of building a small pond in most parts of the country would be no more than the cost of the cooling tower that it could replace. The pond could also serve as storage for the effluent from the liquid waste treatment plant, which could be used for system makeup water, fire protection, irrigation, and other processes.

In a small MIUS, it will probably be less expensive to include a separate fire protection system than to size the potable water storage and distribution system for fire protection. The fire protection system could then be used to deliver process water to consumers and may also be used as one leg of a water loop for a water source heat pump system. An alternative approach is to use the fire protection system as one leg of the chilled water system.

One other advantage of the MIUS concept is that the integration of management and planning for all utilities increases the potential use of common trenching for all or most of the utility distribution lines.

Water Supply and Treatment

The MIUS water supply subsystem will provide water for potable purposes (drinking, washing, etc.), for associated commercial and industrial uses, and perhaps for fire protection and agricultural uses. Per capita potable water consumption in a housing development will range from 60 to 80 gpd. For a 100-unit development, this would be about 20,000 to 27,000 gpd, and for a 3000-unit development from 600,000 to 800,000 gpd. These figures can be expected to increase by the addition of associated commercial and industrial facility requirements. The type of water supply selected will depend on the size and water requirements of the MIUS, availability of ground or surface water, composition of the water available, and availability of land. A more detailed description can be found in the technology evaluation on water supplies and their treatment.[4]

Water saving devices are available that can reduce the amount of household water consumption.[15] These include a toilet that uses less water for flushing and reduced flow faucets and shower heads. If water saving devices are used in the development, the water consumption would be lower than the values given previously and would result in smaller MIUS water subsystems.

Source of water supply

There are two primary water sources for a MIUS; groundwater or surface water. Groundwater (or "well water") is preferable in most cases because it often requires less treatment than surface waters. Groundwaters may also be obtained onsite, eliminating the need for transmission mains. Many groundwater supplies will require only disinfection; but others may require iron or manganese removal, or softening and pH readjustment, followed by disinfection prior to distribution. If groundwater is used in MIUS, care must be taken to insure that the supply is not contaminated by leaching from sanitary landfills or by improper disposal of sewage treatment system effluents.

Surface waters can also be used for the MIUS water supply. In general, surface waters require more treatment than groundwaters. Surface waters can be obtained from streams, lakes, or specially built reservoirs. Minimum surface water treatment would probably involve sedimentation for solids removal and disinfection. However, in most cases, treatment will be required to remove fine suspended solids, colloidal matter, and aquatic microorganisms. Since surface water supplies exhibit a greater fluctuation of composition with time than groundwaters, adequate monitoring is required to insure adequate chemical dosages for removal of solids and microorganisms. Taste and odor control may also be more of a problem in surface waters.

Water treatment

Package plants are available for treating surface and groundwaters.[4] Components are available which could be added to the package plants to increase treatment, or these components could be assembled to provide the necessary treatment. For example, it might be possible to use a diatomaceous earth precoat filter preceded by a microstrainer to replace a coagulation-sedimentation-filtration type package plant. This combination offers low capital and operating cost and minimum space requirements. However, the combination does not exist as a pre-engineered package plant.

Groundwaters are usually preferable where available and of acceptable quality. They are generally treated with simple disinfection. Disinfection units are available as an off-the-shelf item from several manufacturers. Package units for removing specific chemical constituents, such as iron and manganese, or hardness, are also available.

If the MIUS were located in areas where chemically suitable ground or surface water supplies were not available, such as areas with brackish or saline waters, there are technologies available that can be used to produce potable water;[4] however, the costs would be quite high. Package desalination plants are commercially available at this time.[4]

Since bacterial contamination of the potable water supply could cause serious illness or epidemics, and further, since rapid bacterial detection methods are nonexistent, serious consideration should be given to the use of backup disinfection systems. Dual disinfection systems such as chlorination-ozonation or chlorination-ultraviolet are relatively inexpensive and provide a margin of safety over single disinfectants.

An innovation that could be used for water treatment if land area is available would be slow sand filtration followed by disinfection. Historically, slow sand filters have been found to be reliable and safe for water treatment. For developments ranging from 100 to 3000 dwelling units, the filter area required would be from 0.01 to 0.2 acres (435 to 8700 ft^2), respectively.

Schematic flow sheets of the MIUS potable water system and its alternatives are shown in Figs. 10 and 11. As mentioned previously, each MIUS must be evaluated as to the source of water supply, treatment required, and plant capacity.

Fire protection

Some form of fire protection will be required to protect the apartment and commercial buildings and their contents. Water for fire protection can be required at flow rates up to 10 times the flow required for domestic uses. If the firewater flows are to be provided by the MIUS potable water plant, then either the plant must be sized to meet fire protection flows or storage must be provided to meet demands. Appropriate amounts of water and the flows and pressures at the hydrants are specified by the National Board of Fire Underwriters.[16] Recommended firewater amounts and flows for average cities of various sizes are given in Table 2. It should be noted that these are recommended standard fire flows and durations for fire insurance rating purposes only, and may not be representative of existing U.S. water systems.

An alternative to supplying fire protection water from the potable water supply would be to use a separate system for fire protection using untreated water from the MIUS water source or treated waste-water effluents. A similar approach could be used for industrial process water and for irrigation or lawn watering. For each MIUS, an evaluation of the fire protection alternatives must be made.

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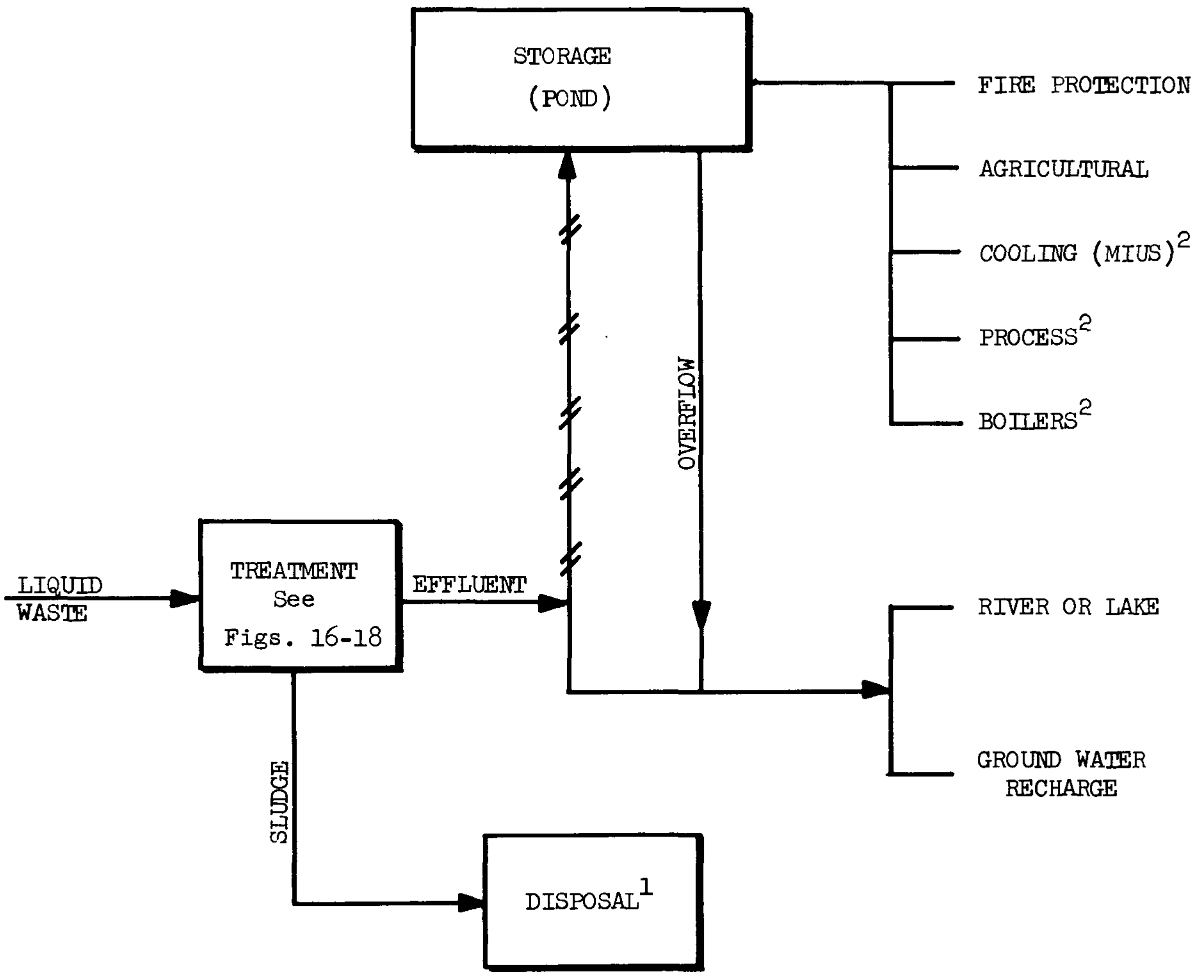

Note: —//——//— indicates alternate system.

[1]May be combined with solid waste disposal.

[2]Additional treatment may be required.

Fig. 10. Flow sheet for potable water system.

