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PRELIMINARY DESIGN STUDY OF A BASELINE MIUS

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

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16 Abstract

The results of a conceptual design study to establish a baseline design for a modular integrated utility system (MIUS) are presented. The system concept developed herein will become a basis for evaluating possible projects to demonstrate an MIUS. For the baseline study, climate conditions for the Washington, D.C., area were used. The baseline design is for a high-density apartment complex of 496 dwelling units with a planned full occupancy of approximately 1200 residents. Environmental considerations and regulations for the MIUS installation are discussed. Detailed cost data for the baseline MIUS are given together with those for design and operating variations under climate conditions typified by Las Vegas, Nevada, Houston, Texas, and Minneapolis, Minnesota. In addition, the results of an investigation of size-variation effects, for 300- and 1000-unit apartment complexes, are presented. Only conceptual aspects of the design are discussed in this report. The results regarding energy savings and costs are intended only as trend information and for use in relative comparisons. Alternate heating, ventilation, and air-conditioning concepts are considered in the appendix.

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PRELIMINARY DESIGN STUDY
OF A BASELINE MIUS

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PREFACE

The Department of Housing and Urban Development (HUD) is conducting the Modular Integrated Utility System (MIUS) Program 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.

Under HUD direction, several agencies are participating in the HUD-MIUS Program, including the Energy Research and Development Administration, the Department of Defense, the Environmental Protection Agency, the National Aeronautics and Space Administration, and the National Bureau of Standards (NBS). The National Academy of Engineering is providing an independent assessment of the program.

This publication is one of a series developed under the HUD-MIUS Program and is intended to further a particular aspect of the program goals.

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Coordinated Technical Review

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

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PRELIMINARY DESIGN STUDY
OF A BASELINE MIUS

By Barry M. Wolfer, Vernon E. Shields, James O. Rippey,
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SUMMARY

A conceptual design study for a high-density, 496-unit apartment complex in a median climate (Washington, D.C.) was performed to determine whether a modular integrated utility system (MIUS) would be cost competitive with conventional utilities and whether implementation of the MIUS would result in use of less fossil fuel. Detailed cost analyses were performed for the baseline MIUS complex and comparisons were made of design and operating variations for climatic conditions typified by Las Vegas, Nevada, Houston, Texas, and Minneapolis, Minnesota. In addition, size-variation effects were investigated using 300- and 1000-unit apartment complexes for comparison with the baseline 496-unit complex. An investigation of possible environmental impacts and of State and local regulations for Montgomery Village, Maryland, indicated that numerous problems would be encountered in implementing an MIUS.

The initial costing plan for the baseline MIUS was based on Chicago, Illinois, costs as representative of the national median. All historical cost data were adjusted by the appropriate Department of Labor cost index to reflect mid-1974 costs. Further adjustment from Chicago to Washington, D.C., costs was made for the baseline MIUS. The costs include subcontractor profit and overhead, but not general contractor profit and overhead. Costs for equipment located in the apartment buildings are not included. Also excluded are individual dwelling metering and billing costs and administrative costs, property taxes, and other such real costs. Both capital costs and operating and maintenance costs are considered. The maintenance costs have been largely based on 20-year average values and represent the costs required to keep equipment in good repair but do not include replacement, depreciation, or amortization values.

The MIUS design presented in this report is not sufficiently detailed for implementation. The MIUS concept, as developed currently, is such that a unique design for each application must be made with respect to capacities, interfaces with existing systems and services, environmental interfaces and impacts, distribution and interfaces with serviced buildings, and other such effects.

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INTRODUCTION

The National Aeronautics and Space Administration (NASA) has conducted modular integrated utility system (MIUS) conceptual design studies for various single types of facilities, including garden apartments, an office building, a shopping center, a hospital, a school, and high-rise apartments. A subsequent NASA study concerned application of the MIUS to the utility system of a new satellite community with a population of 100 000 residents (ref. 1). As a result of these studies, the baseline MIUS characteristics were presented at the Systems Requirements Review held at the NASA Lyndon B. Johnson Space Center (JSC) in September 1973. These characteristics featured the use of diesel generators for electricity production, incineration for solid-waste disposal, a combination of absorption and compression air-conditioning, a biological wastewater treatment plant with physical/chemical tertiary treatment, and recovered heat from power generation and incineration to provide domestic-hot-water heating and space heating and to operate absorption air-conditioning.

Also, as a result of the earlier studies, the Systems Requirements Review, and a market study conducted by the NASA, it was concluded the market with the most potential for MIUS applicability and demonstration was apartment complexes of approximately 300 to 1000 units. Consequently, it was decided to define an MIUS in greater detail for an apartment complex of 500 units in a median climate in the continental United States. This design would serve as a baseline for future MIUS studies and as a base for the evaluation of possible demonstration systems. To understand the effects of variations on that design, it was decided to define changes in the MIUS system that would result from moving such an apartment complex to colder or warmer regions in the United States, as well as changes that would result if the apartment complex were smaller or larger.

The objectives of this study were as follows.

1. To define and cost a baseline MIUS system for a 500-unit apartment complex consisting of a mix of high-rise and garden apartments in a median climate

2. To investigate the deviations from that baseline for variations in location (climate) and size

3. To develop a performance specification (A preliminary performance specification was prepared and circulated; but, because agreement was not reached with other MIUS program participants, the specification was never published.)

4. To assess the environmental impact of the baseline MIUS system

The overall study ground rules were as follows.

1. The MIUS will provide the following services.

   a. Electrical power

b. Space heating and cooling

c. Solid-waste disposal

d. Potable water (including domestic hot water)

e. Wastewater treatment

2. The MIUS design will be based on existing "articles of commerce" as of 1974. "Articles of commerce" for this study are defined as components, materials, and equipment currently in production and readily available without developing special tools or premium cost.

3. Location (climate) variations will be, specifically, Washington, D.C., as median, Minneapolis, Minnesota, and Houston, Texas, as the extremes, and Las Vegas, Nevada, as a hot, as well as dry, extreme.

4. Size variations from the baseline will be 300 units and 1000 units.

5. Changes to the ways in which the utilities are conventionally used will be minimized.

6. A comparison will be made with a conventional system for consumables usage, costs, and environmental impact.

7. The following guidelines will be used in costing.

a. Who pays will not be considered; only total costs.

b. Costs will be in terms of 1974 dollars, project installation will be assumed to be in 1975, and cost projections will be made for all items.

c. Escalation rates will be assumed to be 3 to 5 percent except for fuel costs, which will be analyzed at 5 to 15 percent.

d. Discount rates will be analyzed parametrically between approximately 0 and 15 percent to allow for the options of ownership by local government, a regulated public utility, or a private investor.

e. Cost analysis will be considered over the 20 years following installation.

f. Effects of mass production will not be considered.

As an aid to the reader, where necessary the original units of measure have been converted to the equivalent value in the Systeme International d' Unites (SI). The SI units are written first, and the original units are written parenthetically thereafter.

STUDY LOGIC

Figure 1 illustrates the tasks, together with the corresponding logic flow, that were accomplished in the study.

FACILITY MODEL

The purpose of the facility model was to define a baseline 500-unit apartment complex that would provide a model for engineering calculations of utility loads for MIUS equipment selection and integration and that would allow for variations in size and location (climate). This apartment complex model was not intended to represent an actual design solution for a specific site; rather, it was a diagram to reflect the significant design parameters for apartment complexes so as to serve as a tool for engineering studies.

Task Logic

To develop a baseline apartment-complex model, ground rules were established to define the scope of the task, a survey was performed to determine the state of the art of the apartment construction industry, and some logical assumptions were made. The model was then derived and defined in sufficient detail to enable engineering calculations of the loads. This task logic is illustrated in figure 2.

Ground Rules

The ground rules established for development of the baseline apartment-complex model were as follows.

1. The baseline apartment-complex model is to contain approximately 500 dwelling units and be situated in a climate similar to that of Washington, D.C.

2. The facility model should represent the state of the art in apartment-planning concepts and construction techniques.

3. The apartment-complex model should represent (for utility consumption purposes) the range of typical apartment building and unit types now being built, and these types should be in the same ratio to one another as that which is likely to occur in construction.

Survey: State of the Art

Parameters for the apartment-complex design were researched and developed. The major parameters were the type of apartments, size of apartments, number of buildings, type of buildings, density factors, parking ratios, open-space allotments, construction phasing, and auxiliary services.

To provide a data base range that would accommodate variation studies, data were obtained for the cities selected for climatic data variations - Houston, Texas, Minneapolis, Minnesota, and Las Vegas, Nevada, for the extreme climates, and Washington, D.C., for the median climate. An additional city, Los Angeles, California, was selected for the apartment-complex data base to reflect near-term trends in apartment design, construction, and planning. Los Angeles was chosen from a list of the key market areas.

To supplement research from the literature, a limited survey was made in the selected cities to provide a current data base for the general profile of recent apartment projects. The survey was accomplished by a combination of data-collection techniques - personal visits and inquiries by telephone and by mail - to secure the largest data base possible in a limited time. Although the amount of data available varied with each project, sufficient data were collected to determine the type of apartments, the number of apartments per project, the area for each apartment type, the percentage of each apartment type in each project, and the ratio of singles units to family units. In addition to the survey, other personal visits were made to various people in the apartment industry in each of the selected cities to verify the survey data.

In general, the results of the survey revealed certain trends in apartment construction and equipment, as follows.

1. Most new apartments have a dishwasher.

2. The average ratio of washers and dryers to apartment units is one washer and one dryer for every five to seven dwelling units.

3. Three-story construction is the trend for garden apartments.

4. A variety of well-developed exterior spaces between the units is a market asset (i.e., community space around pools, intimate spaces for cookouts, etc.).

5. Most units offer private outdoor space such as a patio or a balcony.

6. Most complexes offer recreational facilities of a character that varies with the specific market of the project.

7. Most projects have convenience retail outlets nearby.

8. Most garden-apartment buildings are of wood frame construction.

9. Most large projects are built in one phase under one contract.

10. The more recent complexes tend to have a medium- to high-density range (in terms of the number of units per area).

Assumptions

To provide the desired range of building types in the facility model, high-rise apartment buildings were included. The ratio of high-rise to low-rise apartments in the baseline project was assumed to be 1:5; this ratio reflects the national average of high-rise to low-rise apartment buildings.

The apartment types were divided into two basic units, singles units and family units, in a ratio of 2:3, respectively. The basis of this assumption was a combination of information gained from the survey and the desire to include a full range of building types in the model. The family units were limited to the low-rise apartments only, because this type of unit provides a better opportunity for family-oriented activities than does the average high-rise apartment building.

From the survey, the ratio of unit types in a representative low-rise singles project was used for the low-rise-unit and high-rise-unit mix combined in a reasonable way. The family-unit mix was from the survey for the low-rise family buildings. Therefore, the model included high-rise singles units, low-rise singles units, and low-rise family units.

The buildings were arranged into groups of family and singles areas and were modeled to represent the typical height (floors) and number of units for each building type. A parking-space ratio of 1.5 cars/unit was assumed.

Baseline Facility Description

A detailed description of the baseline facility model for apartment complexes is contained in tables 1 to 6 and in figures 3 to 6.

BASELINE MIUS DESIGN

Ground Rules and Criteria

The following paragraphs describe the ground rules and criteria used in the design of the baseline MIUS.

Optimization approach.- The selection parameters for subsystem and system alternatives were the cost of utilities to the MIUS-served residents, energy and water consumption, reliability, and environmental impact. The cost of utilities was the primary selection parameter, with alternatives evaluated where necessary. When results of the economic selection caused substantial adverse effects on consumables usage, reliability, or environmental impact, a management decision was made on the basis of the relative significance of the four selection parameters. The level of system optimization was limited by the 1974 "articles of commerce" ground rule.

Reliability considerations.- The MIUS is intended to have a reliability comparable to that of conventional systems. The primary considerations are electrical power service and water service. Because the reliability of these conventional utilities is a function of many parameters, including the location of the service relative to the central plants, the reliability requirement will be assumed to be met through adequate reserve capacity high-quality equipment, and continuous operator coverage.

Codes and regulatory agencies.- Any deviations from codes, guidelines, design criteria, and/or regulations produced by national organizations and agencies will be identified and suitably justified.

Electrical power.- The ground rules and criteria used in the electrical power phase of the baseline MIUS design were as follows.

1. The energy source will be fuel oil.

2. The electrical system will be operationally independent of an existing grid. The reliability of the independent system will be comparable to that of a conventional system.

3. Power will be generated at 60 hertz, three-phase.

4. A 30-day fuel-storage capability will be provided.

5. Heat-recovery equipment will be compatible with the heating, ventilation, and air-conditioning (HVAC) subsystem.

6. Stack emissions will comply with applicable Environmental Protection Agency (EPA) guidelines.

Heating, ventilation, and air-conditioning.- The ground rules and criteria for the HVAC phase of the design were as follows.

1. A four-pipe system for circulating hot and chilled water will be used.

2. Maximum use of recovered heat will be made for both cooling and heating.

3. For cooling, compression machines will be used for supplemental cooling if sufficient recovered heat for total absorption cooling is not available.

4. For heating, boilers will be used for supplemental space heating if sufficient recovered heat is not available from the engines and from incineration of solid waste.

5. Treated wastewater will be used in the cooling tower or towers.

Solid waste.- The solid-waste phase of the design was based on the following ground rules and criteria.

1. Solid-waste processing will include incineration.

2. Utilization of supplemental fuel will be minimized.

3. Solid waste will not be imported to the facilities being served by the MIUS.

4. Disposal of the incinerator residue will be in a landfill remote from the facilities being served by the MIUS.

5. A 3-day supply of solid waste will be stored for the possibility of system failure and so that incineration will not be required during weekends.

6. The burning schedule will conform to HVAC requirements when it is possible.

7. Heat-recovery equipment will be compatible with the HVAC subsystem.

8. Stack emissions will comply with applicable EPA guidelines.

Water.- The water phase of the system design was based on the following ground rules and criteria.

1. No consideration will be given to storm water.

2. Adequate pressure and storage for firefighting purposes will be provided.

3. The design of the potable-water-treatment and firefighting capabilities will enable optional use in the MIUS.

Potable water: The guidelines concerning potable water were as follows.

1. Potable water will comply with the 1962 U.S. Public Health Service standards for drinking water (ref. 3).

2. Domestic hot water of potable quality will be heated to a temperature of 338.7 K (150° F) with the use of recovered heat.

Wastewater: The guidelines concerning wastewater were as follows.

1. Wastewater treatment will be consistent with requirements for recycling for nonpotable use and/or disposal to the external environment.

2. Human contact with treated wastewater will be minimized.

3. Treated wastewater may be utilized in heat rejection and other MIUS processes.

4. Treated wastewater may be used for firefighting.

5. Treated wastewater may be used for lawn watering.

6. Because of the site-unique problems that will arise in the off-site disposal of treated wastewater, only nominal consideration will be given to this function.

Design Approach

The general approach used in the design of an MIUS is discussed in this subsection. The discussion is not limited to the specific MIUS design described in this document and applies only to a preliminary or conceptual design rather than to the detailed hardware design of piping layout, pumps, tanks, etc.

Typical MIUS design features.- A "typical" MIUS consists of the equipment necessary to provide all required utility and HVAC services, integrated into a single system. Electrical power is generated and distributed to satisfy the various electrical demands of building equipment and occupants, as well as the ancillary MIUS equipment such as pumps, and cooling towers. Heat is recovered from the prime-mover exhaust, the water jacket, and the oil cooler and is added to the heat recovered from solid-waste incineration. The recovered heat is first used for domestic hot-water-heating and domestic space-heating requirements. Additional recovered heat that is at a sufficient temperature level is utilized for absorption cooling to satisfy air-conditioning requirements. If the amount of cooling available from waste heat is insufficient, electrically driven compression cooling is used to satisfy the remaining cooling load. As the electrical load on the prime mover is increased to drive the compression chiller, the additional waste heat available is used to provide additional absorption chiller capacity. A boiler is used to satisfy any domestic space-heating or hot-water requirement that cannot be met by recovered heat but is never used to satisfy a cooling load. A wastewater treatment facility is integrated with the other equipment in that it provides treated water for heat rejection in wet-cooling towers and other process makeup water to the MIUS plant. Potable-water treatment is optional, as required, at the specific site.

Several options are available for tailoring an MIUS for specific applications and load profiles. The incinerator operation profiles and capacity can be adjusted to provide waste heat at the times of greatest demand. The prime-mover size and type can be varied to optimize reliability and fuel utilization. Thermal storage of hot and chilled water can be incorporated to reduce installed electrical generation capacity and improve heat utilization. For most MIUS applications, boilers can be eliminated either by the use of thermal storage or by the use of the incinerator without solid waste for short time periods.

General MIUS design procedure.- The general MIUS design procedure flow is shown in figure 7. The initial step is the facility model definition, which is a result of the architectural design of the facility. From this model, the buildings are characterized in terms of heat-transfer coefficients (U-values), areas, orientation, occupancy profiles, ventilation rates, etc., and a preliminary estimate is made of system loads such as solid-waste type and quantity, domestic and auxiliary electric loads, etc. Auxiliary loads are defined as all electrical loads, including MIUS plant loads, not located in environmentally conditioned space. These preliminary loads and building characterization data are used with design weather data in a computer design analysis, with use of the Energy Systems Optimization Program (ESOP) (ref. 4), to determine peak loads and equipment requirements. The ESOP design analysis provides information required to select MIUS equipment and to refine all the system loads. Another ESOP analysis is then performed with use of the updated equipment-selection information and mean weather data to provide seasonal and annual system performance data. Performance analyses and energy balances are performed; and, if it is required, equipment selection is updated to optimize annual performance and the second ESOP analysis is performed again. Competitive system configurations can be further evaluated by using economic considerations.

If thermal storage is desired, its primary effect is to reduce electrical power generator installed capacity requirements and, therefore, capital costs. Accordingly, the generators are sized to satisfy the peak non-air-conditioning electrical demands, and the excess generator capacity during offpeak periods is used to produce chilled water for use during peak periods; or, in the case of hot storage, all unused heat is stored up to the volume of the storage facility, which is sized for the cooling load. Several iterations with both design data and mean weather data are often required to accurately size the storage facilities, the HVAC equipment, and the prime movers and to provide meaningful annual-energy-consumption estimates.

Computer input and output summary.- The ESOP and its use are described in reference 4. The ESOP is basically composed of a loads section and an energy analysis section. The input data are summarized as they apply to these two sections; the loads section requires data relating primarily to building and environmental parameters, and the energy analysis section requires data relating primarily to MIUS equipment and output from the loads section. The output is also summarized for the loads section and the energy analysis section. The system loads are summarized and automatically provided to the energy section during one execution of the program. The detailed loads output is provided by the program hourly for each building type, as well as the totals for the entire facility. Output from the energy analysis section is provided hourly for one mean day per season and totaled for each season. The output data basically show fuel requirements and a detailed accounting of all energy uses. Some additional information on the ESOP is given in the subsection entitled "Energy and Consumables Usage Analyses." The following list is a summary of the input and output data for the ESOP.

Input data

- Loads analysis
  - Building characterization
    - U-values for walls, roof, and glass
    - Areas of walls, roof, and glass
    - Glass-type factors (for solar admittance into building)
    - Occupancy profile
    - Domestic electricity profile (for loads inside conditioned space)
    - Ventilation rates
    - Design inside temperature and enthalpy profiles
  - Water loads analysis
    - Number of occupants per building
    - Type of building (currently, residential only)
  - Environmental parameters
    - Hourly profile of outside dry-bulb temperature
    - Latitude and longitude
    - Building orientation
    - Atmospheric clearness index
    - Profile of outside air enthalpy
- Energy analysis
  - Solid-waste data
    - Solid-waste contents and amount
    - Heat value of solid waste
    - Fuel requirements
    - Disposal method (incinerator and/or pyrolysis)
    - Waste-heat-utilization profile
    - Heat-recovery efficiency

    - Operation cost factors
- HVAC data
    - Boiler efficiency
    - Absorption/compression ratio
    - Coefficient-of-performance profiles for absorption and compression chillers
    - Heat-rejection water requirements
    - Thermal-storage parameters
- Electrical power generation
    - Generator rated capacity
    - Engine rated capacity
    - Fuel heating values
    - Fuel as a function of load data
    - Waste heat as a function of load data (for oil coolers, water jacket, and exhaust jacket)
    - Steam-cycle data if these data are required
- Waster and energy uses
    - Uses for excess 388.7 K (240° F) heat
    - Uses for excess 349.8 K (170° F) heat
    - Uses for excess 310.9 K (100° F) heat
    - Uses for wastewater effluent

Output data

Loads analysis

- Hourly heat gain from walls, roof, windows ventilation, hot water, electricity, etc.
- Total hourly space-heating demand
- Total hourly air-conditioning demand
- Power requirements

Hot-water requirements

Potable-water requirements

Totals of the previous items for the entire facility served by the MIUS

Energy analysis

Generator data (engine output, fuel consumption, thermal efficiency, generator output, etc.)

Number of generators required

Waste heat available and its sources

Boiler heat and fuel

Amount of absorption and compression air-conditioning

Waste heat not used at each of three temperature levels

Waste heat used at three levels

Waste-heat requirements not met

Thermal-storage accounting

Cooling-tower water requirements

Wastewater requirements not met

Wastewater available for reuse

Solid waste, disposal costs, and effluent

Seasonal and yearly fuel consumption

Comparison of as many as 24 fixed MIUS configurations and 1 conventional system

Utility Loads

The various utility loads are discussed in the following subsections.

Electrical power.- The electrical load profiles used in this study were developed from metered electrical data for two garden-apartment complexes in the Washington, D.C., metropolitan area. One of the complexes consisted of 286 dwelling units and the other, 100 units.[1]

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[1] Data from GATE Information Center, Southwest Research Institute, 8500 Culebra Road, San Antonio, Texas.

The domestic electrical load is based on the assumption that each apartment contains lighting, small appliances, air-handler motor loads, an electric refrigerator, an electric range, and a garbage disposal. Hallway and outdoor lighting is at 79 W/dwelling unit and is assumed to be continuous. The difference in the electrical demand and the energy consumed by the subsystem is not significantly impacted by this assumption.

The auxiliary loads for the design (2σ, where σ is standard deviation) summer day are based on a maximum outside temperature of 308.7 K (96° F) and a building-temperature control at 296.5 K (74° F) in a floating-split air-conditioning scheme; i.e., all the recovered heat energy from the prime movers will be used in absorption air-conditioning before supplemental air-conditioning is made up by compression-type cooling. The peak MIUS (and conventional) electrical demand for the Washington, D.C., area occurs on the 2σ summer days.

The domestic electrical demand and auxiliary electrical demand (excluding chiller power) daily profiles are given in table 7. Of the auxiliary loads, which have been defined as all electrical loads (including the MIUS plant loads) not located in environmentally conditioned space, the chiller loads are developed in the ESOP.

The apartment complex was divided into four groups by building type. The total domestic electric load profile for each building type is given in table 8. It was necessary to define the loads in this manner so that the electrical distribution subsystem could be optimized and the total heating and cooling loads could be calculated for the HVAC subsection.

Heating, ventilation, and air-conditioning.- The load inputs and results for the HVAC subsystem are discussed in the following subsections.

Load inputs: The load inputs to the computer necessary to establish HVAC load characteristics were as follows.

1. Heat-transfer coefficients (U-factors) of roof, walls, and windows
2. Respective roof, wall, and window areas
3. Indoor environmental design conditions
4. Building orientation and location
5. Ventilation and infiltration criteria
6. Occupancy profiles
7. Domestic-hot-water-requirement profiles
8. Domestic electrical load profiles

The U-factors for walls and roofs were selected from those for similar buildings typically constructed in the locations investigated. It was determined that most garden-apartment/high-rise-apartment walls could be defined by U = 0.07. Similarly, residential buildings with pitched roofs and 15.2-centimeter (6 inch) batt insulation or flat roofs with mineral fiber insulation are frequently represented throughout the country and have a U = 0.05. A typical single-pane-glass U-factor with 3.4-m/sec (7.5 mph) wind is 1.06. A typical shade factor on all the windows of 0.7 accounted for external shading devices, draperies, and blinds.

Building arrangements and dimensions were supplied by consulting architects. Exposed roof, wall, and window areas were calculated from the drawings.

A baseline indoor environment of 296.5 K (74° F) (dry bulb) and 50-percent relative humidity was chosen for the year-round environment because this condition is an acceptable mean according to the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) (ref. 5, p. 137). The outdoor air requirement used in this study and recommended by ASHRAE for apartments was 0.6 m^3/min (20 ft^3/min) per person. Design occupancy used for establishing ventilation loads was based on the Uniform Building Code (ref. 2, p. 443) criteria of 27.9 m^2/person (300 ft^2/person) for low-rise apartments and 18.6 m^2/person (200 ft^2/person) for high-rise apartments.

Outdoor design conditions were based on hourly weather data (ref. 6) for the Washington, D.C., area. Summer peaks were set at the peak of the average profile plus two standard deviations, and winter minimums were set at the minimum of the average profile minus two standard deviations.

The domestic-hot-water requirement and domestic electrical load profiles used were obtained from the water and electrical load determinations, respectively.

Load results (for baseline heating and cooling): Maximum heating loads were determined for two cases - winter days without clouds and winter days with full cloud cover (ref. 6) - by using the resulting temperatures two standard deviations below the mean (260.9-K (10.0° F) minimum at 6 a.m. and 7 a.m.). The peak heating load occurred at 8 a.m., with full cloud cover, and the following components contributed to the load as indicated.

Component	Contribution to load, percent
Roofs	7.4
Walls	18.0
Windows	16.1
Ventilation	40.7
Occupancy	-3.2
Electric	-25.1
Hot water	46.1
	100.0

The total load is equivalent to 1735.5 kilowatts (5 925 857 Btu/hr). An additional 109.9 kilowatts (375 378 Btu/hr) were attributable to the maximum distribution losses to all the buildings by means of a two-pipe hot-water system. Several distribution-loop arrangements were investigated for hardware cost effectiveness, and the least-cost arrangement was chosen. The resulting losses were calculated on the basis of nominal underground insulation performance for extreme ambient conditions.

With the use of representative average-day profiles, seasonal heating loads for each season were calculated, primarily for use in establishing annual energy balance and consumption values. Average monthly weather data from reference 6 for the months of January, April, July, and October were taken as seasonal representative days. An annual energy-balance determination was conducted to incorporate and account for the effects of the thermal-storage equipment.

Maximum cooling loads were determined for a cloudless summer day with temperatures two standard deviations above the mean (309.3 K (97.0° F) maximum, dry bulb, and 300.4 K (81.0° F), maximum wet bulb, at 2 p.m. and 3 p.m.). The peak cooling load of 1906.1 kilowatts (542 tons) occurred at 4 p.m., and the following components contributed to the load as indicated.

Component	Contribution to load, percent
Roofs	7.1
Walls	11.3
Windows	16.2
Ventilation	41.3
Occupants	3.4
Electrical	20.7
	100.0

Maximum distribution losses in the two-pipe chilled-water system to the buildings contributed an additional 34.04 kilowatts (9.68 tons). Several distribution-loop arrangements were investigated for hardware cost effectiveness, and the least-cost arrangement was chosen. The resulting losses were calculated on the basis of nominal underground insulation performance for extreme ambient conditions.

Seasonal cooling loads based on an average day in each season were calculated to establish profiles for annual energy calculations and consumables.

Solid waste.- The stipulated quantity of solid waste generated within the apartment complex was based on a daily generation rate of 2.3 kg/person (5 lb/person). This generation rate is based on a 1980 time frame and was projected by using references 7 and 8. The heating value of the solid waste was considered to be 11 622.2 kJ/kg (5000 Btu/lb). Collection and storage capacities were based on a solid-waste density of approximately 160.2 kg/m^3 (10 lb/ft^3). Reference 9 indicates densities of 64.1 to 176.2 kg/m^3 (4 to 11 lb/ft^3). The total solid waste produced daily in the complex is 2721.6 kilograms (6000 pounds). The amount of sludge received daily from the wastewater treatment subsystem is 1814.4 kilograms (4000 pounds), with a 20-percent solids concentration. The heating value of the sludge is 11 622.2 kJ/kg (5000 Btu/lb) of dry solids.

Water.- The water management subsystem is designed to service loads generated by the apartment occupant, the apartment facility, and functions associated with the MIUS facility. The loads development and analysis are conducted separately for the potable-water subsystem and the wastewater subsystem and are based on average annual water usage.

Potable-water subsystem: The potable-water subsystem will supply water to meet the loads determined from published surveys of industry associations and private and governmental research organizations and from other published data in which the variables of flow are considered with respect to time, property evaluation, average-user education and occupational type, general occupant age, natural location, and number of occupants per dwelling unit. References 10 to 29 represent a partial list of the material used to develop water requirements and wastewater loads. The user functions considered for the residence demand include kitchen, laundry, bath, and toilet demands. The functions considered for the daily exterior demand include recreational use and carwashing.

The average daily residence demand was calculated to be 0.27 m^3/person/day (72 gal/person). The average daily domestic water demands for total water use, hot-water use, and cold-water use with respect to building type are shown in table 9. The average daily potable-water-usage profiles and the treatment plant capacity are shown in figure 8.

The daily exterior demand for recreational use was calculated by assuming that the swimming pools require a 5.1-centimeter (2 inch) fill once per day during the summer. The apartment facility has two pools, one with a 128.0-square-meter (1378 square foot) surface area and one with a 339.6-square-meter (3655 square foot) surface area. On the basis of these numbers, the total quantity of water required for pools during the summer will be 23.8 m^3/day (6300 gal/day). The water required for spring and fall usage for pools is assumed to be half the summer usage, or 11.9 m^3/day (3150 gal/day).

The daily exterior demand for carwashing was calculated by assuming the faucets used would have a flow capability of 0.01 m^3/min (3 gal/min) and that the daily usage during the spring and fall would be 3 hours. Summer usage was assumed to be 4 hr/day, or 2.7 m^3/day (720 gal/day). The winter usage is assumed to be half the summer usage, or 1.4 m^3/day (360 gal/day). With use of the water quantities developed, the average seasonal potable-water usage is as follows.

Season	Water usage, m^3/day (gal/day)
Summer	350.0 (92 462)
Fall	337.4 (89 132)
Winter	324.8 (85 802)
Spring	337.4 (89 132)

Wastewater subsystem: The wastewater subsystem will be capable of handling the loads described under the potable-water subsystem as the average daily residence demand. This subsystem will not be required to handle the loads described as the daily exterior demand under the potable-water subsystem. This subsystem will also be capable of accepting the blowdown loads of the MIUS processes, particularly from the heat-rejection system in the HVAC subsystem. The wastewater treatment plant effluent will be retained and used to satisfy the demands for firefighting-water storage, irrigation, heat-rejection-system water makeup, and a small amount of other MIUS process water makeup as shown in figure 9. The average flow of wastewater through the treatment plant during the summer will be 347.9 m^3/day (91 900 gal/day).

The firefighting-water storage system is sized at 1 022 058 liters (270 000 gallons). The irrigation water requirements for the apartments are based on the area of irrigation and the climatic conditions. The water quantities were calculated on the assumption of water requirements of 0.64 cm/week (0.25 in/week) for summer, 0.48 cm/week (0.19 in/week) for fall, and 0.16 cm/week (0.06 in/week) for spring. The area to be irrigated is 8832.3 square meters (95 070 square feet). Thus, the irrigation water required is approximately 8.3 m^3/day (2200 gal/day) in summer, 6.1 m^3/day (1600 gal/day) in fall, and 2.3 m^3/day (600 gal/day) in spring.

The heat-rejection-system water requirements are determined by the HVAC subsystem. The quantities of water required are shown in figure 10.

Functional Description

An overview of the MIUS is illustrated by the schematic in figure 11. The power generation subsystem consists of three 478-kilowatt diesel generators and one 400-kilowatt generator. The 478-kilowatt generators are ebulliently cooled with recovery of water-jacket and exhaust heat in the form of 103.4-kN/m^2 (15 psi), 394.3-K (250° F) steam and recovery of lubrication-oil heat in the form of 355.4-K (180° F) water. The 400-kilowatt generator, which does not have heat-recovery equipment, provides backup power for the three engine-generators having heat-recovery equipment.

Solid-waste management is accomplished by a 362.9-kg/hr (800 lb/hr) incinerator, with heat recovery from the exhaust gas in the form of 103.4-kN/m^2 (15 psi), 394.3-K (250° F) steam, which is channeled to the steam header from the prime movers.