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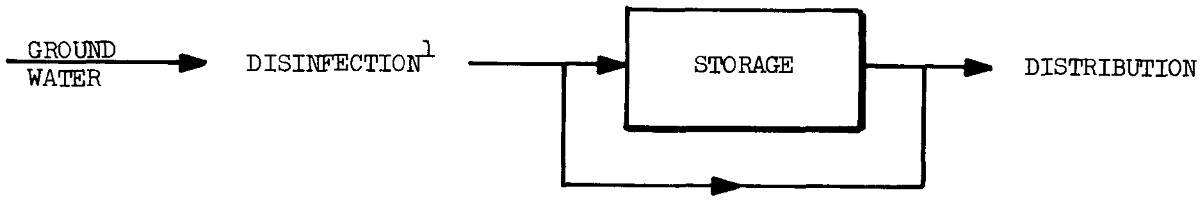
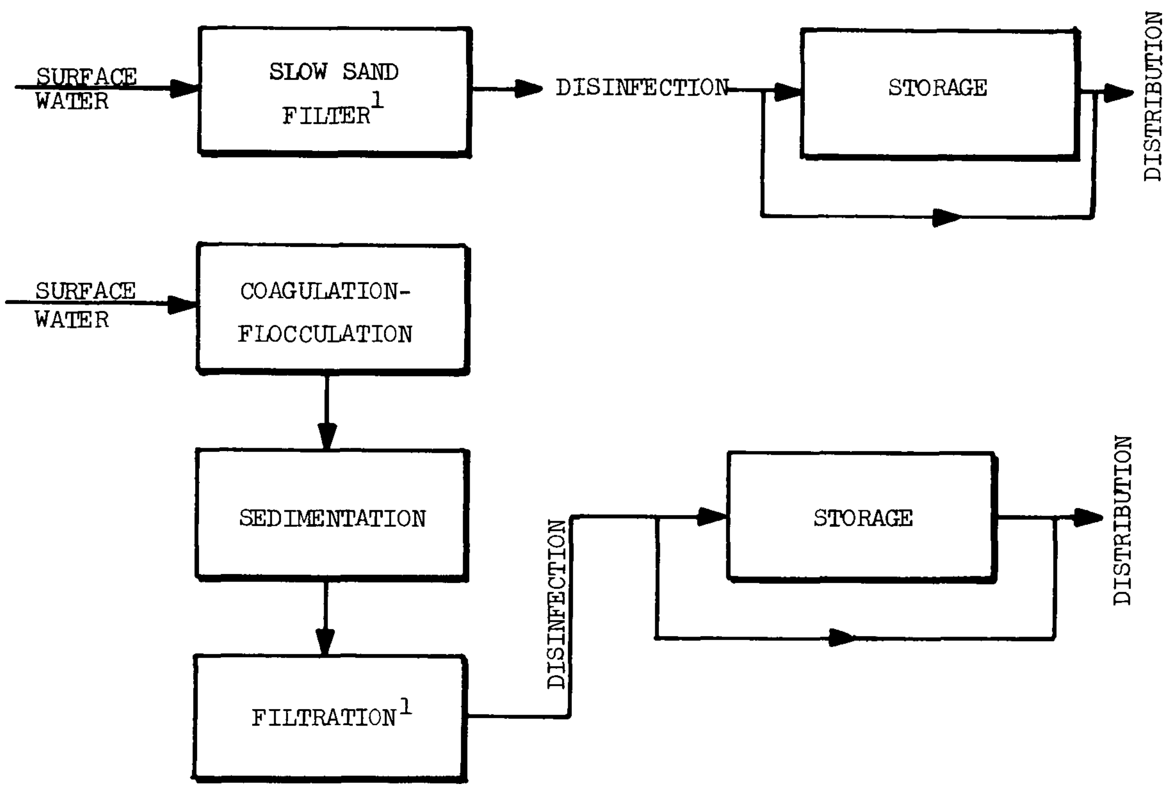


TYPICAL GROUND WATER TREATMENT PROCESS



TYPICAL SURFACE WATER TREATMENT PROCESSES

[1]Some water may require further treatment; e.g., hardness removal, iron and manganese removal, taste and odor control, and turbidity.

Fig. 11. Flow sheet for potable water treatment processes.

Table 2. Required fire flows for average small cities[16]

Population	Flow rate		Flow duration	Total flow	
	gpm	gpm/cap	(hr)	gallons	gal/cap
100	250	2.5	4	60,000	600
250	500	2.0	4	120,000	480
500	750	1.5	4	180,000	360
1000	1000	1.0	4	240,000	240
1500	1250	0.83	5	375,000	250
2000	1500	0.75	6	540,000	270
3000	1750	0.58	7	735,000	245
4000	2000	0.50	8	960,000	240
5000	2250	0.45	9	1,215,000	243
6000	2500	0.42	10	1,500,000	250
10,000	3000	0.30	10	1,800,000	180

Liquid Wastes

Liquid wastes will be generated in housing complexes at a rate about equal to potable water consumption: from 60 to 80 gpd per person. If the MIUS serves associated commercial and industrial facilities, additional waste volumes can be anticipated. The type of collection system and disposal process used will depend on the local geology and topography, availability of land, effluent discharge standards, or the water quality required for any proposed reuse of treated effluent. A schematic flow sheet for the liquid waste subsystem for a near-term MIUS is shown in Fig. 12. Additional detailed information on the technologies selected are given in ref. 5.

Collection

Gravity flow sewers will probably be used in MIUS except when geologic or topographic reasons rule them out. Both pumped or vacuum sewers can be used throughout all or portions of a development when found to be economical. Use of pumped or vacuum sewers may result in reduced installation costs, but require greater operating costs than gravity sewers. The vacuum sewer combined with a special vacuum toilet can produce water

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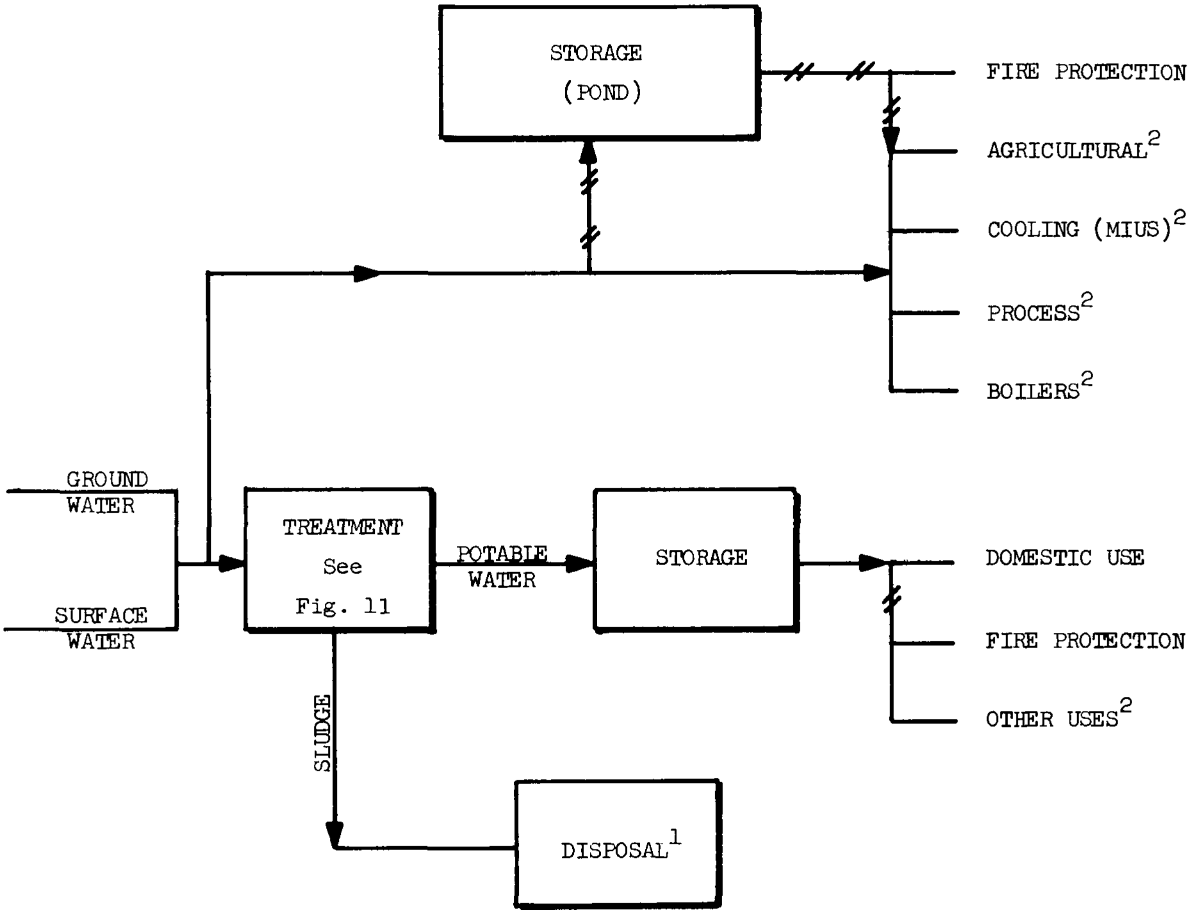

Note: —//——————//—— indicates alternate system.

[1]May be combined with solid waste disposal.

[2]Additional treatment may be required.