The steam is used in three ways. First, it is routed to a heat exchanger that is used to heat a hot-water loop to 366.5 K (200° F); the loop has been preheated by another heat exchanger using the heat recovered from the engine lubrication oil. This 366.5-K (200° F) hot water provided heating of the domestic hot water and space heating. Second, the steam is routed to a 777.2-kilowatt (221 ton) absorption chiller that is supplemented by two 703.4-kilowatt (200 ton) compression chillers to provide chilled water for space cooling. Third, the unused steam is rejected through a heat exchanger to a cooling tower that also provides heat rejection for the three chillers and the 366.5-K (200° F) hot-water loop. Provision is made to store thermal energy from both the chiller-water and hot-water loops in a 724 525.6-liter (191 400 gallon) water tank. The principal effect of such storage is reduction of the peak electrical load required for compression cooling and thus reduction of the required electrical generating capacity that needs to be installed.

The potable-water peak requirement for the apartment complex is 420.2 m^3/day (111 000 gal/day). If the MIUS treats this water, the source could be either a surface supply or a well. In the worst case, for a surface supply, it would be treated by using clarification, filtration, and chlorination processes. Required sewage-treatment capacity is 446.7 m^3/day (118 000 gal/day), and the treatment is accomplished by using a biological system supplemented by a tertiary physical-chemical system. Sludge is transferred to the incinerator for disposal. The treated wastewater is stored in a 454 248-liter (120 000 gallon) retention tank and used in cooling-tower heat rejection and blowdown, makeup and blowdown for other MIUS processes, firefighting, and irrigation of the apartment complex. Disposal of the unused wastewater is to a stream.

Electrical power.- The prime movers for the power generation subsystem were selected on the basis of the peak electrical energy requirement calculated through use of the ESOP. The inputs to the program are domestic electrical loads, auxiliary electrical loads, (excluding chiller power) and cooling loads. All the electrical and heat energy required by all subsystems is considered in the ESOP output: an electrical demand profile to be produced by the power generation subsystem. The profile given in table 10 was calculated for a 2σ summer day, and the demand peak represents the maximum electrical demand anticipated for the power generation subsystem.

The number and size of prime movers were chosen such that the part-load electrical conversion efficiency decreases no more than 3 percent from that achieved at full load. The prime movers selected offer the best energy savings possible over a conventional system and are consistent with good reliability and commercial availability. Electrical power is generated at 460 volts root mean square (rms), three-phase, 60 hertz.

The configuration for the electrical power subsystem is given in figure 12. The subsystem consists of three model 38D8 1/8 Fairbanks-Morse[2]

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[2] Fairbanks-Morse Co., 701 Lawton Ave., Beloit, Wis. 53511.

diesel generators with heat-recovery units on the exhaust and lubrication-oil circuits. The backup prime mover/generator is included as a standby to provide additional redundancy for the generation of electricity only. Heat-recovery equipment is not used with this prime mover. For the units with heat recovery, the water jackets and exhaust boilers are integrated into a pressurized forced-circulation hot-water cooling system, with hot water leaving the water jackets at 383.2 K (230° F) and feeding into the exhaust boiler. This pressurized water is flashed to steam in the exhaust boiler. The steam, regulated at 103.4 kN/m^2 (15 psig) and 394.3 K (250° F), is mixed with steam from the incinerator, and the resultant steam is provided to the HVAC subsystem. When there is more steam than required, the excess is reduced to condensate through a heat exchanger and held in a tank for recirculation through both the prime movers and the incinerator. Makeup water for the entire heat-recovery system is provided by means of this holding tank containing treated wastewater.

The lubrication oil is circulated through an oil-to-water heat exchanger that produces water heated to a temperature of approximately 355 K (180° F). This water loop provides for space heating and also (through a water-to-water heat exchanger) provides heat for the domestic hot water. When there is no demand for this heat, the oil is routed through an air-blast heat exchanger for heat rejection.

The performance data used for the prime movers are given in table 11. A list of the major subsystem equipment is given in table 12.

An economic trade-off was conducted between the Fairbanks-Morse model 38D8 1/8 and the Caterpillar[3] model D398 prime movers. The total subsystem cost with use of the Fairbanks-Morse diesel engines increased the capital cost of the MIUS by approximately 5 percent over that using the Caterpillar engine. At the same time, fuel consumption was decreased by 10 percent annually, with an undetermined reduction in maintenance. It was decided that the 10 percent annual energy savings over the life of the system offset the penalty of increased initial costs.

Heating, ventilation, and air-conditioning.- The HVAC subsystem is illustrated in figure 13; the major components are shown, as well as the interfaces with other MIUS subsystems and the typical building equipment. Heating and cooling systems will be described separately but share much of the same equipment. Heat exchanger number 1 allows high-energy steam supplied from the incinerator and prime-mover stack and jacket to supplement the lubrication oil heat for the hot-water distribution loop. The number 2 heat exchanger is used to transfer excess heat from the hot-water distribution loop during moderate seasons to the cooling-tower loop. Similarly, the number 3 heat exchanger delivers excess high-energy heat to the tower loop. The thermal storage is usable for heating and cooling; filling and the supply to a hot- or cold-water distribution loop are accomplished by valving. Several alternatives to the HVAC subsystem design were considered and are discussed in the appendix.

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[3] Caterpillar Tractor Co., Industrial Division, Peoria, Ill. 61602.

Heating: Energy for domestic-hot-water and space heating is supplied by the hot-water distribution loop, which delivers water to each building at a temperature of approximately 366.5 K (200° F) and returns it for reheating at a temperature of approximately 333.2 K (140° F). This energy comes primarily from prime-mover lubrication-oil heat and can be supplemented with energy from the higher energy steam loop and from the prestored energy thermal-storage system. The winter levels of energy required are shown in figure 14. The domestic hot-water requirements show a peak of 799 kilowatts (2 729 000 Btu/hr) at 8 a.m. and a minimum of only 33 kilowatts (114 000 Btu/hr) at 4 and 5 a.m.; the total daily requirement is 33.2 gigajoules (31.5×10^6 British thermal units). Heating loads are also shown for (1) space heating on the design winter day with and without cloud cover, (2) the total heating load - consisting of space heating and domestic hot water - for the average winter day, and (3) the total heating load for the full-cloud-cover design winter day. The maximum-demand profile points out the requirement to meet a peak demand of 1736 kilowatts (5 928 000 Btu/hr) at 8 a.m. (the sizing requirement for a boiler in a conventional system) and a daily capability of 103.5 gigajoules (98.2×10^6 British thermal units). Figure 15 shows the winter average day and design day heat requirements in conjunction with the available heat from prime movers and trash incineration. The shaded areas show hourly supplemental requirements for the winter days, and the areas below the heat-available line show the hourly heat excesses. The maximum hourly deficiency, with only the available heat for the hour used, occurs at 8 a.m. and amounts to 647 kilowatts (2.208×10^6 Btu/hr) (the size of a boiler or a fuel-fired incinerator in an MIUS without storage). It is apparent that sufficient excess heat is available during the average day to meet the requirements from 6 to 10 a.m., when supplemental heat is needed, either by altering the incinerator schedule and size or by storage. The following table shows daily energy totals for the three winter conditions analyzed.

Design winter day, no clouds	12 533 058 kilojoules (11 887 000 British thermal units) required
Design winter day, 100 percent clouds	24 838 377 kilojoules (23 558 000 British thermal units) required
Average winter day	20 305 726 kilojoules (19 259 000 British thermal units) excess

The data show that sufficient energy is available from the average winter day for storage to satisfy the requirements of a design winter day without clouds or to satisfy approximately 81 percent of the amount required for a design day with 100-percent cloud cover. As an example, a storage tank with the capacity to satisfy the requirements for 3 consecutive design winter days with 100-percent cloud cover (3 x 24 838 377 kilojoules (3 x 23 558 000 British thermal units)) could be fully replenished in less than 4 average winter days with the available excess heat. Because only a small quantity of data exists on the occurrence of consecutive design days, the actual sizing of the tank requires cold-storage-tank considerations and will be discussed in the subsection on cooling. As mentioned previously, with a hot-thermal-storage system, boilers or other supplemental heating equipment are no longer needed.

Cooling: The design-summer-day total cooling loads and absorption/compression splits resulting from the baseline study are shown in figure 16. The absorption chillers would be supplied with 103.4-kN/m^2 (15 psig) steam from the prime movers and the incinerator after domestic-hot-water requirements were met. Distribution losses are added to the compression chiller requirements, and equipment is selected on the basis of the peak requirement during the design day; i.e., 789.9 kilowatts (224.6 tons) for absorption and 1274.1 kilowatts (362.3 tons) (plus 34.1 kilowatts (9.7 tons) distribution losses) for compression.

The design-summer-day electrical load components are shown in figure 17. The domestic and auxiliary load profile without compression air-conditioning and the profiles with compression air-conditioning are presented. In the MIUS without cold thermal storage, the total demand reaches a peak of 1249.9 kilowatts at 9 p.m. and necessitates the use of three prime-mover/generator sets from 5 to 11 p.m. The introduction of the cold-thermal-storage capability results in the use of only two prime-mover/generator sets, as shown (at 104 percent rated load for 3 hours); chilled water is supplied for space cooling and storage in the more efficient early morning hours until a level in storage is reached (5626.9 kilowatts (1600 tons)) to meet the remainder of the design-day requirements. The revised design-summer-day cooling requirements with storage available are shown in figure 18. The compression capacity was raised from 1308.2 to 1406.7 kilowatts (372 to 400 tons) to ensure that storage would be completed before the demand period on storage occurred. Additional program runs would further optimize this sizing.

For a cold-thermal-storage tank for design summer days, a capacity of 5626.9 kilowatts (1600 tons) would be required and a temperature increment (ΔT) of 6.67 K (12° F) would be used. This description equates to a volume of 724.6 cubic meters (25 590 cubic feet), or a right cylinder of 9.8 meters (32 feet) diameter. The requirement for heat storage on the design winter day, discussed in the section on heating, was 185.4 cubic meters (6549 cubic feet). Hence, the 9.8-meter (32 foot) diameter tank could hold supplemental heat for 3.9 consecutive design winter days.

In the layout and costing, the thermal-storage tank was considered to be a rectangular tank located under the MIUS building. Additional detailed information about the tank is given in the subsection entitled "Heating, Ventilation, and Air-Conditioning Subsystem," under "Baseline MIUS Costs." The tank was considered to be dry-earth insulated (U = 0.027). Losses were estimated to be approximately 1 percent of the stored energy in 24 hours. Seasonal changeover from hot-water storage to chilled-water storage would occur in the late spring, and the change back to hot-water storage would occur in the fall. In consideration of certain baffle arrangement thermal-layer films, and other stratification techniques, near zero-percent mixing efficiencies have been reported. No mixing was considered in the storage tank.

The HVAC equipment selection based on the aforementioned loads and criteria is presented in table 13. The equipment was selected on the basis of the following economic justifications.

1. Most HVAC systems would use compression air-conditioning exclusively. This study shows that the moderate increase in initial costs necessary to incorporate an absorption chiller is compensated for by the significant energy savings achieved by using the otherwise unused high-grade heat from the prime movers and the incinerator.

2. The addition of the thermal-storage system for storing heat eliminates the need for boilers or fuel-firing provisions on the incinerator. As a result, there are no fuel requirements attributed to space heating.

3. The use of the thermal-storage system for supplementing cooling reduces the number of prime-mover/generator sets required, and this reduction represents a significant initial cost saving.

Solid waste.- The solid-waste management subsystem provides for the storage, collection and transportation, processing, and disposal of solid wastes generated within the complex, and the disposal of wastewater treatment subsystem sludge. Components are listed in table 14. Each building is equipped with gravity chutes. Building type 1 has two chutes per building (one per wing). Building types 2, 3, and 4 have one gravity chute per building. There is one solid-waste charging station per floor per gravity chute. There are 23 gravity chutes in the complex and 76 charging stations. Solid waste is directly deposited into a 1062-liter (37.5 cubic foot) capacity wheeled cart located at the base of each chute. Collection is made in building types 1 and 3 on odd-numbered days and in building types 2 and 4 on even-numbered days. Fourteen carts are collected daily (approximately 2721.6 kilograms (6000 pounds) of solid waste daily). Each cart collected is replaced by an empty cart. Carts are transported to the incinerator by a tractor capable of pulling as many as six carts simultaneously. Twenty spare carts are available to provide replacement for full carts and to provide total storage capacity for 3 days' solid-waste generation. Three days' storage was chosen to allow for 5-day operation if 7 days were not desirable and to compensate for system failures. The storage carts are compatible with the incinerator loader. The capability to mechanically transfer the solid waste from the storage container to the incinerator loader is included. A disposal subsystem schematic is shown in figure 19. An incinerator with a capacity of at least 362.9 kg/hr (800 lb/hr) was selected to handle the load. The supplementary-fuel requirement per hour is 369 022.5 kilojoules (350 000 British thermal units). The daily startup-fuel-energy requirement is 527 175.0 kilojoules (500 000 British thermal units). The incinerator is operated 12 hr/day (8 a.m. to 8 p.m.), 7 days/week. Ash is stored in a 7645-liter (10 cubic yard) container to be picked up once per week by truck and hauled to a remote landfill. Bulk waste is collected on an as-required basis and is transported from the incinerator simultaneously with the ashes. The heat produced by the incineration of the solid waste is recovered at 103.4 kN/m^2 (15 psi) as 394.3-K (250^0 F) steam in a boiler. The recovery efficiency is at least 60 percent of the input fuel and solid-waste heating value. The amount of heat recovered is shown in figure 19. Wastewater treatment subsystem sludge is gravity-fed to a holding tank with a 3-day capacity and then auger-fed into the incinerator such that a mixture of 60 percent solid waste and 40 percent sludge is maintained.

The solid-waste input provides 31.6 gigajoules (30 x 10^6 British thermal units) of energy per day. Sixty percent of this amount is recovered, or 19.0 gigajoules (18 x 10^6 British thermal units) per day. The supplementary fuel energy required per day is 5.0 gigajoules (4.7 x 10^6 British thermal units); and of this, 3.0 gigajoules (2.8 x 10^6 British thermal units) per day are recovered. The sludge solids possess a heating value of 4.2 gigajoules (4 x 10^6 British thermal units) per day. However, the water content of the sludge requires approximately 4.21 gigajoules (4 x 10^6 British thermal units) per day for evaporation; therefore, no heat was assumed recovered from the sludge incineration. The total quantity of heat recovered daily from incineration is 21.9 gigajoules (20.8 x 10^6 British thermal units) or 1.8 gigajoules (1.7 x 10^6 British thermal units) per hour during the 12-hour operating period. This energy is supplied to the HVAC subsystem.

The choice of a starved-air incinerator with a stack-heat-recovery boiler was made because it was the lowest priced commercially available system for both disposing of solid waste and recovering the energy from the waste. Other potential processes, such as pyrolysis, are developmental. On the basis of processing 4535.9 kg/day (5 ton/day), the capital cost of the system chosen (including heat recovery) was approximately $13 228/Mg ($12 000/ton) per day processed.

Water management.- The water management subsystem is responsible for the supply and disposal of all water associated with the functions within or between the apartment facility and the MIUS facility. For potable-water treatment, the system complexity and cost are contingent on the nature of the water source. For wastewater treatment to meet the desired effluent quality, primary, secondary, and tertiary treatment is required. There are several economically competitive manufacturers of both single processes and package treatment plants of the size and complexity required. However, there is a definite economy of scale; i.e., if large-scale water and wastewater treatment (>3785.4 m^3/day (>1 x 10^6 gal/day)) is required, the construction of site-specific treatment plants would have an economic advantage.

Potable water: The design of the potable-water subsystem was based on the ground rule that the potable water will meet the 1962 U.S. Public Health Service drinking-water standards (ref. 3) and on the assumption that the water coming to the treatment plant will be surface water. In table 9, the average annual residence demand was shown to be 323 cubic meters (85 444 gallons) daily. The potable-water-treatment-plant design capacity (maximum day demand) is 130 percent of the average annual residence demand. This design capacity factor was determined from published surveys of governmental, private, and institutional organizations (refs. 10 to 29). The published data were surveyed for information on facilities similar in all respects (location, apartment type, number of occupants, etc.) to the apartments selected for the basic design. The potable-water-treatment-plant design selected for surface water is a conventional type plant, a schematic of which is shown in figure 20. The individual processes selected are as follows.

1. Raw-water pumping - Raw-water pumps are provided to deliver the raw water from the source. There are two pumps, each of which - for redundancy - is capable of delivering the 0.3-m^3/min (78 gal/min) design flow at a 179.3-kN/m^2 (60 foot) head pressure.