Fig. 12. Flow sheet for liquid waste system.

savings in MIUS. Use of a two-pipe sewer system, with one vacuum sewer for toilet wastes and one sewer for all other liquid wastes, does not appear attractive for MIUS. Use of two-pipe systems would require modifications in the plumbing within the buildings.

Treatment and disposal

Five systems for liquid waste treatment are available that could be used in the MIUS subsystems. These are:[17]

1. biological treatment,
2. biological-physical treatment,
3. biological-chemical treatment,
4. biological-chemical-physical treatment, and
5. physical-chemical treatment.

Biological treatment systems are illustrated in Fig. 13. These systems are composed of some form of preliminary treatment followed by sedimentation for solids removal. The next step is biological oxidation, using either activated sludge or trickling filters. Following final sedimentation, effluent is disinfected and released. Sludge from the primary sedimentation tank and excess sludge from the secondary sedimentation tank undergoes anaerobic or aerobic digestion followed by vacuum filtration dewatering or by drying on sand beds. Ultimate disposal of sludge solids can be performed by incineration, wet oxidation, or land spreading.

Biological-physical treatment systems are also illustrated in Fig. 13. In this treatment system essentially all of the treatment steps used for biological treatment are provided, and some form of filtration is provided to increase solids and biochemical oxygen demand (BOD) removal in the final effluent. Types of filtration used could be microstrainers, sand filters, or mixed media filters.

Biological-chemical treatment systems are illustrated in Fig. 13. This form of treatment employs the steps used in biological treatment plus coagulant addition to either the influent to the primary sedimentation tank or to the influent to the biological treatment process. Advantages gained are greater removal of BOD, suspended solids, and nutrients.

Biological-chemical-physical treatment systems are illustrated in Fig. 14. This system uses biological treatment as the initial step followed by coagulation and sedimentation and carbon adsorption. Nitrogen

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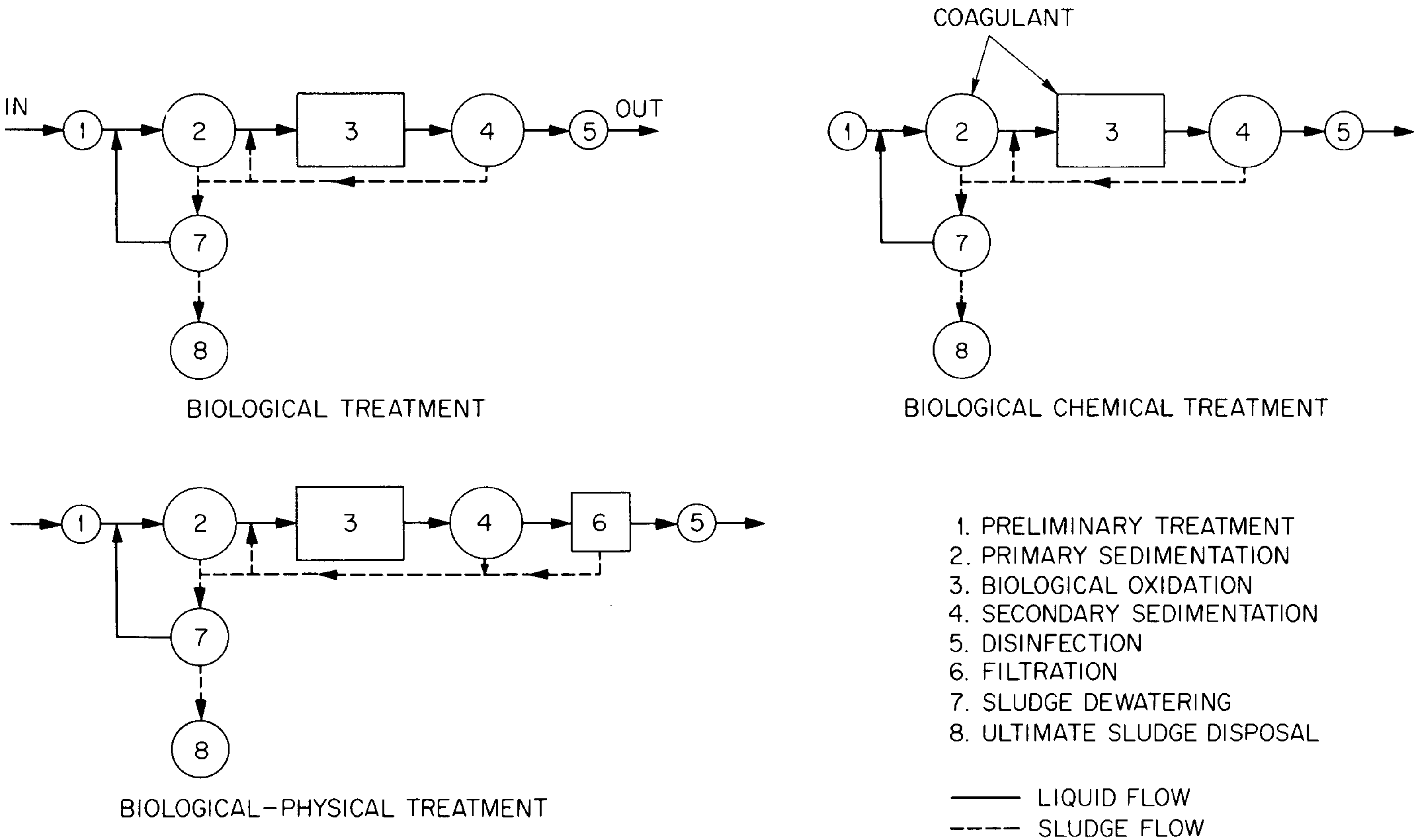

Fig. 13. Biological, biological-chemical, and biological-physical liquid waste treatment flow sheets.

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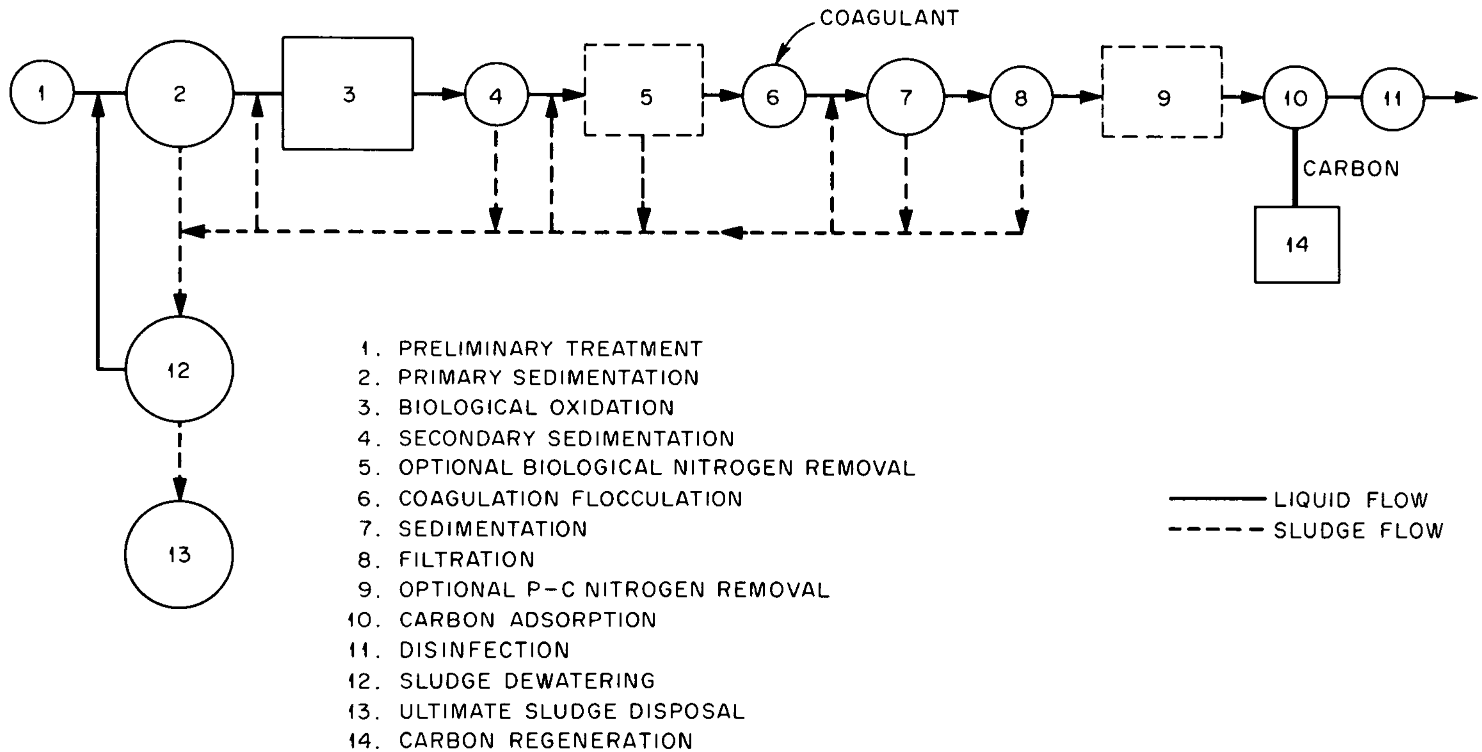


Fig. 14. Biological-chemical-physical liquid waste treatment flow sheet.

removal can be achieved by biological methods prior to coagulation, or by physical-chemical methods (such as air stripping) after coagulation and prior to carbon adsorption. Effluent from the carbon columns is disinfected, and sludge from the various steps is dewatered for ultimate disposal. Although the flow diagram shows carbon regeneration, small plants using powdered carbon may waste the carbon to the sludge handling subsystem. This type of processing system achieves high BOD, solids, and nutrient removal.[17]

Physical-chemical treatment systems are illustrated in Fig. 15. Many modifications of this system have been proposed. Biological processing is characteristically excluded from these systems. Following preliminary treatment, coagulation, flocculation, and sedimentation are normally performed for solid removal. Additional solids removal can be achieved by filtration. Nitrogen removal can be performed by air stripping or ion exchange followed by carbon adsorption. Filtration can be performed prior to or after the carbon adsorption step depending on whether the influent to the carbon system is low in suspended solids or the designer is willing to allow the carbon system to act as a filter. If powdered carbon contacting is used, filtration may be required after the carbon adsorption step. Effluent disinfection and sludge handling must also be provided. Biological treatment of sludge is normally not used; rather treatment is by some form of sludge drying or incineration.