2. Chemical clarification - Chemical clarification is provided to remove the turbidity in the raw water such that the filter can remove the balance without excessive clogging. The clarification is sized to adequately treat a 0.3-m^3/min (78 gal/min) raw-water flow. The solids removed by this process are stored in the bottom of the tank for periodic removal to the wastewater subsystem sludge-handling equipment.

3. Filtration - Filtration is included in the treatment plant to remove bacteria and finely divided suspended particles remaining after chemical clarification. The filter is sized to handle the maximum plant flow of 0.3 m^3/min (78 gal/min). The water used for periodically back washing of the filters is returned to the initial stage of the plant to mix with the raw water.

4. Chlorination - Chlorination is included to provide disinfection and eliminate tastes and odors. Chlorine is added in sufficient amounts to maintain a free-available-chlorine residual of 0.2 to 0.3 p/m after 30 minutes contact time.

5. Potable-water storage - Storage of potable water is included to provide the quantities of water required for the peak hourly flow (200 percent of the average annual demand) to enable plant operation at a constant rate (removal of the peaks in the daily profile). The storage volume provided is 113 562 liters (30 000 gallons).

If underground water is used instead of surface water, the chemical clarification and filtration steps can be removed and replaced with a simple settling tank with a 3-hour detention time and a 32.6-(m^3/day)/m^2 (800 (gal/day)/ft^2) surface overflow rate. Whether the potable-water subsystem will be required depends on the application of the MIUS. If the subsystem is not included, no other subsystem is affected.

Wastewater: The wastewater subsystem was designed to satisfy the ground rule that the quality of the effluent from the treatment plant must be acceptable for discharging the effluent to the environment and also for using the effluent for process water and irrigation. The effluent-quality design parameters selected for the plant are shown in table 15. With such design requirements, it is recognized that desalination equipment would be required in some parts of the country on specific water types; and reuse requirements are a site-specific evaluation beyond the scope of this document. In table 9, the average annual residence demand (i.e., the wastewater flow is assumed to be equal to the residence usage) was established as 323 m^3/day (85 444 gal/day). The wastewater treatment plant design capacity (equivalent to maximum day demand) is 130 percent of the average annual residence demand plus 26 m^3/day (7000 gal/day) of process water blowdown. A schematic of the wastewater treatment plant is presented in figure 21. The individual processes selected to produce the required effluent are as follows.

1. Raw-wastewater pumping - The raw-wastewater pumps are provided to transfer the wastewater from the wastewater-collection pipe to the initial stage of the treatment plant. There are two pumps, each of which - for redundancy - is capable of delivering the 0.3 m^3/min (82 gal/min) design flow at a 179.3-kN/m^2 (60 foot) head pressure.

2. Preliminary/primary treatment - The purpose of the preliminary/primary treatment step is to remove the suspended solids (and consequently a part of the biological oxygen demand (BOD)) from the wastewater. The apparatus selected for this function is an inclined screen capable of removing the solids that can be removed with a primary clarifier. (The inclined screen requires less space than a primary clarifier.) The unit is sized to handle the flow of 0.3 m^3/min (82 gal/min). Solids are collected in the unit and periodically sent to the sludge-handling equipment.

3. Flow equalization - The flow-equalization tank is used to maintain a constant flow of water through the plant by storing water during high periods of flow and furnishing water during low periods. To prevent septic conditions in the tank, aeration is provided. On the basis of the design flow of the plant and the projected daily water usage profile, the volume of the tank is 113 562 liters (30 000 gallons). The volume of air required is that necessary to provide 1 136 000 mg/hr of oxygen.

4. Biological oxidation/nitrification - The water is pumped from the flow-equalization tank to a unit for the biological oxidation process, which disposes of most of the biodegradable components (BOD, chemical oxygen demand (COD), etc.) of the wastewater. Nitrification is incorporated in the process as an extension to the biological oxidation step, to provide for the conversion of nitrogenous matter into nitrates by means of aerobic bacteria. The apparatus selected for these functions is the rotating-disk biological contactor. The process is simpler in operation and control than the conventional, activated-sludge process. The process is sized to adequately treat a flow of 0.3 m^3/min (82 gal/min).

5. Denitrification - Denitrification is included to biologically reduce (under anaerobic conditions) the nitrate nitrogen (NO_3) to nitrogen gas (N_2), which is released to the atmosphere. The process selected for this function is the submerged rotating-disk contactor. The unit is sized to denitrify 0.3 m^3/min (82 gal/min) of wastewater.

6. Secondary clarification - The purpose of secondary clarification is to remove the solids produced from the biological oxidation/nitrification and denitrification processes. A conventional gravity-settling tank is used for this function. The tank is designed to an overflow rate of 32.6 (m^3/day)/m^2 (800 (gal/day)/ft^2) of surface area and a 2-hour detention time. The solids removed by the settling process are stored in the bottom of the tank for periodic removal to the sludge-handling equipment.

7. Chemical clarification - The primary purpose of chemical clarification is to remove phosphorus from the wastewater. Alum was selected as the chemical to be added in this process. The amount of alum added will be 125 000 mg/m^3 (125 mg/liter). After coagulation and flocculation (all

within this function), the precipitate is settled in the tank, which is designed to an overflow rate of 26.5 $(m^3/day)/m^2$ (650 $(gal/day)/ft^2$) of surface area and a 5-hour detention time. The solids removed from the wastewater in this tank are periodically transferred to the sludge-handling equipment.

8. Tertiary pumping - Tertiary pumping is used to put the wastewater flow by gravity under sufficient pressure to flow the wastewater through the carbon columns and filter. The pumps selected will be capable of delivering 0.3 m^3/min (82 gal/min) at a 179.3-kN/m^2 (60 foot) head pressure. Two pumps are provided, each capable of full flow, for redundancy.

9. Carbon absorption - The carbon absorption process is included to remove the remaining unacceptable quantities of BOD, COD, color, odor, etc. The apparatus selected for this process is the upflow contactor column designed for 13 minutes of contactor time and 0.3 $(m^3/min)/m^2$ (8 $(gal/min)/ft^2$) of cross-sectional area. The carbon column is an 8- by 30-mesh size, and the dosage of carbon will be 0.032 kg/m^3 (250 $lb/10^6$ gal) of wastewater. The design flow through this process is 0.3 m^3/min (82 gal/min). The spent carbon is discharged to the sludge-handling equipment.

10. Filtration - Filtration is provided as a final polishing step to remove any fine suspended solids remaining in the wastewater. The filter selected for this function is a dual-media filter with a 76.2-centimeter (30 inch) media bed depth and rated at 0.16 $(m^3/min)/m^2$ (4 $(gal/min)/ft^2$) of surface area. The design flow for the filter is 0.3 m^3/min (82 gal/min). The water used for periodically backwashing the filter is returned to the initial stage of the plant.

11. Disinfection - Disinfection is included to ensure that no live organisms are discharged in the effluent from the wastewater treatment plant. The dosage of chlorine added is 2000 mg/m^3 (2 mg/liter), which is sufficient for maintaining the required residual after 15 minutes of contact time.

12. Holding tank - A holding tank is provided so that water will be available when it is needed for use in waste-heat rejection, other process water makeup, irrigation, and filter backwash. The tank is also used to store water for fighting fires. The volume of the tank is 454 249 liters (120 000 gallons), with the thermal-storage tank being used to make up the balance of the required amount of water for fighting fires.

13. Sludge pumping - Pumps are provided to transfer sludge collected in the preliminary/primary treatment, secondary clarification, chemical clarification, and potable-water-treatment processes and to transfer spent carbon. The pumps selected are capable of transferring 0.1 m^3/min (30 gal/min) at a 44.8-kN/m^2 (15 foot) head pressure. Two pumps are used, each capable of full flow.

14. Sludge thickening - Sludge thickening is used to reduce the volume of sludge by gravity settling. The volume of sludge to be handled by this process is 16.4 m^3/day (4345 gal/day). The solids content of the incoming sludge is 2.4 percent. The tank is designed for a dry-solids loading of 122.1 kg/m^2 (25 lb/ft^2) of surface area and a 1-day detention time. The outgoing sludge is reduced to a volume of 7.7 m^3/day (2039 gal/day), with

5-percent solids content. The water that is separated from the solids is returned to the initial stage of the plant..

15. Vacuum filter - Sludge is pumped to a vacuum filter that further reduces the volumn of the sludge after the gravity-settling step. The quantity of sludge to be handled by this process is 7.7 m^3/day (2039 gal/day) with a 5-percent solids content. The quantity of filter cake (outgoing sludge) is 0.6 m^3/day (150 gal/day), with a 20-percent solids content. The filter is loaded with dry solids at the rate of 24.4 kg/hr/m^2 (5 lb/hr/ft^2) of surface area for 6 hr/day. This loading requires a filter surface area of 2.6 square meters (28 square feet). The filter cake is gravity-fed to the solid-waste subsystem for final disposal. The water that is separated from the solids is returned to the initial stage of the plant.

16. Pumps - In addition to those pumps previously described, the following pumps are required.

a. Two pumps are included to handle the process water makeup. These pumps are each capable of full flow, 0.02 m^3/min (5 gal/min) at a 149.4-kN/m^2 (50 foot) head pressure.

b. Two pumps are provided for discharging the treatment plant effluent to the environment. The pumps are the same size as the raw-wastewater pumps.

17. Pressure tanks - Pressure tanks are used in two locations in the wastewater subsystem to enable efficient operation of the pumps.

a. One of the pressure tanks (241.3-kN/m^2 (35 psi) operating pressure) is provided in the process water makeup system. The tank will have a 15 141.6-liter (4000 gallon) capacity to satisfy maximum hourly demand and so that water can be used for several hours during low demands without pump operation. The capability of using potable water as a backup for this function is provided.

b. The other pressure tank (241.3-kN/m^2 (35 psi) operating pressure) is provided in the firefighting system because this system is also used for irrigation. The tank will hold 11 356.2 liters (3000 gallons) to allow for a day's irrigation without pump operation.

18. Odor control - The possible sources of objectionable odors in the wastewater treatment plant are the preliminary/primary treatment and sludge-thickening processes. To preclude the evolution of the odors, covers are installed on these processes and they are vented to the exhaust stacks of the power generators. Applicable precautions (e.g., check valves) are taken to prevent exhaust gases from the power generators from flowing into the wastewater processes.

Utility distribution and collection.- The utility distribution system is totally underground. A plan layout of the distribution for all the utilities in the complex is shown in figure 22. The electrical, potable-water, chilled-water, and hot-water infrastructures are contained in constant-depth common trenches located parallel to the sidewalks throughout the building complexes. The total length of these trenches is 792.5 meters (2600 feet), at a depth of 1.1 meters (3.5 feet). Included in each trench with the utility infrastructures is a 15.2-centimeter (6 inch) layer of wash gravel for pipe support.

The wastewater and firefighting-water distribution systems are contained in a single trench separate from those for the other utilities because of widespread codes on separating trenches for sewage and potable water. The trench is common to both systems for a distance of 824.5 meters (2705 feet), with an additional 173.7 meters (570 feet) being contained in the firefighting-water distribution system. The maximum depth is 7.3 meters (24 feet), with the average depth being approximately 3.8 meters (12.5 feet). This depth permits an average grade of 0.8 percent for the gravity-flow wastewater system. The trenching for the 173.7 meters (570 feet) of the firefighting-water distribution system only is 1.4 meters (4.5 feet) deep. A typical cross section of the trenches is shown in figure 23.

Electrical distribution: Electricity will be generated at 460 volts (rms), three-phase, at a frequency of 60 hertz. The voltage will be stepped up to 4160 volts (rms) for primary distribution. There will be five main feeders connected at the main bus, and they will serve the entire complex. Each feeder contains fault-current protection, plus switchgear and three single-phase transformers for stepping down the distribution voltage to residential voltage. Special transformers will be included where they are required for special electrical motor loads. Major equipment is listed in table 16.

The primary distribution system will be a wye-connected, four-wire system. Neutral current will be minimized by balancing the loads on each phase of the primary feeders. A one-line diagram of the primary distribution system is given in figure 24. Feeder lengths and wire sizes are given in the following table.

Feeder	Volts (phase-phase)	Length (one conductor), m (ft)	Wire size, American wire gage (AWG) no.
1	4160	219.5 (720)	8
2	4160	172.2 (565)	8
3	4160	297.2 (975)	8
4	4160	253.0 (830)	8
5	4160	48.8 (160)	8
Neutral	--	990.6 (3250)	8

A three-phase power circuit breaker exists between the main bus and the local electrical grid. It is normally open and will only be closed if emergency electrical power is required.

Heating, ventilation, and air-conditioning: The HVAC system supplies 366.5-K (200° F) water for domestic-hot-water and space heating by means of a five-loop system in common trenches with a two-pipe cold-water system and other utility distribution lines as shown in figure 23. The hot-water return temperature is 333.2 K (140° F), and flow velocities are limited to 3.0 m/sec (10 ft/sec) to size pipes and determine losses. A good-quality insulation with a thermal conductivity of 0.058 W/(m-K) (0.40 Btu-in)/(hr-ft^2-°F) at a 55.55-K (100° F) ΔT was used instead of in-ground performance consideration.

Maximum distribution losses in the two-pipe cold-water system to the buildings contribute an additional 34.04 kilowatts (9.68 tons). The system supplies 280.4-K (45° F) water by means of five loops to the building complexes and returns it at 287.0 K (57° F). Flow velocities are limited to 3.0 m/sec (10 ft/sec), as in the hot-water system, and a similar type of insulation is applicable.

Water distribution and collection: The potable-water distribution system will deliver all potable water required in the apartment facility and the MIUS facility by means of a pump pressure distribution system. The system is designed according to the current American Water Works Association[4] (AWWA) standards. The apartment complex was divided into four areas so that the water lines could be designed more efficiently. The system is constructed of plastic pipe, in 7.6-centimeter (3 inch) and 5.1-centimeter (2 inch) diameters, that meets all applicable codes and standards (National Science Foundation (seal of approval), American Society for Testing Materials, AWWA, etc.). The layout of the water lines to each building is shown in figure 22. The pumps for the system are sized to deliver a line pressure of 241.3 kN/m^2 (35 psi) to each service outlet; all pressure drops within the lines and buildings are considered. A design with two pumps was selected so that either pump could meet the maximum demand, with the second pump used as a standby for redundancy. The pumps required are 0.3-m^3/min (78 gal/min) pumps with a head-pressure capacity of 343.7 kN/m^2 (115 feet).

The wastewater collection system will collect all wastewater from the apartment facility and the MIUS facility through a standard gravity collection system. The system is designed according to current applicable local and State codes and standard civil-engineering practices. The pipe selected for the design is 15.2-centimeter (6 inch) cast-iron pipe. The 15.2-centimeter (6 inch) diameter will minimize the slope of the pipe so that a minimum full-flow velocity of 0.8 m/sec (2.5 ft/sec) will be maintained. In sizing the pipe, the peak flow conditions (peak hourly and instantaneous flows) were also considered.

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[4] American Water Works Association, New York, N.Y.

The firefighting-water/irrigation-water distribution system will deliver all water required at the apartment site for extinguishing fires and irrigating green areas. The system is designed to the same standards as the potable-water distribution system but is a completely separate system. The firefighting-water requirements are much greater than the irrigation requirements; thus, the system is designed according to the requirements specified by the National Board of Fire Underwriters (Fire Protection Handbook). The system is constructed of plastic pipe (30.5-centimeter (12 inch) diameter) that meets all applicable codes and standards. The system flow capability is 22.7 m^3/min (6000 gal/min), based on the size of the apartment, and the service is delivered to four points within the site. Each pump has a flow capability of 11.4 m^3/min (3000 gal/min), and three pumps are provided; thus, any two pumps will provide the required service. The system will use reclaimed-wastewater storage and the thermal-storage tanks to meet the required storage volume of 1022 cubic meters (270 000 gallons). The use of a conventional potable-water supply for firefighting without any effect on other subsystems depends on the application of the MIUS.

Fuel supply.- The function of the fuel supply system is to ensure the availability of number 2 diesel fuel to prime movers and incinerators on demand. The system uses a 151 416-liter (40 000 gallon) underground fuel storage tank for primary storage and a 378.5-liter (100 gallon) day tank. The 151 416 liters (40 000 gallons) are sufficient for a 30-day supply, with refills occurring every 2 weeks. Fuel is pumped directly from the main tank to the day tank. The day tank, in turn, distributes fuel to the prime movers and to the incinerator. A functional diagram of the fuel supply system is shown in figure 25.

Two positive-displacement rotary-gear-type pumps will be used for pumping fuel from the main storage tank to the day tank. Each pump will have a pumping rating of 0.38 m^3/hr (100 gal/hr). The day tank will be located in the MIUS building and will provide a head pressure of 17.9 ± 9.0 kN/m^2 (6 ± 3 feet) at a common manifold for the prime movers and the incinerator. Two fuel pumps for pumping from the day tank to the prime movers and the incinerator will be included. Each of these pumps will also be rated at 0.38 m^3/hr (100 gal/hr). The system will also incorporate controls for metering the fuel, regulating fuel flow, heating the fuel, and filtering the fuel.

Control/monitoring.- The selection of a control/monitoring subsystem was made after a thorough consideration of control and monitoring systems used in conventional utilities and petrochemical installations. These installations contain components of equipment that function similarly to certain MIUS subsystems. Primarily, the functions of process control using flow, temperature, level, and pressure sensors and controllers were analyzed in these conventional installations.

Requirements: Equipment representative of subsystem components was analyzed for control and monitoring requirements. Quantities of sensors, actuators, and controllers for these pieces of equipment were developed in this analysis. The results were documented in reference 32. The control/monitoring subsystem consists of conventional, commercially available hardware from established manufacturers.

Table 17 is a summary listing of the instrumentation and control requirements. This table was compiled from the information contained in reference 32 and from an analysis of the 496-unit-apartment MIUS. Additional equipment added over that included in reference 32 imposed new control and monitoring requirements. Airblast heat exchangers for heat-rejection techniques, storage tanks for thermal-control water, and storage tanks for firefighting water are some of the additional items. The resulting pressures, temperatures, flows, etc. and the necessary control signals are included as requirements in table 17.

The control and monitoring hardware selected for meeting these requirements was selected with cost as a primary consideration, particularly in the selection of the control valves. Although it is not customary for the instrumentation and control equipment to include the control valves, they have been included in this instance. Generally, the distribution of the hardware breakdown and the associative costs would be such that the valves would not appear as a separate entity but as a portion of each major subsystem. The type of valves selected directly affects the control and monitoring subsystem; hence, they are shown as control hardware.

In the consideration of valving requirements, the primary emphasis was on the function. If modulating control is deemed necessary, then a throttling valve should be utilized; this valve was included as required in table 17. On the other hand, if only an open/close capability is necessary, then solenoid-operated valves should be specified. Solenoid valves of large sizes (7.1 centimeters (3 inches) or greater) either are not available or are unreasonably high priced, whereas throttling valves are available in most large sizes and, although more expensive in smaller sizes, are slightly less expensive than the large-version solenoid-operated valves. Therefore, throttling valves that are air operated have been substituted for the large-solenoid requirements. The distribution of the valves by type and size is shown in table 18. The control of each throttling valve used as an on/off valve will be by use of a latching-relay contact closure to a small three-way solenoid valve; full air will be applied to the throttling valve when the relay is pulsed, and the air will bleed off when the relay is unlatched. This method has less impact on the control center than an implementation of the full-range modulating capability of the valve.

Functionally, the requirements for control-room hardware consist of displays, controllers, mounting panels, and any auxiliary equipment necessary for monitoring or logging the data. All this equipment in conventional installations is considered standard. The MIUS will contain all conventional control-room equipment, with the added feature of computerized digital control and monitoring.

Description: The control/monitoring subsystem for the MIUS consists of two major functional components: namely, a conventional instrument monitoring and control system and a computerized digital monitoring and control system, as depicted in figure 26. Interfacing of the control room with subsystem sensors and actuators is by means of conventional individual wiring arrangements. Sensors and actuators are standard catalog items for determining and controlling flow, temperature, pressure, level, and water quality, as well as other parameters. In the event of failure of either the instrument controllers or the computer, a selectable manual operation will enable process valve opening, closing, or throttling from the control room. In addition to the two primary control techniques and the manual override capability, it is still necessary for operator or maintenance personnel to be able to control motor switches and to operate valves at local positions on the equipment-room floor. The control/monitoring subsystem is implemented to provide an optimum level of operation reliability with minimal equipment cost and complexity.

The primary control and monitoring equipment is the digital computer system. A functional block diagram of the primary equipment involved in computer control is shown in figure 27. Analog signals are individually converted to digital representation and then processed by the computer. If incoming signals should vary above or below specified limits or rate-of-change values, an alarm condition is indicated and appropriate control signals are transmitted to the actuator. This action will automatically accomplish a required change in configurations of the subsystem to return the operations to within the desired range. If the configuration changes such that expected limits also change, the computer will compensate for this result through prestored programs. Updating of the instrument controllers during such an occurrence is likewise appropriate, and the computer will change set points in the instrument controllers continually so that their operation (should it be necessary) is based upon the latest configurations.

Use of the computer for processing incoming measurement data from the subsystems enables overall MIUS performance to be integrated to all optimum levels through use of preprogramed options. Several variables from portions of the same subsystem and from associated subsystems are considered to enhance the decisionmaking process. For example, associated temperature and pressure valves are considered in computing and controlling flow rate to achieve greater accuracy than that provided by the use of flow-sensor output only.

A real-time display of processed data is available on a cathode-ray tube (CRT). Selected preprogramed sets of data are established on the basis of anticipated operation of the MIUS. The display format is changeable to the extent of selection of particular displays and is updated by the computer continuously. The capability to select individual parameters and schematics by use of an alphanumeric keyboard is also provided. A printer is included in the design for the express purpose of providing log information to either operator or supervisor personnel.

The instrument control and monitoring portion of the system includes all the functions of a conventional controller/indicator installation. Figure 28 is a functional block diagram of the instrument control operational mode. This unit serves as backup to the computer digital system. A failure in the computer that would prohibit proper functioning of the primary system actuates a switch and diverts all controlled signals to the backup instrument controllers. This changeover also can be accomplished from the console by the operator as desired. In addition, switches are incorporated so that the operator can divert individual parameters to the instrument controllers while the computer system continues control of all other parameters.

Not all the signal loops are incorporated in the instrument system. Only those functions essential to safe operation of the MIUS need to be included, because they are backups to the primary computer controller. Certain parameters in subsystems controlled by instrument controllers dictate the use of cascade arrangements wherein a second parameter is monitored by the cascaded controller and its output adjusts the set point on the first controller. This technique often causes improved performance because greater operating accuracy is provided by the combined action of the cascaded controllers. It is an expensive additional factor that may not be justified in a backup system; hence, only a minimum of cascade loops are included in the instrument system. These instrument control loops are included only if they are necessary to safely operate the MIUS while the computer is out of service.

As was mentioned in the earlier discussion of the computer system, set points of the instrument controllers are adjustable by the computer even though the instrument controllers are not functioning. Thus, the instrument control system is updated as the computer changes the MIUS configuration. Set-point adjustment by the operator from the console is included also. This capability is necessary for continued smooth control of operations upon failure of the computer. There are displays available to the operator while he is using instrument controllers, with indicating lights and meters located on the controllers. In addition, recording of selected parameters is possible through use of several multipen strip-chart recorders.

Manual operation of valves from the control console is a selectable option in the event that both the computer and the instrument controllers are unable to transmit required signals to the valves. A functional block diagram of the manual mode of operation is shown in figure 29. Opening and/or closing signals to the valve actuator are controlled by the operator's pressing an "Open" or "Close" pushbutton. Associated parameters of temperature, pressures, flow, etc., must furnish the operator with direct readout of the parameter being controlled if failure occurs in the sensor portion of the instrument of in the computer controllers.

Energy and Consumables Usage Analyses

Analyses of the utilization of energy and other consumables were accomplished primarily with the ESOP. The techniques used for these analyses are described, and the data derived from the analyses are presented.

Energy Systems Optimization Program description.- This description of the ESOP is taken from the introduction of reference 4. The ESOP consists primarily of subroutines that model each of the MIUS subsystems integrated together, along with subroutines that predict HVAC and water system loads. The program is divided into five general analytical components plus input/output components as shown in the generalized ESOP analysis schematic presented in figure 30 (taken from ref. 4).

Solid-waste disposal: The waste-disposal-calculation section predicts the daily total energy required to operate a specific waste disposal system (for a given trash load) and the daily quantity of usable waste-heat energy that is recovered from the specific disposal process.

Heating, ventilation, and air-conditioning loads: The HVAC loads section predicts hourly heating and cooling loads on the buildings to be serviced by the MIUS as a function of indoor- and outdoor-air conditions, solar effects, building construction and geometry, domestic electric power profiles, and occupancy profiles. These loads are calculated for each building type and totaled for the entire complex to obtain a total 24-hour load profile for each seasonal analysis.

Energy requirements: The energy requirements section determines the energy requirements for the MIUS complex on an hourly basis for a "typical" day of each season. Annual energy requirements are taken from these values. Load information from the HVAC loads section, heat-recovery and fuel requirement data from the solid-waste section, and waste-heat data from the power generation section are used to determine energy utilization and requirements for HVAC equipment, boilers, cooling towers, etc. Thermal storage is an optional feature in this section.

Power generation section: The power generation section calculates the energy requirements of specific prime-mover systems to provide required electrical power as defined by the energy requirements section. This section also defines for the energy requirements section the amount and type of waste heat available from the prime-mover system. The interface between these two sections accounts for electrical power demands created by compression air-conditioning required to supplement air-conditioning provided with waste heat.

Conventional utility system: The ESOP conventional utility system section calculates the energy required by a conventional commercial utility system to provide the same services provided by the MIUS. The conventional system consists of a central power generation facility, all compression air-conditioning, and a gas-fired boiler for space heating and hot-water heating.

Program output: The ESOP output, in general, consists of the operating characteristics and recoverable waste-heat energy of the solid-waste-disposal systems; all components of the heating or cooling loads; the load demands, operating characteristics, and energy requirements of the specific prime mover being analyzed; an indication of degree of utilization of waste-heat energy; and a summary of daily, seasonal, and yearly energy requirements of the specific MIUS configurations required.

<u>Energy Systems Optimization Program analyses</u>.- The ESOP was first used to determine peak equipment loads for equipment sizing. This determination is accomplished by performing analyses for the summer and winter seasons using hourly weather data that are two standard deviations above and below the mean, respectively, for the Washington, D.C., area. January data were used for the winter season, and July data were used for the summer season.

After the design loads were determined, preliminary prime-mover selections were made and used for subsequent energy analyses with mean weather data. Mean data for January, April, July, and October were used, rspectively, for winter, spring, summer, and fall seasonal analyses.

Baseline energy and consumables analyses data.- The MIUS energy and consumables data are presented in two formats, the first of which represents a summary of annual energy requirements, water consumption, wastewater effluent, and solid-waste effluent for the MIUS and the conventional system. The summary chart also shows a percentage comparison to the conventional system in each of these areas. Figure 31 shows the annual summary for the MIUS consisting of two operational 478-kilowatt Fairbanks-Morse prime movers, hot and cold thermal storage, incineration of solid waste, and a floating split between absorption and compression air-conditioning.

The second format in which energy analysis data are presented is an energy utilization flow chart showing, on a seasonal and annual basis, the sources and uses of all energy consumed by the utility system. These charts are shown in figures 32(a) to 32(e) for the baseline MIUS and in figures 33(a) to 33(e) for the conventional system providing the same services. In each set of energy utilization flow charts, the data are presented in the following order: annual, winter, spring, summer, and fall. All the energy inputs to the system are shown on the extreme left of the flow charts, with the values shown representing the heat value in joules (British thermal units) of the fuels and solid waste entering the system. In all cases, the label "fuel" refers to a purchased fuel. The values shown for losses include the heat content of exhaust gases, as well as distribution losses. The two vertical lines near the center of the charts represent recovered-waste-heat loops at the temperatures shown. Services provided by the systems are shown to the right of the vertical lines. For each service, the amount of waste heat or electricity required is shown, as well as the quantity of the service provided to the facility. Thermal storage does not appear on the flow charts because it has an insignificant effect on fuel consumption and because storage data are meaningful only on an hourly basis; that is, the primary benefit of thermal storage is reduction of daily peak demands. The heat rejected in the air-conditioning condensers and the resulting water required by the cooling towers are shown also. At the lower end of the flow charts, the unused recoverable heat is shown, as well as the thermal efficiency and the fraction of waste heat used. The thermal efficiency presented here is the summation of the heat value of all the services provided divided by the heat value of the purchased fuel.

It should be noted that the energy required for eventual disposal of incineration residue, or solid waste in the conventional case, is not considered anywhere in the analyses. This factor is considered beyond the scope of the preliminary design energy analysis because it is heavily site dependent and is not a part of the MIUS.

The MIUS Building

The MIUS building, which houses the utility equipment, should be compatible with residential surroundings in terms of noise levels and visual esthetics. (Refer to figs. 34(a) and 34(b).) The location of the MIUS building on the project site is the first decision in the design process. The three main factors that determine its placement are as follows.

1. Economy of utility distribution

2. Land use economy and ease of truck service

3. Consideration of the noise, air, and thermal pollution resulting from plant operation

The MIUS building was placed near the middle of the longitudinal axis of the apartment project for economy of utility distribution. Its placement near the edge of the project facilitates ease of truck access and economy of land use for truck access. Parking lots were placed around the buildings to isolate the residential buildings and exterior activity areas from noise, air, and thermal pollution.

The placement of the equipment in the building is generally determined by the subsystem function and interface requirements. The four basic subsystems are electrical power generation; heating, ventilation, and air-conditioning; solid-waste management; and potable-water and liquid-waste management.

The electrical power generation equipment is grouped together because of common requirements for fresh air for combustion, unique dynamic loads imposed on the structure by the prime movers, and common interface requirements with the heat-exchange loops, the common exhaust emissions system and switchgear and distribution elements.

The HVAC subsystem equipment is grouped adjacent to the power generation equipment for economy of heat-exchange-line runs. Maintenance of the chillers requires periodic pulling of the tubes, which are equal in length to the chillers. For economy of floorspace, they are placed in parallel on two levels and adjacent to a wall of removable louvers that facilitate tube pulling and natural ventilation of the space.

The solid-waste management subsystem equipment includes an incinerator, a loader, and a heat-recovery unit, together with a cart storage area. This equipment is arranged such that the carts can be moved in and out efficiently both from the service yard and the incinerating area. The cart storage area is designed to preclude the spread of undesirable odors to the interior of the rest of the building and to screen unsightly views from the rest of the project. The incinerator, the loader, and the heat-recovery unit, which are physically one element, are located adjacent to the cart storage area for economy of operation and close to the power generation and HVAC subsystems for economy of heat-exchange-line runs. The incinerator also burns the sludge collected by the liquid-waste management subsystem; therefore, because of its multiple interfaces with other subsystems, it is located along the center of the longitudinal axis of the building. The incinerator also has stringent building code requirements that make outside placement economical; but for weather protection of loading operations, it is placed under a roof. An ash storage container is also required for this subsystem, and it must be adjacent to the incinerator and be easily emptied by a truck in the service yard.

The potable-water and liquid-waste management subsystem equipment requires the greatest amount of space and has the least requirements for interface. The major pieces of equipment are arranged to facilitate economy-of-floorspace requirements and to allow for ease of piping. The interface requirements include makeup-water lines to the heat-exchange loop and the cooling tower, and a forced-gas-exhaust duct to the common exhaust emissions header for removal of noxious gases from the liquid-waste management subsystem.

A computerized control system is required for operation of the MIUS, and it is centrally located above the cart storage area so that its operator can have full visual control of the facility, both inside and outside. This space functions like an office and is air-conditioned and sound insulated.

The service yard runs parallel to the longitudinal axis of the building and is adjacent to the street for truck access. Under the drive are located the fuel tank, the potable-water storage tank, and the flow-equalization tank. Located on a grade in the service yard are the ash storage container and the electrical power transformer for the backup grid-supplied power. Activities the yard accommodates include truck circulation for numerous services, trash cart circulation, and equipment removal from and placement to the building. The service yard is visually screened both from the project site and the street, and a sound-attenuating element is desirable such as a high grass berm, as is included in this design.

The large storage tanks required for thermal storage and for treated wastewater holding and firefighting-water storage are located under the building and constructed of reinforced concrete with a vapor barrier. The thermal-storage tank is located near the HVAC subsystem for economy of line runs; however, to avoid the dynamic loads that prime movers would impose on the structure, the tank is not located under the power generation system. The treated wastewater holding and firefighting-water tank is adjacent to the thermal-storage tank for economy of construction and close to the liquid-waste management subsystem for economy of line runs.