Small, factory-built package plants that could be used for sewage treatment in a MIUS are commercially available from more than 50 manufacturers.[5] Because of the small size of the building complexes to be served by MIUS installations (less than about 0.5 million gallons per day), the use of plants that can be prefabricated and shipped to the building complex for installation appears to be the most attractive method of handling liquid waste treatment and disposal. The majority of available package plants use biological treatment systems, but units are available that can be added to increase the degree of treatment. Although there are at present only about five manufacturers of physical-treatment plants, a number of manufacturers have indicated that they are now developing such plants, and more should be available in the near future.[5]

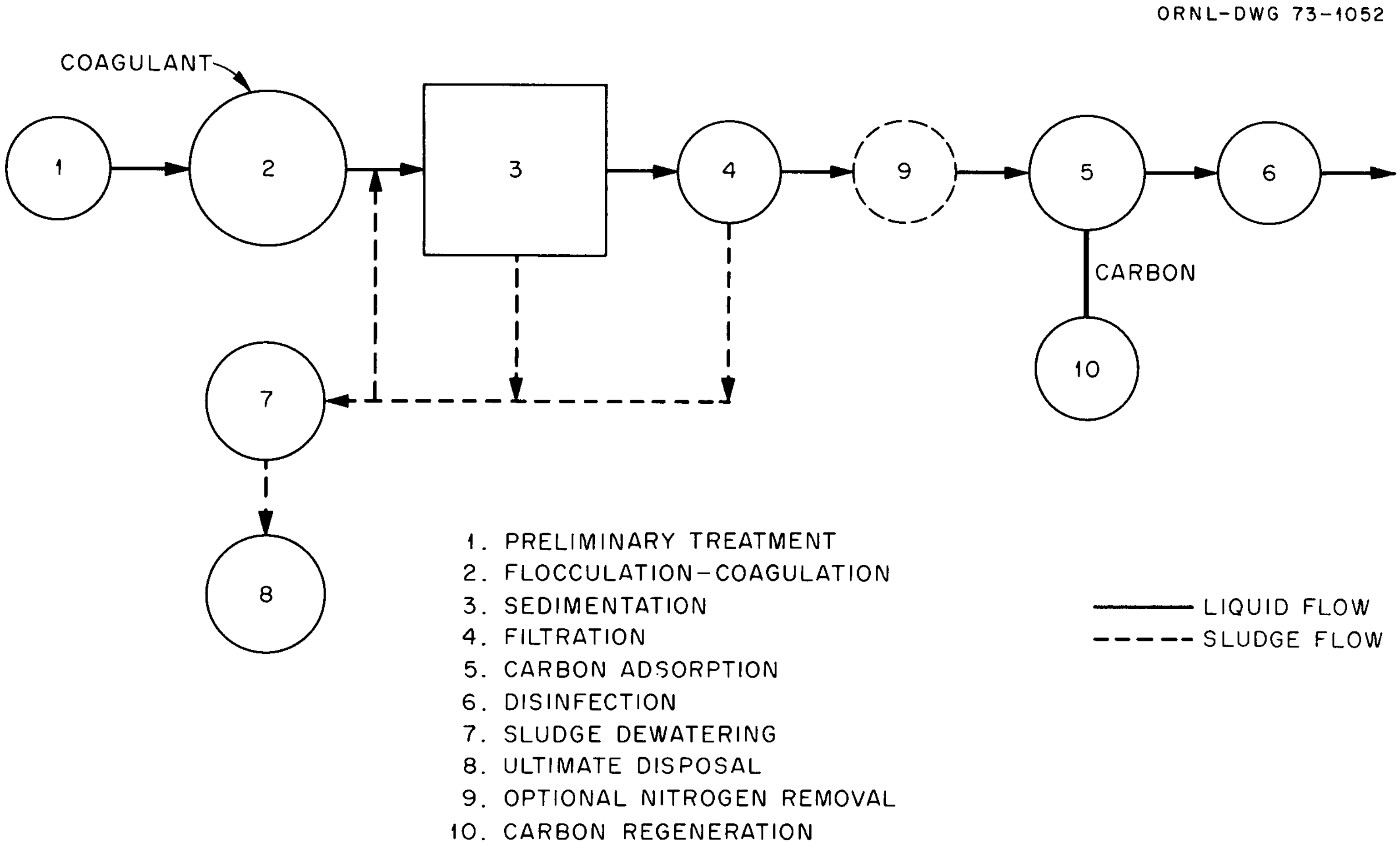


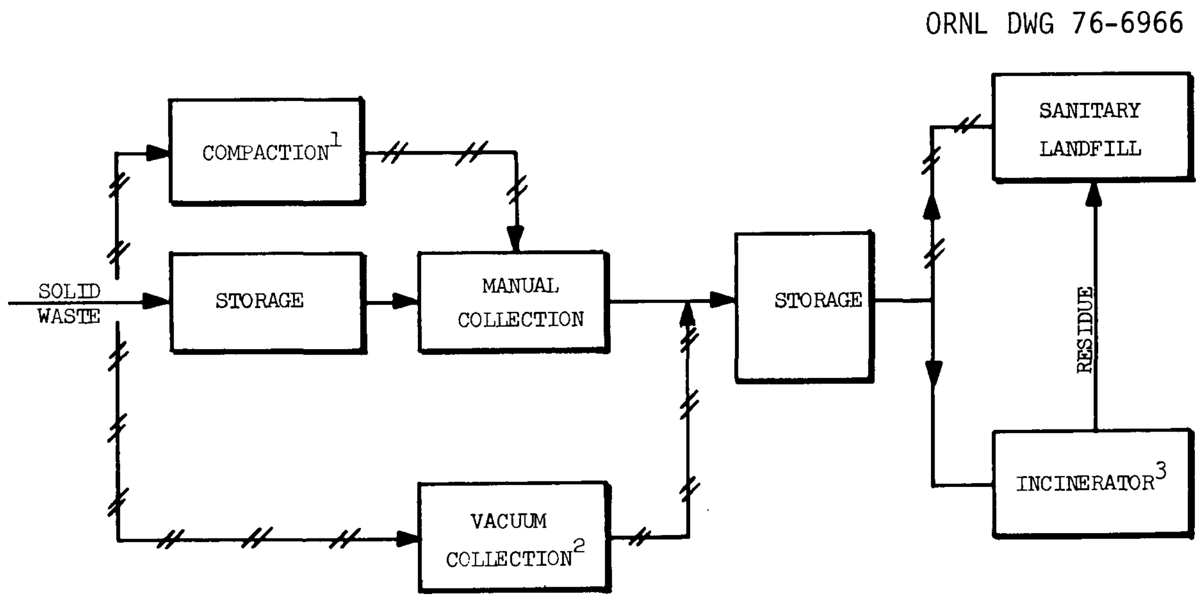
Fig. 15. Physical-chemical liquid waste treatment flow sheet.

Basically, the decision to use one treatment system over another is one of economics and effluent quality requirements.[5] Biological treatment is less expensive than physical-chemical; however, the final effluent produced by a physical-chemical plant is lower in BOD, suspended solids, and nutrients.[17] Each individual MIUS site must be evaluated to see if effluents can be released to nearby bodies of water, and if so, what effluent quality will be required by local or state agencies. Whether the treated effluent could be used in the MIUS for other purposes such as cooling water, process water, water for fire protection, irrigation, or other uses should also be determined, along with the water quality required for each reuse and the economics of providing waste effluents that meet these quality criteria. Treatment systems are available as package plants, or can be built up of various units to provide effluent with various qualities. In any case, whatever use is made of the effluent, disinfection will be required. At this time, use of treated effluents for potable purposes must be ruled out because of concern with viruses and other disease producing organisms, and due to the lack of instantaneous, fail-safe detection systems for bacteria and viruses. EPA is currently encouraging the reuse of treated liquid waste effluents as a water source for purposes other than potable water.[18]

Unless treatment process such as distillation or electrodialysis are required, the MIUS liquid waste treatment subsystem will not be a significant consumer of heat. However, it may be feasible in certain situations to use excess waste heat for sludge drying, heating of incoming sewage in biological treatment plants, or for heating anaerobic digestors. Some electricity will be required for pumps, chemical feeders, blowers, etc., but the total requirements will be small.[5] Sludge produced as a part of the sewage treatment operation can be incinerated either with solid wastes or separately, or it can be landfilled.