The roof-mounted equipment includes the airblast heat exchanger, vents for natural ventilation and prime-mover combustion air, the cooling tower, and the exhaust emissions stack. The cooling tower and the exhaust emissions stack are adjacent to one another; thus, the cooling tower can structurally brace the stack, and the upward blast of the cooling tower can help take the exhaust gases upward for dispersion. A high parapet wall with air slots along the bottom is placed around the cooling tower for noise abatement and esthetic purposes.

The building usage is as follows.

Category	Area, m^2 (ft^2)
Office	37.2 (400)
Restroom	7.4 (80)
Storage	11.6 (125)
Total air-conditioned area	56.2 (605)

Category	Area, m^2 (ft^2)
Subsystem equipment floor area	655.0 (7050)
Maintenance shop	34.8 (375)
Cart storage	81.3 (875)
Total enclosed area	827.3 (8905)

The building construction materials are as follows.

Wall section

10.2-centimeter (4 inch) face brick

5.1-centimeter (2 inch) airspace

20.3-centimeter (8 inch) concrete masonry unit

Floor - 19.1- to 30.5-centimeter (7.5 to 12 inch) reinforced concrete

Category	Area, m^2 (ft^2)
Office	37.2 (400)
Restroom	7.4 (80)
Storage	11.6 (125)
Total air-conditioned area	56.2 (605)
Subsystems equipment floor area	655.0 (7050)
Maintenance shop	34.8 (375)
Cart storage	81.3 (875)
Total enclosed area	827.3 (8905)

Roof

Three-ply built-up roof

6.4-centimeter (2.5 inch) lightweight concrete

Metal deck

15.2-centimeter (6 inch) glass batt insulation

The vertical dimensions are as follows.

Category	Height, m (ft)
Floor to roof	6.1 (20)
Clear height	5.5 (18)

ENVIRONMENTAL IMPACT

The purpose of this section is to point out those areas of environmental impact that are peculiar to the MIUS. A specific location has been chosen for testing the MIUS against State and local regulations and for evaluating the MIUS effects in an air quality control region and in a water quality control region. The MIUS for this study is hypothetically located in Montgomery Village, Maryland. To discharge its responsibilities under the Clean Air Act (ref. 33) and the Clean Water Act (ref. 34), the EPA has been requiring the States to prepare plans to ensure that clean air and clean water levels are achieved.

For air polution, the requirements of these plans are described in reference 35. The Administrator of the EPA reviews these plans, and the results of these reviews are published in reference 36, which is being continuously modified and updated.

In the water pollution area, the EPA has prepared a series of regulations to provide water pollution control. Oil pollution is a major item in water pollution control, and the Federal Maritime Commission, the Coast Guard, and the Corps of Engineers also have regulations in this area. The Federal regulations found in reference 37 spell out the various EPA water regulations. As in the case of air pollution, the EPA is requiring the various States to prepare plans in accordance with EPA regulations (ref. 38). In addition, the EPA is providing funds and support in achieving clean water through the National Pollution Discharge Elimination System (NPDES) (ref. 39).

In addition to recognizing the need for pollution control, States are beginning to recognize that natural resources are limited and that control must be exercised over their use. Water resources and utility plant sites are under the control of the Maryland Department of Natural Resources. Noise pollution is now receiving considerable attention, and Maryland laws and regulations in this area can be anticipated in the near future.

The result of the aforementioned activities has been the creation, within the States, of one or more agencies for the planned orderly growth of industry and communities, and it is in this framework that the MIUS must operate.

Air Pollution

Montgomery Village, Maryland, is located on Interstate 70S, approximately 19.3 kilometers (12 statute miles) north-northeast of the northwest boundry of the District of Columbia in Montgomery County, Maryland. Reference 40 (from ref. 41) designates Montgomery County, Maryland, as part of the National Capital Interstate Quality Control Region (District of Columbia, Maryland, and Virginia).

The regulations in reference 35 (from ref. 42) require States to prepare implementation plans for achieving national air quality standards. These regulations provide a classification system to categorize regions for purposes of plan development. There are three categories, priorities I, II, and III, with respect to the various air pollutants. Paragraph 52.1070 a (4) of reference 35 identified the "Plan for Implementation of Ambient Air Quality Standards in the Maryland Portion of the National Capital Interstate Air Quality Control Region." Paragraph 52.1071 of reference 35 assigns the priorities listed in table 19(a) to Montgomery County. Paragraph 52.1078 of reference 35 sets the dates for national standards to be attained; these dates are listed in table 19(b). The levels of pollution corresponding to the various priority levels are given in table 20.

The goal of an air quality control plan is to meet national primary and secondary ambient air quality standards by the indicated time period. These air quality standards are set forth in reference 43 (from ref. 44) and are paraphased in table 21.

The levels of pollution in the Washington metropolitan area for the years 1962 through 1968 have been tabulated in reference 45 and are tabulated in table 22 to show the concentration levels of various pollutants and the ratio of levels of pollution to national air quality standards. Thus, it would appear that, on the average, pollution sources must be reduced by a factor of approximately 2 in the Washington area by June 1975.

The regulations in reference 35 require States to submit plans for achieving national secondary standards. This plan must state a control strategy for reducing levels in excess of national standards and for maintaining these standards despite projected growth in population, industrial activity, motor vehicle traffic, or other factors that may cause or contribute to increased emissions. The control strategy means a combination of measures designated to achieve the aggregate reduction of emissions necessary to attainment and maintenance of a national standard, including but not limited to the following measures.

1. Emission limitations

2. Emission charges or taxes

3. Closing or relocating of residential, commercial, or industrial facilities

4. Changes in schedules or methods

5. Motor vehicle emission testing

6. Emission control measures

7. Traffic reduction

8. Expansion of use of mass transit

9. Land use measures

10. Variation of or alternates to preceding measures

The State plans must include the following items.

1. General requirements
    a. Interface with national air control regions
    b. Public availability of data
2. Legal authority
3. Control strategy for individual pollutants
4. Compliance schedules
5. Prevention of air pollution emergency episodes
6. Air quality surveillance
7. Review of new sources and modifications
8. Source surveillance
9. Resources
10. Intergovernment cooperation
11. Rules and regulations

The requirements of reference 35 have been met by the State of Maryland by passage of the Maryland Air Quality Control Act, the Maryland Environmental Policy Act, and the Maryland Air Pollution Regulations. The Maryland Air Pollution Regulations require that permits be obtained to construct and to operate installations. For obtaining a construction permit, the following exemption criteria can be applied to the MIUS.

1. Fuel-burning equipment using gaseous fuels or number 1 or number 2 fuel oil with a heat rate of less than 293 kilowatts (1 000 000 Btu/hr)

2. Stationary internal combustion engines with less than 745.7 kilowatts (1000 brake horsepower)

3. Cooling towers unless used with an installation requiring a permit to operate

4. Storage of numbers 1, 2, 4, 5, and 6 and aviation jet fuel

A permit to operate is required for the following types of installations.

1. Incinerators of 907.2 kg/hr (2000 lb/hr) or more rated capacity

2. Fuel-burning installations using liquid or solid fuels with a capacity of 14 644 kilowatts (50 x 10^6 Btu/hr) or more maximum rated input when located on premises where the total rated input for all fuel-burning installations is 29 288 kilowatts (100 x 10^6 Btu/hr) or more

The following saving clause also applies.

> "The possession of a 'permit to operate' does not relieve any person from the obligation to comply with all other provisions of these regulations and Federal Air Pollution Control Regulations."

A set of Maryland regulations, 10.03.39, exists governing the control of air pollution in area IV (Washington metropolitan area, consisting of Montgomery and Prince Georges Counties) that was not available at this time.

Maryland has proposed regulations to control automobile emissions associated with stationary sources in Maryland. These proposals would require complex sources of air pollution to be approved by the Maryland Department of Natural Resources. Complex sources are defined to include residential developments with more than 400 units, parking lots with more than 400 spaces, and commercial facilities larger than 4645.2 square meters (50 000 square feet). Noise regulations are also in preparation. On December 14, 1973, Maryland set an absolute limit of 249.5 kg/day (550 lb/day) of hydrocarbon emissions from new sources.

The MIUS and its associated apartment house complex have the following characteristics.

Installed internal-combustion-engine capacity	2028.3 kilowatts (2720 horsepower)
Maximum engine power used	1044.0 kilowatts (1400 horsepower)
Maximum fuel power used	3015.1 kilowatts (10 295 000 Btu/hr)
Incinerator capacity	362.9 kg/hr (800 lb/hr)
Incinerator maximum number 2 fuel rate	102.5 kilowatts (350 000 Btu/hr)
Incinerator solid-plus-liquid-fuel rate	937.2 kilowatts (3 200 000 Btu/hr)
Units in complex	496
Parking spaces in complex	740

On the basis of the aforementioned charcteristics, it would appear that an Air Pollution Construction Permit would be required in Maryland, but not an Operating Permit.

Maryland regulations require the following information for a construction permit.

1. Description of proposed installation

2. Design capacity of process equipment, process weight, and process weight per hour

3. Expected physical and chemical composition of emissions and pertinent discharge rate, concentration volume, and temperature

4. Type and characteristics of control equipment

5. Description and evaluation of location of discharge point and other factors relating to dispersion and diffusion in the atmosphere

6. Information on the relationship of the discharge point to nearby structures and topography necessary to appraise the possible effects of the emissions

Maryland regulations also provide for coping with an air pollution emergency. This plan has three levels of air contamination that are considered significant.

1. Alert state

2. Warning state

3. Emergency state

When an alert state is declared by the State, the MIUS will be required to shut down incinerators. Coal- or oil-fired electrical generators are required to make substantial reductions in emissions and to divert loads to areas outside the alert area. For the warning and emergency states, maximum reductions are required.

Carbon monoxide and hydrocarbons.- Currently, the EPA is placing particular emphasis on the control of carbon monoxide and hydrocarbons in the National Capital Air Quality Control Regulations. In compliance with the regulations in reference 35, the Maryland Plan reports that, in the 1972 peak period, hydrocarbon emissions were 27 306.3 kilograms (30.1 tons) (47.6 percent of the total regional peak emissions) and that carbon monoxide emissions were 260 112.5 Mg/yr (286 725 tons/yr). The Maryland calculations indicate that hydrocarbons must be reduced by 65 percent of 1972 emissions, to a level of 9525.4 kilograms (10.5 tons). Similarly, carbon monoxide emissions must be reduced by 55 percent of the 1972 levels, to an annual level of 117 050.4 megagrams (129 026 tons). It has been estimated that the Federal Motor Vehicle Control Program will reduce hydrocarbon peak-period emissions by 13 698.5 kilograms (15.1 tons), or approximately 50 percent relative to the 1972 base period. The impact on carbon monoxide levels will be to reduce emissions in Maryland by 131 541.8 megagrams (145 000 tons) yearly, or by 51 percent relative to the 1972 base period. The data in tables 23 to 25 have been extracted from the "Proposed Environmental Protection Agency Regulations on Approval and Promulgation of Implementation Plans" (ref. 46). Table 23 is a summary of the proposed stratagems to effect the total reductions required. The hydrocarbon and carbon monoxide emissions from the MIUS using diesel fuel in the Maryland area and the fractional increase for the MIUS are shown in table 25. In general, it can be seen that the MIUS makes a nearly negligible contribution to carbon monoxide or hydrocarbon pollution in the Maryland portion of the National Capital Air Quality Control Region. Downdraft around buildings has not been addressed and could cause some concentration of carbon monoxide and hydrocarbons. Site-specific data would be required to resolve such problems.

Sulfur dioxide.- The primary method of controlling sulfur dioxide emissions in Maryland appears to be by the use of low-sulfur fuels. Some variances have been permitted during the fuel crisis by the Governor of Maryland. The regulations in reference 36 require that an owner of boilers or furnaces with a fuel input of more than 73.2 megawatts (250 x 10^6 Btu/hr) notify the Administrator by January 1, 1974, of his intention to use low-sulfur fuel or stack desulfurization to comply with Maryland Regulation 10.03.39 entitled "Regulations Governing the Control of Air Pollution in Area IV (Washington Metropolitan Area Comprising Montgomery and Prince Georges Counties)." The EPA requires that a contract be made by the operator assuring that low-sulfur fuel will be available through 1976. If boiler modifications are required, then the completion data must be July 1, 1975. The EPA gives the total emission of sulfur oxides as 224 075 Mg/yr (247 000 tons/yr) in Washington, D.C. Reference 45 gives the annual arithmetic mean concentration of sulfur dioxide in the Washington area for the years 1961 through 1968 as 0.05 p/m. Reference 36 places the Washington area in category 1. The concentration, therefore, must have exceeded 0.05 p/m in 1972, and at least a 33-percent reduction in sulfur oxides will be required to meet Federal air quality standards in the Washington, D.C., area.

The current design of the MIUS specifies the use of number 2 diesel fuel, with sulfur content a nominal 0.2 percent. This usage produces 6522.66 kilograms (7.19 tons) of sulfur dioxide per year. The incinerator is estimated to release 2041.17 kilograms (2.25 tons) of sulfur per year. A comparison can be made on the basis of the annual emission weight per person and the annual emission weight per unit area. A second comparison can be made against emission standards for large stationary sources. On the basis of emissions in 1967 and 1968, in Washington, D.C., annual emission amounted to 82.3724 kg/person (0.0908 ton/person) and 381 089.4 kg/km^2 (1088 tons/s. mi^2). The national standards limitation is 54.8847 kg/person (0.0605 ton/person) and 257 445.5 kg/km^2 (735 tons/s. mi^2) annually. The MIUS annual production, consisting of 7.257 kg/person (0.008 ton/person) and 189 143.6 kg/km^2 (540 tons/s. mi^2), is considerably lower than that allowed by the standards. For large stationary sources burning fuel oil, the allowed sulfur dioxide output per heat input is 0.34 g/MJ (0.80 lb/10^6 Btu).

The MIUS prime-mover system produces 0.14 g/MJ (0.32 lb/10^6 Btu), a ratio considerably less than the allowed limit for stationary sources.

Particulates.- The diesel is a clean-burning engine. The allowed emission for large stationary plants is 43.0 mg/MJ (0.1 lb/10^6 Btu), and the MIUS prime mover emits approximately 5.163 mg/MJ (0.012 lb/10^6 Btu). The starved-air incinerator also has very low emission and meets all required EPA standards.

Oxides of nitrogen.- The adoption of control strategy for carbon monoxide and hydrocarbons has been given precedence over that for nitrogen oxides. In June 1973, the EPA published "A Notice of Proposed Rulemaking to Revise National Primary and Secondary Ambient Air Quality Standards - Reference Method for the Determination of Nitrogen Dioxide" (ref. 47). In "Proposed Environmental Protection Agency Regulations to Reclassify Air Quality Control Regions" (ref. 48), the EPA proposed reclassification of the 43 of 47 air quality regions originally classified as priority I to priority III. Thus, Montgomery County, the site for the proposed MIUS, will meet national secondary air quality standards if the proposed legislation is adopted.

The following data for the National Capital has been extracted from reference 48.

Nitrogen dioxide concentration, arithmetic average per period of operation, micrograms per cubic meter

Federal reference method (old method)	146
Arsenite method (first candidate method)	88
Chemiluminescence method (second candidate method)	64

Projected growth rates, nitrogen oxides emissions (National Capital), percent per year

Light-duty vehicles	2.0
Medium-duty vehicles	2.0
Heavy-duty vehicles	2.0
Powerplants	4.4
Industry sources	4.9
Area sources	4.9

Projected emission distribution for the National Capital

1.9-g/km (3.1 g/s. mi.) light-duty-vehicle standard, percent of total emissions

	1977	1980	1985
Light-duty vehicles	50.3	49.7	47.9
Medium-duty vehicles	.6	.6	.4
Heavy-duty vehicles	7.6	7.1	7.1
Powerplants	25.2	22.7	22.5
Industrial sources	0	0	0
Area sources	16.4	19.9	24.1
Total, motor vehicles	58.5	57.4	55.4
Total, stationary sources	41.6	42.6	46.6

0.2-g/km (0.4 g/s. mi.) light-duty-vehicle standard, percent of total emissions

	1977	1980	1985
Light-duty vehicles	45.8	34.4	15.7
Medium-duty vehicles	.6	.7	.7
Heavy-duty vehicles	8.2	9.3	8.3
Powerplants	27.4	29.7	36.3
Industrial sources	0	0	0
Area sources	17.9	26.0	38.9
Total, motor vehicles	54.6	44.4	24.7
Total, stationary sources	45.3	55.7	75.2

The EPA gives the amount of nitrogen oxides emission in Washington, D.C., as 122.5 Gg/yr (1.35 x 10^5 tons/yr). This amount equates to 23.41 kg/person (2.58 x 10^{-2} ton/person) and to 10 823.2 kg/km^2 (30.9 tons/s. mi^2). The MIUS plant produces 137 438.5 kg/yr (151.5 tons/yr) of nitrogen oxides. This amount equates to 115.212 kg/person (0.127 ton/person) and to 3 038 907.7 kg/km^2 (8676 tons/s. mi^2). Although these emission rates are high, until a control strategy for nitrogen oxides is adopted, these emissions will not constrain operation of the MIUS.

State regulation summary.- The releases by the MIUS of carbon monoxide, hydrocarbons, sulfur dioxide, and particulates should cause no major obstacles in obtaining State of Maryland construction permits. The associated apartment houses could prove more of a stumbling block because of the associated vehicle traffic. Oxides of nitrogen are not currently a problem in obtaining a construction permit; however, their emission rate is high and could be a source of future difficulty.

The use of natural gas should be reconsidered for its environmental effects. Use of natural gas would eliminate hydrocarbon and sulfur dioxide pollutants from the prime mover and would reduce the amount of nitrogen oxides emission because of the lower combustion temperature.

State regulation effects on MIUS operations.- All State regulations include provisions for coping with air episodes. Under these episode regulations, the MIUS will be required to shut down incinerators whenever alert warnings are made by State agencies. The possibility exists that the State could require that prime movers be shut down for the duration of the air episodes and that power be obtained from an electrical source outside the air episode area. This action could mean the loss of absorption air-conditioning and hence a loss in total deliverable air-conditioning during the episode. Maryland air episode criteria are contained in Maryland Air Pollution Regulations 10.03.35, section 03. These regulations appear to be copied nearly verbatim from appendix L to reference 35 and hence are probably very similar to those of other States. An air pollution emergency progresses through three stages, with the following criteria.

1. Alert warning - This condition is considered to exist when any one of the following levels is reached at the monitoring site.

Pollutant	Level
Sulfur dioxide	800 μg/m^3 (0.3 p/m) (24-hour average)
Particulate matter	A coefficient of haze (COH) of 3.0 or 375 μg/m^3 (24-hour average)
Sulfur dioxide and particulates	Product of sulfur dioxide part-per-million concentration (24-hour average) and a COH equal to 0.2
Carbon monoxide	15 p/m (8-hour average)
Photochemical oxidant	0.1 p/m (1-hour average)
Nitrogen dioxide	0.6 p/m (1-hour average) or 0.15 p/m (24-hour average)

The applicable actions for the MIUS are as follows.

"4.	Onsite incineration.	Stop completely.
"5.	Any source of air pollution, not covered above, upon written request of the Department may be required to submit standby plans describing emission cutbacks to be taken in the event an alert is called.	Substantial reduction possible consistent with requirements for safety of people and preservation of property."

2. Warning stage

Pollutant	Level
Sulfur dioxide	0.6 p/m (24-hour average)
Particulate matter	5.0 COH (24-hour average)
Sulfur dioxide and particulate matter	Combined product of sulfur dioxide part-per-million concentration and a COH equal to 0.8
Carbon monoxide	30 p/m (8-hour average)
Photochemical oxidant	0.4 p/m (1-hour average)
Nitrogen dioxide	1.2 p/m (1-hour average) or 0.3 p/m (24-hour average)

The required action is as follows.

"5.	Any source of air pollution, not covered above, upon written request of the Department may be required to submit standby plans describing emission cutbacks to be taken in the event an alert is called.	Maximum reduction possible consistent with requirements for safety of people and preservation of property."

3. Emergency stage

Pollutant	Level
Sulfur dioxide	0.8 p/m (24-hour average)
Particulate matter	7.0 COH (24-hour average)
Sulfur dioxide and particulate matter	Combined product of 24-hour average sulfur dioxide part-per-million concentration and a COH equal to 1.2
Carbon monoxide	40 p/m (8-hour average)
Photochemical oxidant	0.6 p/m (1-hour average)
Nitrogen dioxide	1.6 p/m (1-hour average) or 0.4 p/m (24-hour average)

The required action is as follows.

> "5. All standby emission reduction plans required by the Department and not already in effect or described above shall be implemented.
>
> "Actions specified are primarily for control of particulate matter and oxides of sulfur emissions and will be instituted when an alert, warning, or emergency stage is called for these pollutants. An alert, warning, or emergency stage called for other pollutants may not require instituting these actions if no reduction in pollutant level will be attained."

A review of the data for the Washington, D.C., area from reference 45 indicates that the probability of exceeding even the alert-stage levels specified previously appears vanishingly small and that such an event should occur about once every 25 years, on the basis of air quality data for the 1961 to 1968 period, which is an era before the institution of air quality standards. The fact that air quality is being improved makes the possibility even smaller, and hence this consideration should offer no problems to the operation of the MIUS in the Washington, D.C., area.

Micropollution problems.- So far in this environmental impact analysis, it has been established that the standard-method MIUS should not encounter difficulties because of limitations on total emissions in the Maryland portion of the National Capital Air Quality Control Regulations and that the possibility of having to shut down part or all of the MIUS operation because of air pollution episodes is vanishingly small. To complete the air analysis, one other area needs consideration, the concentration of pollutants emitted from the MIUS plant in the immediate area surrounding the MIUS.

Analysis of the dispersion of gases from the exhausts of an MIUS plant and the resultant concentrations downwind is complicated for the case wherein the MIUS is located in a multistoried apartment complex. All receptors of interest would lie within a highly turbulent region, where rapid dilution of the emitted pollutants can be expected. The use of tall stacks to clear the turbulent area is feasible, but the required stack height is 2.5 times that of the highest building.

For the local pollution problem, the nature of the emitted pollutants should be considered. Hydrocarbons and oxides of nitrogen are considered indirect pollutants when regional air pollution is studied. Hydrocarbons and nitric oxide are transformed by ultraviolet Sun rays in the atmosphere to form proxy acyl nitrates, ozone, and nitrogen dioxide, all of which are known respiratory and eye irritants. A fairly long period of time, 3 hours, is required for occurrence of these atmospheric reactions; hence, the final products are not formed until emissions are a long distance from the MIUS site.

Almost all the oxides of nitrogen emitted by the prime mover will be in the form of nitric oxide. The EPA has stated that at concentrations found in the atmosphere, nitric oxide is not an irritant and is not considered to have adverse health effects. Nitric oxide, therefore, should not be considered in micropollution problems.

The type of fuel used will influence the analysis of the hydrocarbon emissions. If natural gas is used as a fuel, there should be no known pollutant that needs to be considered on a microscopic scale. If diesel fuel is used, the emissions of interest are formaldehyde and acrolein. The concentration of these two compounds has been shown to correlate with the intensity and odor of diesel exhaust. If the odor threshold is taken as the upper limit for these compounds, the formaldehyde concentration would be 0.01 p/m (12 $\mu g/m^3$) and the acrolein concentration would be 1600 $\mu g/m^3$ (0.25 p/m). The expected background levels of these compounds in the atmosphere in various cities of the United States is not known but is probably very low.

Other pollutants that enter into the micropollution analysis are sulfur dioxide and particulates. Sulfur dioxide is emitted by both the diesel generator and the incinerator in the MIUS. Approximately 75 percent of the sulfur dioxide is emitted by the generators, and approximately 25 percent is emitted by the incinerators. There is a great deal of uncertainty about the amount emitted by the incinerator. The use of natural gas could significantly reduce sulfur emissions from the generator. Both the incinerator and the generators are low emitters of particulate matter. The background concentrations of these materials drop as more and more pollution control equipment is installed in cities across the country. Sulfur dioxide should be the principal pollutant of significance to the MIUS prime mover. The gases released by the incinerator could include, but are not limited to, mercaptans, carbon disulfide, hydrogen sulfide, hydrogen chloride, and hydrogen fluoride. For the evaluation of local hazards associated with these materials, more information on the emission rates of these materials is required.

In summation, sulfur dioxide should be the most prevalent pollutant if diesel oil is used, followed by formaldehyde and acrolein. The use of natural gas would eliminate all but the incinerator sulfur dioxide, and the amount of sulfur in the incinerator trash load is highly uncertain. The other pollutants from the incinerator cannot be analyzed at this time because of insufficient data. The dispersion of pollutants locally was not addressed for the MIUS and its associated apartment complex, but it is believed that dilution by the air is sufficient and that high stacks or stack pollution control equipment for microscopic air pollution cannot be justified.

Overall summary.- For the Maryland region, State regulations require that the construction permit be obtained for the MIUS. The emissions from the MIUS would appear to be secondary to the emissions associated with parking and car traffic of the dwelling units serviced by the MIUS. Building constraints will be based on carbon monoxide and hydrocarbon releases, which are low for the MIUS, and the latter problem can be eliminated by the use of natural gas. Oxides of nitrogen are the most significant emission from the MIUS; but, because the National Capital Air Quality Control Regulations meet the EPA secondary standards, no construction constraints due to this pollutant are expected.

Micropollution in the immediate vicinity of the MIUS cannot be analyzed, but observations of similar plants indicate that no major problem should be anticipated. The major pollutant on a microscopic scale is probably sulfur dioxide.

Water, Sewage, and Solid Waste

The State of Maryland has extensive regulations to ensure adequate drinking water for its citizens, both as to amount and quality. To protect the environment, Maryland has adopted regulations for the disposal of sewage and solid wastes. The region around the National Capital requires interstate cooperation that involves the Washington Suburban Sanitary Commission and the Maryland-National Capital Park and Planning Commission. In addition, sewage systems can be funded under the NPDES and hence are subject to Federal regulations.

Water sources.- The Maryland Water Resource Law, Title 8, Water and Water Resources, charges the Maryland Department of Natural Resources with "Responsibility to supervise development of a general water resources program . . . . The Department shall exercise to the fullest extent possible the State's responsibility for its water resources . . . . It shall develop a general water resources program which contemplates proper conservation and development of the waters of the State, in a manner compatible with multiple purpose management, on a watershed or aquifer basis or any other appropriate geographical unit."

If the MIUS is supplied with water from a well, the well must be dug by a licensed well digger, who cannot dig the well until a permit is obtained from the Department of Natural Resources. The decision on whether to issue a well-digging permit will be based upon the requirements of the Maryland Water Pollution Control Laws, Annotated Code of Maryland, Article 43 - Health Sections 387 through 406A: Water, Ice, and Sewage - amended by chapter 661, Laws of 1970. These laws are administered by the Environmental Health Services, State Department of Health. The law requires each county to "Adopt and submit to the Department, a county plan dealing with water supply systems and sewage systems . . . and a complete county plan dealing with solid waste disposal systems and solid waste acceptance systems . . . ." Updating and review are performed by the principal elected officials of any municipal corporation. In Prince Georges and Montgomery Counties, the governing bodies establish goals, purposes, and concepts that each desires and submit these to the Washington Suburban Sanitary Commission. These requirements are updated annually. These county recommendations must have a public hearing and are subject to recommendations from the Maryland-National Capital Park and Planning Commission. The Department of Health must approve or disapprove the counties' plans within 6 months of their submittal. No State or local authority can issue a building permit for potable-water, sewage, or solid-waste-disposal systems that are not part of the county's approved plan. The State laws also require recordkeeping and certification of operators of waterworks and wastewater works.

In addition to regulatory action, Maryland has enacted laws for providing environmental services. The Maryland Environmental Service Agency of the Department of Natural Resources performs this function. This agency is responsible for planning, integrating, establishing, and optionally operating geographic service regions and districts in cooperation with affected municipalities on the basis of State-approved master plans for water, sewage, and solid-waste disposal.

In summary, a potable-water supply will have to be obtained in a manner that fits the State of Maryland overall plans. If a well is not approved, the MIUS will probably receive treated water from one of the State systems, probably under the cognizance of the Washington Suburban Sanitary Commission.

Wastewater disposal.- On May 1, 1973, the Water Resources Administration of the State of Maryland (Regulation 08.05.04.08) discontinued the issuance of State Discharge Permits and became a participant in the NPDES. A permit is required for the discharge of any water in excess of 37.85 m^3/day (10 000 gal/day) into State waters and for the discharge of any waste or wastewater, regardless of volume. A permit application must be filed 180 days before the date of planned operations on appropriate NPDES forms, and the following information must be submitted with the complete form.

1. The names of any affiliates

2. The locations of all sites involved in storage of solid or liquid waste and ultimate disposal sites of solid or liquid wastes from any treatment system

3. If the discharge is from a new processing facility or new treatment facility, preliminary plans and specifications sufficiently adequate in scope and form to enable the Administration to evaluate the proposed facility

4. If required by the Administration, additional reports, specifications, plans, or other information on the proposed pollution control program, including a material balance (an inventory accounting system for determining quantities of materials on hand, used in the process, converted to the product, lost to the environment, and/or contained in waste matter generated, stored, discharged, or otherwise processed) if deemed necessary

The Administration shall submit to the EPA a copy of each application for a permit unless the Administration and the EPA agree that such submission is not required. The NPDES application must be signed by a responsible official at the company that will operate the facility. The application for an NPDES permit is subject to a public hearing; the costs of the notice of the hearing and a transcript must be borne by the applicant.

The criteria for issuance of an NPDES permit are as follows.

1. The discharge of proposed discharge will be in compliance with the requirements of effluent limitations and/or receiving-water quality standards and/or ground-water quality standards as established by the State.

2. The discharge is in compliance with the Comprehensive County Water and Sewage Plan and/or other applicable planning process.

Maryland Discharge Permit regulations require monitoring, recording, and reporting on plant operation. Monitoring equipment may be specified by the Administrator; records, including original strip charts, calibrations, etc., must be maintained for 3 years or longer in case of litigation. The NPDES permit will specify the reporting period to the Administration.

For a new plant, the NPDES permit will not be subject to more stringent requirements for 10 years after completion, or over the period of depreciation or amortization specified by the Internal Revenue Service.

The proposed discharge from the MIUS into Maryland waters is as follows. For the MIUS, located in Montgomery County, it is proposed to release treated effluent into the Little Seneca Creek. This creek and its tributaries are classified by Maryland Regulation 09.05.04.09 as in Sub Basin Code 02-14-02 and are class IV recreational trout waters; i.e., waters that are capable of holding or supporting adult trout for "put and take" fishing and that are managed as a special fishery by periodic stocking and seasonal catching. These streams have the following receiving-water standards (Maryland Regulation 09.05.04.03).

Class IV Recreational Trout Waters

Bacteriological Standards

There shall be no source of pollution as determined by a sanitary survey, and the fecal coliform content of these waters shall not exceed a log mean of 200/100 cm^3 (200/100 ml).

Dissolved Oxygen Standard

The dissolved oxygen concentration must not be less than 4000 mg/m^3 (4.0 mg/liter) at any time, with a minimum daily average of not less than 5000 mg/m^3 (5.0 mg/liter) except where - and to the extent that - lower values occur naturally.

Temperature Standard

1. Thermal effects shall be limited and controlled so as to prevent:
    a. Temperature effects that adversely affect aquatic life
    b. Temperature effects that adversely affect spawning success
    c. Thermal barriers to the passage of fish
2. Temperature must not exceed 297 K (75° F) beyond such distance from any point of discharge as specified by the Administration, except where - and to the extent that - higher temperatures occur naturally.

pH Standard

Normal pH values must not be less than 6.5 nor greater than 8.5 except where - and to the extent that - pH values outside the range occur naturally.

Turbidity Standards

1. Turbidity shall not exceed levels detrimental to aquatic life.
2. Within the limits of Best Practical Control Technology currently available, turbidity shall not exceed for extended periods of time those levels normally prevailing during periods of base flow in the surface waters.
3. Turbidity in the receiving waters shall not exceed 50 JTU (Jackson Turbidity Units) as a monthly average nor exceed 150 JTU at any time.

As far as can be established at this time, the effluent from the MIUS will equal or exceed the water quality of the receiving stream, with the possible exception of meeting the temperature requirement. Because the General Requirements Section of the Maryland Water Control Regulations (08.05.04.02) indicates that the Administration will establish a mixing zone in the vicinity of the discharge, no major problem is expected to result from the temperature of the discharge.

A potential problem area in wastewater treatment is the exact treatment for process water used by the cooling tower of the baseline MIUS. At this point in the design, an exact method of treatment to prevent corrosion and algae growth has not been specified.