Solid Wastes

Solid wastes generated in housing complexes ranging from 100 to 3000 dwelling units will range from 1000 to 40,000 lb/day, respectively. In terms of volumes to be handled (as generated and uncompacted) the corresponding figures are 200 to 7000 ft^3/day. The type and number of commercial facilities associated with the development will have some effect on the quantities. The method of collection and disposal of solid wastes will depend on the size of the development, population density, types of buildings (high rise, garden, or single family), availability of land for landfilling, local labor costs, and availability of nearby alternative disposal sites. A schematic flow sheet of the alternatives for solid waste collection and disposal for a near-term MIUS concept is shown in Fig. 16. The following sections will describe the alternatives that could be used. A more detailed description can be found in the technology evaluation on solid waste.[6]



[1]Can be considered a form of storage.
[2]High-density, high-rise buildings.
[3]May have heat-recovery equipment.

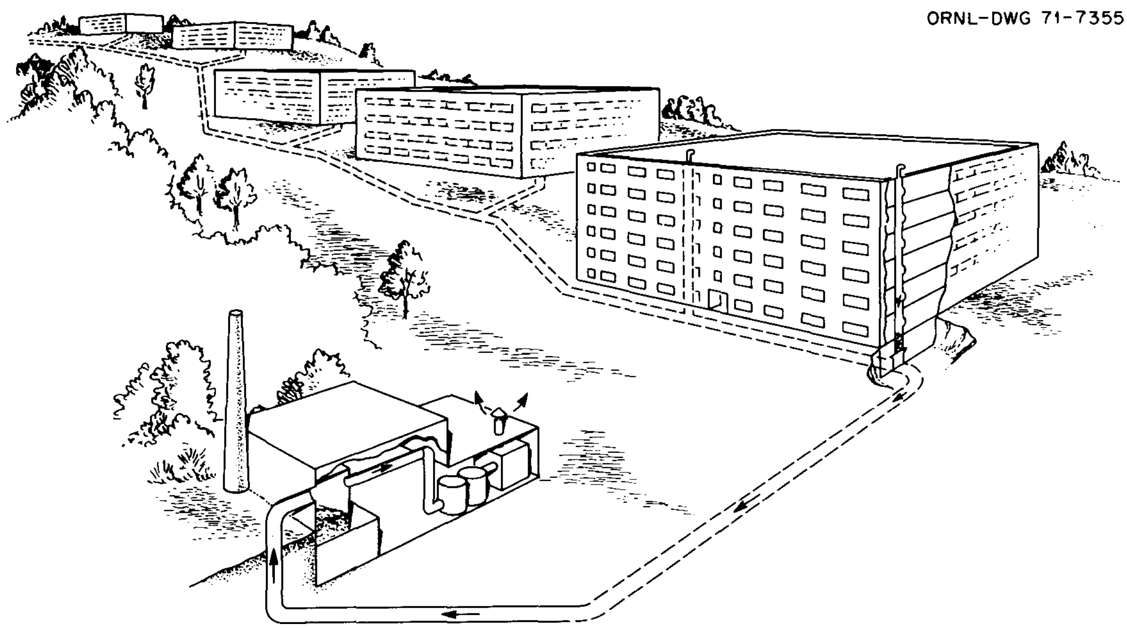
Fig. 16. Flow sheet for solid waste.

Collection

Solid waste collection in MIUS can be provided by traditional manual methods followed by truck transfer, or by the use of a vacuum collection system. Manual collection will probably be used, unless all of the dwelling units are located in a few tall buildings which are fairly close together.[6] Vacuum collection (see Fig. 17) will probably only be considered in areas where the buildings are close together and of the high-rise type, or in areas where access to the buildings for manual collection is limited. In single-family or low-density housing areas, the cost of the charging stations (normally a special control valve at the end of a chute) and the cost of installing the large diameter pipes required will probably make vacuum collection more expensive than manual collection and truck transfer.[6]

If in-sink garbage grinders are installed in each dwelling unit served by the MIUS, it may be possible to reduce the frequency of collection. A reduction of the putrescible portion of solid waste would allow longer storage periods without odor, insect, or rodent problems. When used with vacuum systems, many of the advantages cited for grinders are eliminated; however, eliminating garbage from the chute system and the vacuum piping should reduce the need for cleaning. Use of garbage grinders does transfer additional solids and grease to the sewage treatment plant; the end result is that gas production in digestors would increase when using biological treatment, and sludge production would increase when using either biological or physical-chemical treatment.

Storage facilities must be provided prior to and possibly following collection operations. Storage prior to collection will be either in the dwelling unit, outside the building, or in the basement of the building. This storage is required to reduce the frequency of collection. In the case of vacuum collection, storage is in the chute feeding the main collection piping. The amount of storage space required can be reduced by bailing or compacting the solid waste. Storage after collection may be required to allow incinerator operations to be carried out continuously over a 24-hr period (probably for large developments) or to allow incineration to be performed in phase with heating needs. If landfilling is used, additional storage is not required.



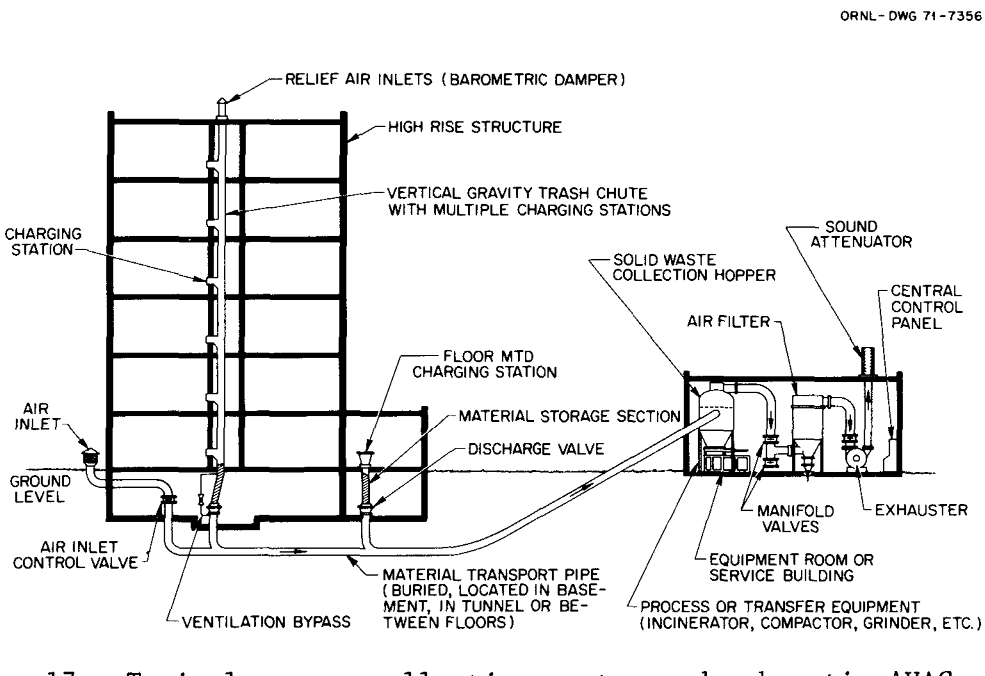


Fig. 17. Typical vacuum collection system and schematic AVAC system flow diagram.

Disposal

Two methods of solid waste disposal appear feasible for the MIUS subsystem. They are: sanitary landfill and incineration with heat recovery.[6] At the time of this analysis, small-capacity incinerators had not been developed with heat recovery capability and this method could not be recommended for small communities. Since even incineration produces a residue that must be disposed of in landfills, it appears that the most practical disposal method for small developments would be complete use of sanitary landfilling — either onsite or in some offsite disposal facility. In the case of larger developments, however, incineration with heat recovery becomes more attractive. A rough estimate of the cost of incineration with heat recovery made in ref. 6 indicates that, if a large fraction of the waste heat can be recovered and utilized, a development generating 6000 lb of solid waste per day may have an annual savings in fuel costs equal to the additional annual cost of supplying the heat-recovery boiler; at a burning rate of 12,000 lb/day, cost savings from reduced MIUS fuel consumption may also offset part of the cost of owning and operating the incinerator. It should be understood that operation and maintenance costs of an incinerator system are not well defined and that the residue from an incinerator must be sent to ultimate disposal. The amounts cited above would be equivalent to burning 8 hr/day on a 5-day per week basis at rates of 1000 and 2000 lb/hr, which would treat wastes produced in a development containing about 500 and 1000 dwelling units, respectively. As in the case of the smaller MIUS, sanitary landfill can be an alternative to incineration, with or without heat recovery, if land is available within or nearby the MIUS.

Although the economics of incineration with heat recovery may not be favorable, it is recommended that this system be installed for study and demonstration purposes in an installation in which the solid waste generation rate is 4 tons/day or more (equivalent to a population of about 2000).

NEAR-TERM MIUS SUBSYSTEMS

The final selection of the various utility subsystems of a MIUS installation will depend on the climate, population density, total population, consumer mix or demand, local geology, and local resources such as water, natural gas, and land. Table 3 lists major components and subsystems considered applicable based on initial evaluations of currently available technology (1973)[1-6] and very preliminary model analyses.[7]

Internal combustion piston engines (gas, diesel, or dual fuel) are recommended for the prime movers. The final selection of the type will depend on the availability and dependability of fuel supplies. The best choice for the heat-recovery system will probably be a 240°F to 250°F system suitable only for single-stage absorption chillers. A complete commercial package is available only for the ebullient heat-recovery system. Heat rejection from the system may be by cooling tower or a cooling pond. The pond, in addition to serving as the heat rejection system, could be used as a source of water for fire protection, to hold up the runoff of storm water, and in some areas of the country could serve as a solar energy collector and water supply for a water source heat pump system. The pond is preferred unless land values preclude its use.

The space heating and cooling and domestic hot water subsystems listed in Table 3 overlap in several cases. The type, or perhaps the combination of subsystems used will depend primarily on the climate and population density. The high-population density areas would be supplied heat for space heating and domestic hot water through a two-pipe hot water distribution system with space cooling provided by aseparate two-pipe chilled water distribution system. A two-pipe system may be acceptable, but further evaluation of its merits relative to the four-pipe system is needed. Individual dwelling units in a low-population density area could be heated and cooled by air-to-air heat pumps (with auxiliary electric heat) with heat for domestic hot water from gas or oil. Electricity should also be considered as a heating source for domestic hot water in the low-population density area. This would eliminate the need for gas or oil service to the dwellings. Heat recovered as a result of generation of electricity for these heat pumps could be used in the district heating and

Table 3. Major components and subsystems applicable for near-term MIUS

A. Prime movers	B. Heat recovery	C. Heat rejection
*1) Internal combustion piston engines (gas, diesel, or dual fuel).	*1) Ebullient (240 to 250°F). 2) Forced-convection hot water (240 to 250°F).	*1) Cooling pond. 2) Cooling tower - wet or dry.
D. Space heating	**E. Space cooling**	**F. Domestic hot water**
*1) Central TE plant with two-pipe hot water distribution system (auxiliary heat from oil or gas and possibly solid waste). 2) Some may be as follows: a) Apartment building heaters with gas, oil, or electricity. b) Apartment building heat pumps (air-to-water or water-to-water) with supplemental heat from gas, oil, or electricity. c) Individual apartment or home heaters with gas, oil, or electricity. d) Individual apartment or home heat pumps (air-to-air or water-to-air) with supplemental electric heat.	*1) Central TE plant with two-pipe chilled water distribution system (compressive and single-stage absorption chillers). 2) Some may be as follows: a) Apartment building compressive air-conditioning system. b) Apartment building heat pumps (air-to-water or water-to-water). c) Individual apartment or home compressive air-conditioning units. d) Individual apartment or home heat pumps (air-to-air or water-to-air).	*1) Heat supplied from central plant through a two-pipe hot hot water system (i.e., the part D.1 system). 2) Some may be as follows: a) Building hot water heater using gas, oil, or electricity. b) Building hot water heater with preheating from heat pump compressor discharge and supplemental heat by gas, oil, or electricity. c) Individual apartment or home hot water heaters using gas or electricity. d) Individual apartment or home hot water heater with preheating from heat pump compressor discharge and supplemental heat by gas or electricity.

*Preferred or essential element.

Table 3. (continued)

G. Potable water	H. Fire protection	I. Liquid waste collection
*1) Groundwater (well) with disinfection and finished water storage.[1]	*1) Separate piping system using liquid waste treatment plant effluent and pond for storage.	*1) Gravity flow sewers.
2) Surface water supply (stream, lake, reservoir) with complete treatment, including sedimentation, coagulation, flocculation, filtration, and disinfection, and finished water storage.[2]	*2) Separate piping system using untreated supply water and pond for storage.	2) Pumped system.
3) Surface water supply with slow sand filter, disinfection, and finished water storage.[3]	3) Potable water system with large lines and storage system.	3) Vacuum system.
J. Liquid waste treatment	**K. Solid waste collection**	**L. Solid waste disposal**
1) Biological (secondary) treatment (sedimentation, aerobic biological process, and disinfection).	*1) Manual	1) Incineration and sanitary landfill,[4] no heat recovery.
2) Biological-physical treatment (sedimentation, aerobic biological process, filtration, and disinfection).	2) Automatic vacuum system.	2) Incineration and sanitary landfill,[4] heat recovery from the incinerator.
3) Biological-chemical treatment (sedimentation, aerobic biological process, nutrient removal including coagulation/flocculation and disinfection).		3) Sanitary landfill.[4]
4) Biological-chemical-physical treatment (sedimentary biological treatment, coagulation/flocculation, and carbon adsorption).		
5) Physical-chemical treatment (sedimentation, coagulation/flocculation, filtration, and disinfection; additional processes such as nitrogen removal, and carbon adsorption may be used where suitable).		

*Preferred or essential.

[1]Softening or other treatment may be required.

[2]New technology may be employed; both preengineered systems and components are available.

[3]Other treatment may be required.

[4]Landfill site controlled by cost or regulations; possibly onsite.

cooling system for the high-density population area. An alternate combination could be the use of individual package or split air-conditioning units with heat for space and water heating provided by gas, oil, or electricity. Larger buildings in the low-population density area could use air-to-water heat pumps (with auxiliary electric, oil, or gas heat) with heat for domestic hot water from oil, gas, or electricity; or they could use a central compressive air-conditioning system with heat for space heating and domestic hot water by oil, gas, or electricity.

Medium-population density areas could be served by any of the above systems; however, there are two other methods that should be considered. Because the preferred use of low-temperature heat is for heating purposes, as compared to cooling, this area could be supplied with heat from a hot water distribution system and cooled by individual apartment or apartment building air-conditioning units. The second method is to use water-to-water or water-to-air heat pumps. This method requires a two-pipe water loop which serves as both a heat source and heat dump. Use of the fire protection water loop as a source for the hydronic heat pump should be considered for both medium- and low-density areas. The water source or dump improves the coefficient of performance for both heating and cooling and, during the spring and fall when both heating and cooling is needed, the heat rejected from units supplying air conditioning is used as the heat source for the units supplying heat. This system can also use low-grade heat recovered from the engine lube oil coolers, after coolers, liquid waste effluent, and possibly solar heat collected in a pond. During extended cold periods heat would be added to the loop by a gas- or oil-fired boiler.

The final selection will probably be based on obtaining a good balance or match between the heat available from the engines and the heat demand on the district system, while maintaining a reasonable match between the maximum summer and winter electrical demand.

Some consideration should be given to including a demonstration or evaluation of the use of solar energy collectors to provide heat for domestic hot water. Heat from a solar device to heat water to 120 to 150°F will probably cost \$5 to \$6 per million Btu (equivalent to 1.7¢ to 2.0¢/kWhr) in the most favorable U.S. climate.

Potable water for the installation would be from either a ground (well) or a surface (stream, lake, or reservoir) source. Ground water is preferred if available in sufficient quantity and of reasonable quality. Minimum treatment would consist of disinfection; but additional treatment to remove hardness, iron and manganese, taste, and odor could be necessary. Treatment of surface water depends on the quality of the water, availability of land and local resources (sand), and climate. Treatment may be by a package plant which includes sedimentation, coagulation, flocculation, filtration, and disinfection. An alternate approach would be slow sand filtration followed by disinfection plus additional treatment as necessary. Dual disinfection systems such as chlorination-ozonation or chlorination-ultraviolet can be used to increase safety and reliability.

Two methods of supplying water for fire protection are considered. The first is a conventional system using potable water. Because the flow requirements for fire protection are much larger than for domestic use, the conventional system requires much larger capacities of potable water distribution and storage systems. The second method is to provide a separate fire protection system. The water storage reservoir for this system could be a pond with the water supply being the normal water supply (untreated) or the effluent from the liquid waste treatment plant. Use of liquid waste effluent would be advantageous for conserving water in installations where the fire protection system would also supply process water for industrial, commercial, or agriculatural uses and for MIUS heat rejection.

The liquid waste collection system would probably be gravity flow sewers except where geologic or topographic reasons prevent their use. Where gravity sewers are impractical, either pumped or vacuum sewers could be used. These latter systems may reduce the installation cost, but require greater operating cost. The type of liquid waste treatment plant that one uses, biological or physical-chemical or some combination of these, will depend on the effluent quality required and on any intended reuse of the effluent. Biological treatment is less expensive than physical-chemical treatment; however, the effluent produced by a physical-chemical plant is lower in final BOD, suspended solids, and nutrients. Treatment systems are available as package plants, or can be built up of various units to provide effluents with various qualities. Depending on the effluent quality, further treatment may be necessary to use the water for process purposes.

Solid waste collection in small installations or in low- or medium-population density areas would probably be by manual collection. Automatic vacuum collection systems should be considered only in high-population density areas as, for example, those with buildings five stories or higher. Two methods of disposal are considered; these are sanitary landfill and incineration with heat recovery. Although the economics of incineration with or without heat recovery may not be currently favorable, it is suggested that an incinerator heat-recovery system be installed for study and demonstration purposes in an installation with a solid waste generation rate of 4 or more tons per day, which corresponds to developments of at least 2000 residents.

It is obvious from Table 3 that the total number of combinations of possible subsystems is enormous (>100,000). However, once the location, consumer mix, size, layout and process water uses are known, the number of combinations can be quickly reduced to a manageable size. Figs. 18 through 21 show some preliminary suggestions of the subsystem combinations discussed above.

SUMMARY

The major components and subsystems that are considered applicable for near-term MIUS are listed in Table 3 with the types of subsystems that are preferred or considered essential for a MIUS identified by an asterisk.

For the most important parts of the energy subsystem, a single choice (except for fuel options) was recommended for the prime movers and only two choices were listed for the heat recovery system of which the ebbulient type was preferred.

Space heating and space cooling could be provided with a four-pipe hot and chilled water distribution system for applications that avoid long distribution lines. Some use of heat pumps and gas, oil, or electric building or residence heaters may be desirable depending on the climate and the distance from the central equipment building. It is recommended

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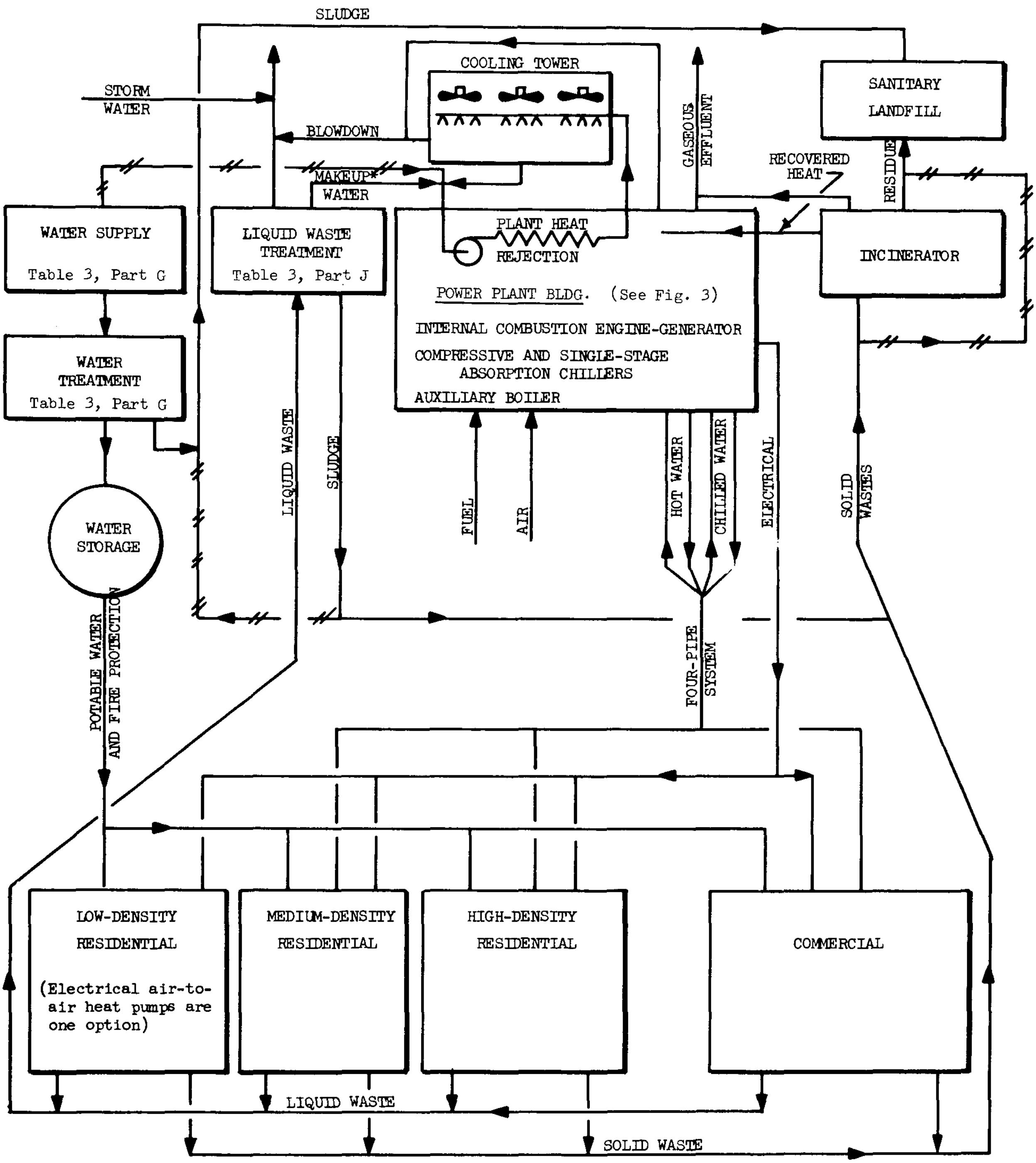

*Additional treatment of makeup water may be required depending on the effluent quality.

Note: —//——//— indicates alternate system.

Fig. 18. Preliminary concept A of a MIUS.

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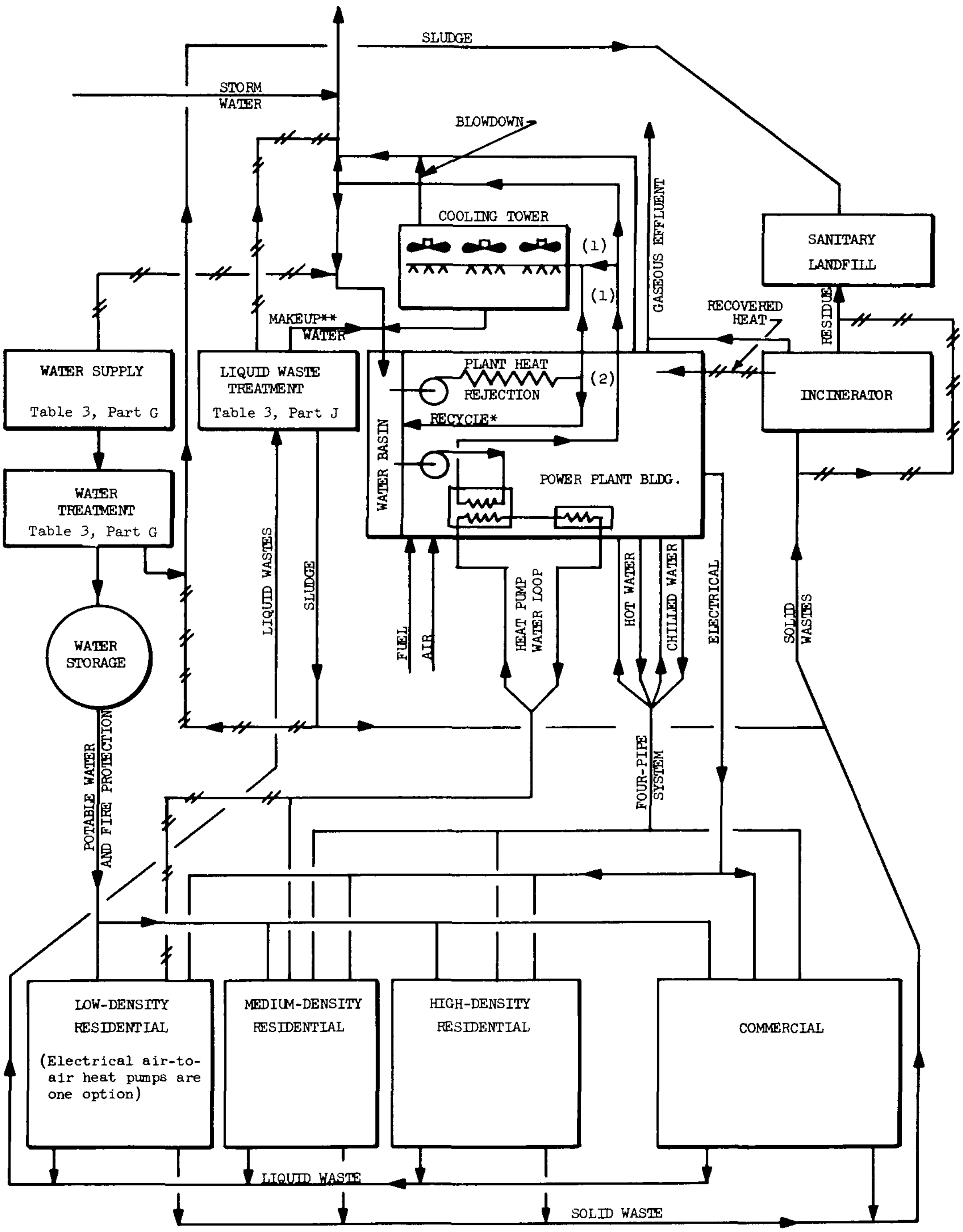

(1) Summer flow direction (2) Winter flow direction

*During winter - plant low grade heat and excess high grade heat recycled to water basin.

**Additional treatment of makeup water may be required depending on the effluent quality.

Note: —//————//—— indicates alternate system.

Fig. 19. Preliminary concept B of a MIUS.

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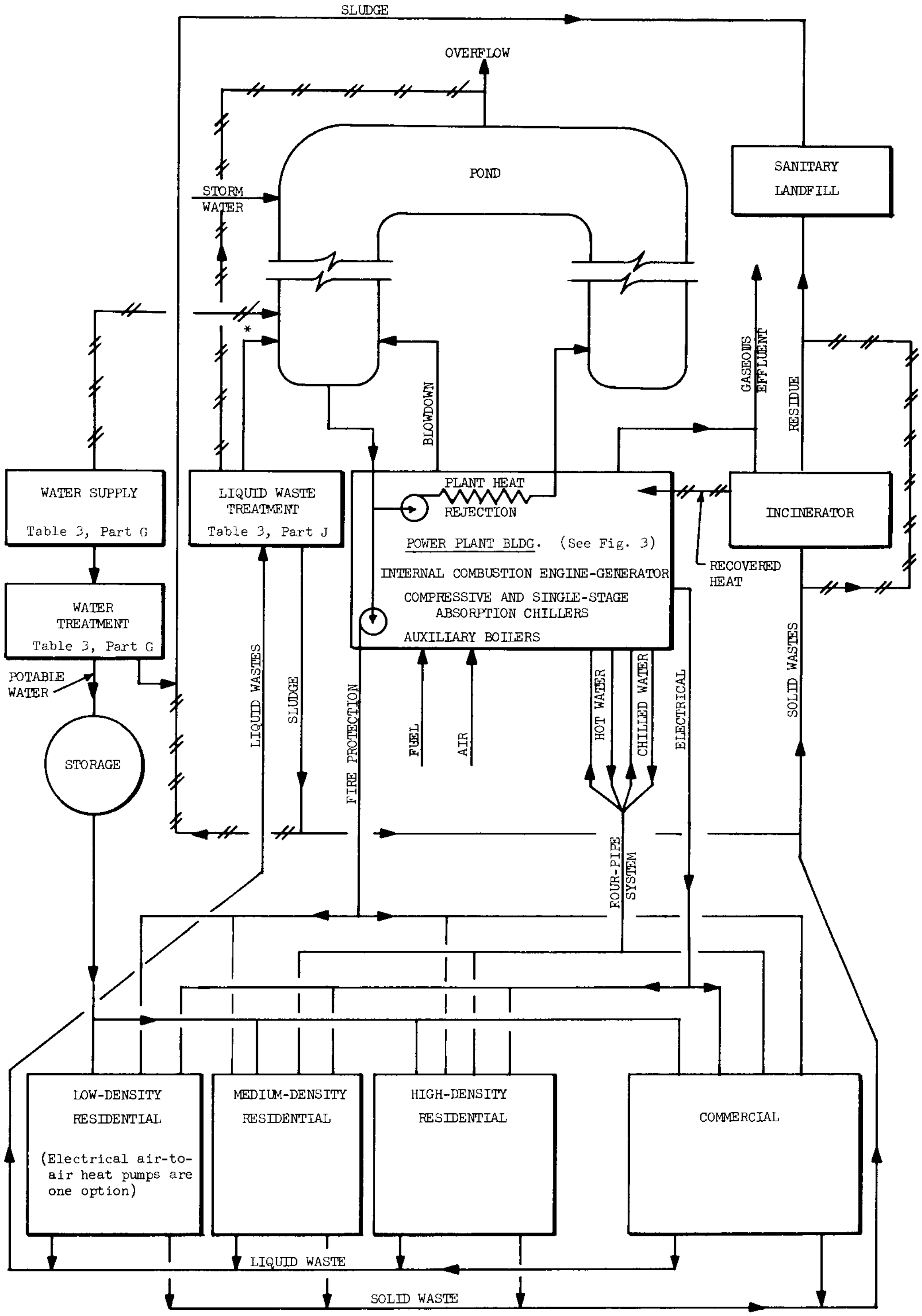

*Additional treatment of water may be required depending on effluent quality.

Note: —//——————//—— indicates alternate system.

Fig. 20. Preliminary concept C of a MIUS.

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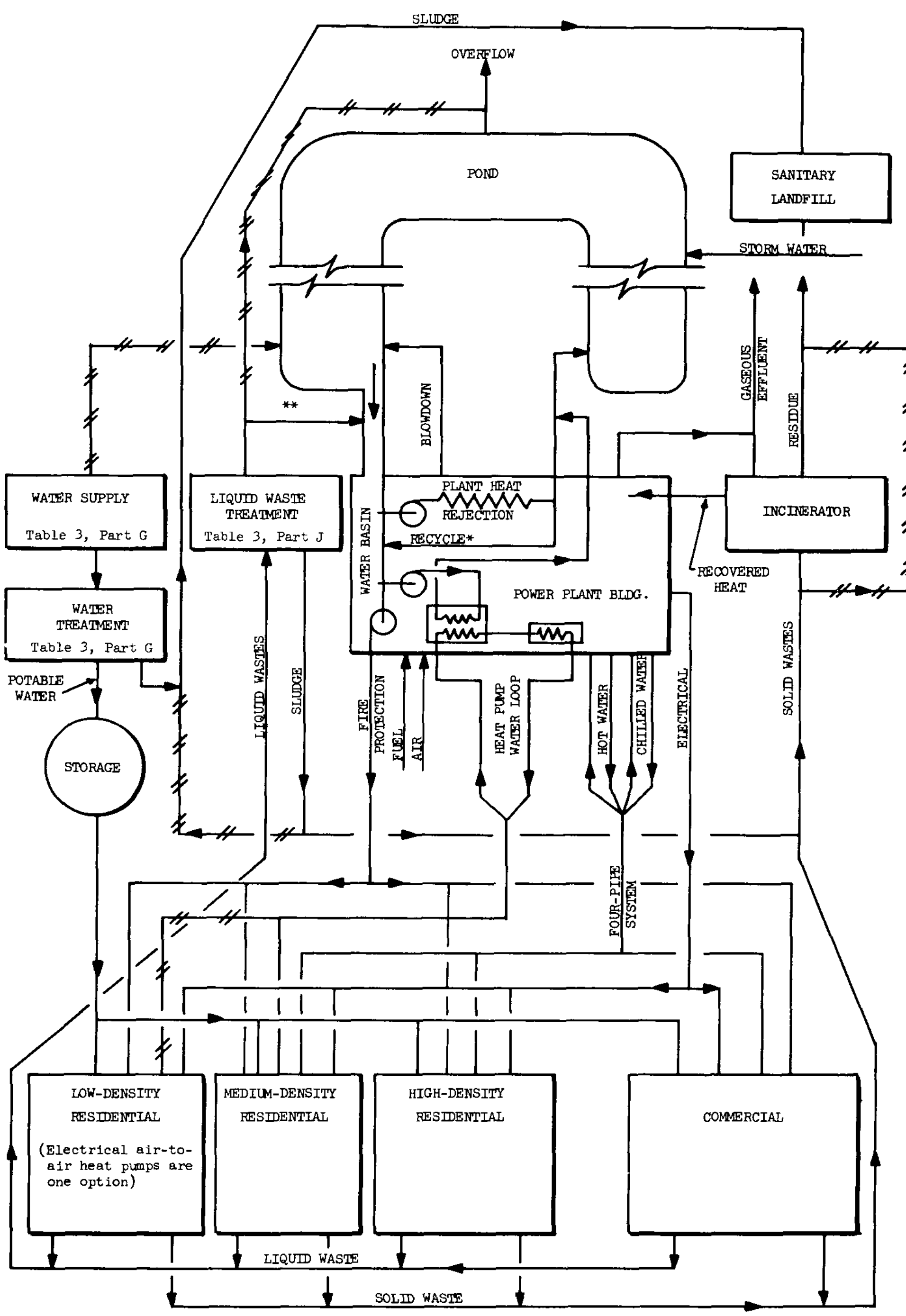

*During winter - plant low grade heat and excess high grade heat recycled to water basin.

**Additional treatment of water may be required depending on effluent quality.

Note: —//——//— indicates alternate system.

Fig. 21. Preliminary concept D of a MIUS.

that domestic hot water be heated by the district hot water system wherever it is available. At other consumers it can be supplied by either building or individual residence heaters using gas, oil, or electricity.

Heat rejection from the prime movers is either to a cooling pond or to a cooling tower. The cooling pond approach is attractive because of its multiple-use aspects and possibilities for conservation of water. Use of the liquid waste effluent for cooling water would reduce water withdrawal. However, depending on the quality of the effluent, further treatment may be required.

The potable water supply can be a surface water source; however, a groundwater (well) source will be better for many locations. Use of a separate piping system from a storage pond (such as the cooling pond) to provide fire protection water also appears to be attractive.

Liquid waste collection by a gravity-flow collection system to a treatment facility is recommended unless there are geologic or topographic problems that require a vacuum or pressure system. The biological liquid-waste treatment system is the least expensive and would be used unless the effluent would not meet the release requirements. Biological treatment effluent would probably require additional treatment before it could be stored in a pond or used as process water. If additional treatment is necessary for the effluent to meet release quality standards, systems other than those described by Figs. 13 through 15 could be incorporated to achieve the desired effluent.

Solid waste collection will probably be manual, except for cases of high-population density where a vacuum system may be desirable. Disposal of the solid waste by incineration with heat recovery is recommended if it is desired to reduce the solid waste requiring ultimate disposal or for high-cost sanitary landfill regions, and if the recovered heat can be utilized. However, for many cases, incineration may not be as economical as sanitary landfilling.

The incorporation of a heat recovery system for the incinerator is recommended for demonstration purposes but should be demonstrated on a development producing at least 4 tons of solid waste per day.

Basic MIUS concepts are illustrated by Figs. 18 through 21. Figures 18 through 21 are merely illustrations of how the various subsystems could be combined and integrated with one another and are not to be interpreted as optimum solutions. Detailed systems analysis using specific site characteristics, local economics, and availability of local utilities will be required to define the best MIUS for a given site.

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