Effects of Federal laws: The Federal Water Pollution Control Act of 1972 (ref. 34), under which Federal construction grants are provided, has a number of interesting facets that affect the water system of the MIUS. The law provides for grants by the Federal Government to defray construction costs: however, such grants are paid only to the State agency designated by State regulations, after the construction has been approved as part of the overall State plan. A State application for a construction grant must demonstrate that the project is the most cost-effective alternate to meeting effluent standards. The defraying of operating costs must be borne by the recipients of the service.

It is expected that EPA discharge standards for cooling-tower blowdown will be promulgated in the near future, probably under the hazardous-substances provisions of the Water Pollution Act. It is expected that pretreatment will be required for cases in which blowdown either is released to the environment or is processed through a sewage facility.

Summary: The outstanding problems in meeting environmental standards associated with the wastewater system in the standard-method MIUS appear to be, in order of priority, as follows.

1. Whether the MIUS will fit into other State, county, and agency plans

2. The long leadtime for approval of an NPDES permit

3. The early establishment of responsibility for operation of the wastewater system

4. The certification of a wastewater system operator in accordance with State regulations

Solid waste.- The Maryland State Department of Health and Mental Hygiene Regulation 43-L09 (Regulations Governing Planning Solid Waste Management Facilities), effective January 1, 1971, requires all counties to prepare a comprehensive overall county solid-waste-disposal plan complete with planned facilities and time schedules to meet requirements for 10 years, commencing in 1973. These plans are reviewed and approved by the Department of Health. Annual updating is required by the regulations. Arrangements will have to be made with the county for the disposal of the noncombustible residue from the incineration process.

The Federal Solid Waste Disposal Act (ref. 49) may offer some opportunity for obtaining grants for the procurement and operation of the incinerator plant. These grants will probably be subject to requirements and limitations similar to those developed for water treatment.

There are no Federal regulations on the disposal of solid waste that are applicable to the MIUS. The regulations proposed in references 50 and 51 are applicable to incinerators of 45 359.2 kg/day (50 tons/day) capacity. However, the suggested subsystems, operation methods, and reporting requirements for these larger incinerators can and probably should be adopted in any final specifications for the MIUS.

The aforementioned proposed regulations cite the mixing of sewage sludge and other waste as nonrecommended practice and indicate that incinerators should be located in industrial areas. The question of odors and toxic gases being emitted from the incinerator is still open and will require that operating data be obtained from an operating or experimental facility. The inability to forecast pollutant concentrations in the immediate vicinity of the MIUS has previously been cited in the subsection of this report entitled "Air Pollution."

BASELINE MIUS COSTS

Costs for the baseline MIUS were compiled on a subsystem basis with the use of Chicago, Illinois, or U.S. average costs as nearly as could be determined. Chicago was used as an appropriate national median. The costs include subcontractor profit and overhead but do not include general contractor profit and overhead.

The cost analysis including operating and maintenance (O&M) costs of the baseline MIUS for mid-1974 Chicago prices is presented in tables 26 to 37. In this activity, costs for equipment located within the apartment buildings have not have included. An estimate of the cost of 1.6 kilometers (1 statute mile) of offsite sewer outfall has been made; however, this cost has not been included with the wastewater subsystem cost because this parameter will vary with any specific site location. Treated wastewater disposal is one cost element of both the community study and the baseline MIUS that is not included in the comparison. An onsite potable-water treatment plant has been costed; however, this cost has not been used in the comparison with conventional utilities. The community-study conventional water supply system cost has been used for both the MIUS and the conventional utilities. Electricity cost for the water system has been based on the community-study conventional electrical power costs. No adjustment has been made in the operating-crew requirements and electrical power subsystem requirements because of deletion of the onsite water-treatment equipment. A flat rate of $70/week has been assumed for offsite disposal of ash, which amounts to about one dump-truck load per week. Individual dwelling unit metering and billing costs were not considered in this study. Administrative costs, property taxes, and other such real costs were also not considered in the study.

A category of miscellaneous initial or capital costs has been included to cover the costs of common trenching, miscellaneous operation and maintenance tools, an initial spare-parts inventory, the initial loading of fuel for the system, and a pneumatic system that services all the subsystems.

A composite (O&M) crew for the system has been assumed, and this operating cost has been separated from the other operating costs of the individual subsystems. The O&M crew will do scheduled and unscheduled maintenance except for major repair of engines, generators, switchgear, chillers, control equipment, heat-recovery equipment, and other maintenance requiring special skills and repair equipment. Cost estimates for these latter items are provided with each individual subsystem.

The data in tables 26 to 37 include the initial cost and annual O&M costs for the system. The maintenance costs have been largely based on 20-year average values and represent the costs required to keep the equipment in good repair but do not include replacement, depreciation, or amortization values.

Electrical Power Subsystem

The baseline electrical power subsystem, for costing, consists of the power generation equipment with heat recovery, the electrical distribution hardware from the generation station to the individual buildings, and the fuel storage and supply equipment. In addition to the major hardware components of this subsystem, an estimate has been made for the plumbing components, based on the system schematics and an illustration of a three-engine total energy plant represented to be similar to this conceptual design.

The baseline annual electrical energy production has been determined as 19 573 200 megajoules (5 437 000 kilowatt-hours) and the fuel consumption as 1552 cubic meters (410 000 gallons) of number 2 diesel fuel. The annual maintenance cost for the powerplant has been based on average data from nine small-baseload municipal powerplants reported in reference 57. These data are included in table 28(e).

Maintenance costs for the electrical power distribution equipment have been based on data from the Department of Housing and Urban Development (HUD) low-cost-housing survey. In the community study conducted by the JSC Urban Systems Project Office (USPO), a cost of 0.62 mill/MJ (2.25 mills/kWh) was used for the distribution equipment O&M cost, the basis of the 1970 Federal Power Commission Survey data for the East Central Power Region (ref. 56). In the initial estimates for the baseline MIUS, a value of 0.28 mill/MJ (1.0 mill/kWh) was arbitrarily assumed for this cost. The maintenance and repair data from the HUD low-cost-housing documentation (ref. 60) indicate that this cost may be high for high-density, local-distribution equipment; the cost factors related to this element of cost are provided in table 28(f). For the baseline MIUS, the electrical distribution equipment initial cost is $63 000; at 2 percent, the maintenance and repair cost would come to $1260/yr, or approximately 0.6 mill/MJ (0.23 mill/kWh). For purposes of this costing study, this value will be used.

Operator cost for the subsystem has been included in the baseline MIUS operating-crew costs, which are detailed in table 37(a).

Water Supply Subsystem

In the initial phases of the baseline MIUS study, it was assumed that raw, untreated water would be purchased and treated onsite. This system was costed, and details of this costing are included in tables 30(a) to 30(d). The costs of this subsystem compared to the costs of a complete water supply system (which has been used for the cost of conventional utilities) biased the comparison in a manner favorable to the MIUS. Because the purchase of untreated water is not typical, the costs of the onsite treatment have not been used in the comparison to conventional costs. The costs for a conventional water supply system, based on the community-study data, have been used. The results of this costing are summarized in table 29. The capital cost has been based on the peak requirements, and the O&M costs have been based on average requirements. The average supply requirements for the baseline MIUS are 335.4 m^3/day (88 600 gal/day), and the peak requirements are 420.6 m^3/day (111 100 gal/day).

Operating personnel and electrical power requirements for the MIUS were evaluated on the basis of the onsite treatment plant requirements summarized in table 30(a). No adjustment has been made to these parameters because of deletion of the onsite treatment plant.

The specifications and the cost breakdown for the raw-water pumps used (table 30(b)) are as follows.

Item	Cost
Single-stage horizontal centrifugal pump, 0.4-m^3/min (100 gal/min), 597.8-kN/m^2 (200 foot) head pressure, 3.8-centimeter (1.5 inch) discharge (Ingersoll-Rand)	$ 610
11.2-kilowatt (15 horsepower), 377.0-rad/sec (3600 rpm) pump motor (Westinghouse)	214
Motor starter and circuit breaker	193
Pad	40
Pump and motor installation (15 man-hours at $15/hr)	225
Total	$1282

Wastewater Subsystem

The wastewater subsystem, for purposes of costing, consists of the collection piping from the individual buildings to the processing equipment, the processing equipment, and the firefighting equipment. A length of 1.6 kilometers (1 statute mile) of 15.2-centimeter (6 inch) cast-iron outfall piping has been costed, but this total has not been included in the summary costs because this cost will vary with each specific site.

Although many of the component equipment costs have been based on vendor quotes as free-on-board the factory, these costs will be taken as representative of U.S. average delivered costs and specific site cost adjustments will be made on the basis of these values. Operator labor has been included with the system operating-crew costs. The average quantity of wastewater processed per day has been determined as 334.6 cubic meters (88 400 gallons). The peak daily processing requirement is 446.7 cubic meters (118 000 gallons).

The baseline MIUS wastewater and firefighting-water subsystem cost analysis is presented in tables 31(a) to 31(c). Specifications and cost breakdowns for major components are as follows.

1. Richardson's 15028-62 vertical nonclog sewage pump (ref. 52): 0.28-m^3/min (75 gal/min) at 191.3-kN/m^2 (64 foot) head pressure; 0.38-m^3/min (100 gal/min) at 182.3-kN/m^2 (61 foot) head pressure; 7.6-centimeter (3 inch) discharge; 1.5-meter (5 foot) depth; 3.7-kilowatt (5 horsepower)

Item	Cost
Pump	$ 805
Weathertight float switch assembly	110
76.2-centimeter (30 inch) sump cover	50
Cast-iron sump (ref. 54)	460
3.7-kilowatt (5 horsepower), 181.0-rad/sec (1728 rpm), normal-thrust vertical motor	193
Starter and circuit breaker (material only)	135
Pump and electrical installation, 10 man-hours at $15/hr	150
Total	$1903

2. Flow-equalization tank (ref. 53), 113 562-liter (30 000 gallon), fuel-oil storage, coated

Item	Cost
0.953-centimeter (0.375 inch) steel tank, 2.4- by 7.6-meter (8 by 25 foot), exterior coated	$5600
Installation	1700
Excavation at $10.46/$m^3$ ($8/$yd^3$)	1240

Interior coating of neoprene, fiber glass reinforced, at $\$8.61/\mathrm{m}^2$ ($\$0.80/\mathrm{ft}^2$)	1200
Fittings	100
Total	$9840

3. Fuel-oil storage tank (ref. 53), 75 708-liter (20 000 gallon), coated

Item	Cost
0.8938-centimeter (0.3125 inch) steel tank, coated	$3500
Installation	1250
Neoprene reinforced with 0.318-centimeter (0.125 inch) fiberglass at $\$8.61/\mathrm{m}^2$ ($\$0.80/\mathrm{ft}^2$)	400
Total	$5150

4. Garver clarifier-reactor, 4.6-meter (15 foot) diameter, 0.26-m^3/min (70 gal/min) flow rate (ref. 52)

Item	Cost
Clarifier-reactor	$11 600
Field weld, 77.7 meters (255 feet) (ref. 53)	900
Installation, 80 man-hours at $20/hr	1 600
Total	$14 100

5. Met-Pro integrated physical-chemical advanced wastewater treatment system: two 189.3-m^3/day (50 000 gal/day) units at $64 900 each; one 94.6-m^3/day (25 000 gal/day) unit at $52 800

Process	Materials
Chemical clarification	125 000 mg/m^3 (125 mg/liter) alum, pH correction 120 000 mg/m^3 (120 mg/liter) sodium hydroxide at 4.4¢/kg (2¢/lb)

Tertiary pumping	
Surge tank	
Carbon absorption	0.03 kg/m^3 (0.25 lb/1000 gal) activated carbon
Filtration	
Disinfection	2000 mg/m^3 (2 mg/liter) chlorine

6. Sludge pump

a. General specification: 0.11 m^3/min (30 gal/min) at 44.8-kN/m^2 (15 foot) head pressure

b. Design assumption: general-purpose internal-gear rotary pump suitable for handling moderately viscous liquids in the range of 0.3 to 1.0 N-sec/m^2 (300 to 1000 centipoise); e.g., Society of Automotive Engineers (SAE) 40 lubrication oil at 288.7 K (60° F), spar varnish at 277.6 to 285.9 K (40° to 55° F), castor oil at 297.0 to 305.4 K (75° to 90° F), number 6 fuel oil at 313.7 K (105° F)

c. Pump selected: Richardson's 15028-41 (ref. 52), 0.09 m^3/min (25 gal/min) at 137.9 kN/m^2 (20 psi), 3.8-centimeter (1.5 inch) discharge, 1.5-kilowatt (2 horsepower), 23.0-rad/sec (220 rpm)

Item	Cost
Pump (23.0 rad/sec (220 rpm))	$340
Motor, 1.5-kilowatt (2 horsepower), close-coupled, 125.7-rad/sec (1200 rpm)	103
Pulley, belt	10
Starter and circuit breaker (material only)	35
Installation, 6 man-hours at $15/hr	90
Total	$578

7. Garver clarifier-reactor, 2.7 meters (9 feet) diameter by 4.6 meters (15 feet) high, 16.7-cubic-meter (4400 gallon) volume (ref. 52)

Item	Cost
Clarifier-reactor	$ 8 100
Field weld (ref. 53)	500
Installation	1 000
Subtotal	$ 9 600
Ventilation	600
Total	$10 200

8. Richardson's vacuum rotary dryer 15019-2 (ref. 52) (Blaw-Knox, Buflovak Div.)

Item	Cost	
	Carbon steel	Stainless steel
Vacuum rotary dryer, 2.3-square-meter (25 square foot)	$ 9 000	$14 000
Installation, 80 man-hours at $15/hr	1 200	1 200
Auxiliary at 50 percent	4 500	7 000
Totals	$14 700	$22 200

9. Firefighting-water pump

Item	Cost
Horizontal pump (Richardson's 15028-2 (ref. 52)), 20.3-centimeter (8 inch) discharge, 597.8-kN/m^2 (200 foot) head pressure, 183.3-rad/sec (1750 rpm)	$2310
Totally enclosed motor, (Richardson's 15036-2 (ref. 52)), 149.2-kilowatt (200 horsepower)	3494
Reduced-voltage starter and circuit breaker	1910

Pump installation, 24 man-hours at $15/hr	360
Electrical installation, 40 man-hours at $15/hr	600
Total	$8674

10. Wastewater subsystem annual operating costs, not including electricity and labor

Item	Unit cost	Cost
Alum (125 000 mg/m^3 (125 mg/liter)): 16 057.2 kg/yr (17.7 tons/yr) at $0.11/kg ($100/ton) (ref. 61)	1.5¢/m^3 (5.5¢/1000 gal)	$1770
Sodium hydroxide (120 000 mg/m^3 (120 mg/liter)): 15 603.6 kg/yr (17.2 tons/yr) at $0.04/kg ($40/ton) (USPO subsystem engineering vendor quote)	0.6¢/m^3 (2.1¢/1000 gal)	688
Activated carbon (0.03 kg/m^3 (0.25 lb/1000 gal)): 3674.1 kg/yr (8100 lb/yr) at 77.2¢/kg (35¢/lb) (ref. 62)	2.3¢/m^3 (8.8¢/1000 gal)	2835
Chlorine (2000 mg/m^3 (2 mg/liter)): 258.5 kg/yr (570 lb/yr) at 33.1¢/kg (15¢/lb) (ref. 58, price range from 30.9¢/kg (14¢/lb) to 6.6¢/kg (3¢/lb) in 725 748-kilogram (800 ton) lots)	0.08¢/m^3 (0.3¢/1000 gal)	86
Total	4.4¢/m^3 (16.7¢/1000 gal)	$5379

Heating, Ventilation, and Air-Conditioning Subsystem

The baseline HVAC subsystem for costing consists of the mechanical room equipment and the hot-water/chilled-water distribution piping. The cost data contained herein are representative of the type of equipment specified but do not necessarily represent the make and model selected for the application. The cost data were all standardized to 1974 dollars in Chicago. The maintenance costs include all expendable items and labor directly required to properly maintain the subsystem. The baseline cost information is summarized in table 32(a), and tables 32(b) and 32(c) provide supporting detail for these estimates.

The thermal-storage tank (and wastewater holding tank) is located under the east end of the MIUS building. The external tank dimensions are approximately 20.4 by 13.7 by 4.9 meters (67 by 45 by 16 feet) (length by width by depth), and a partition divides the tank into two compartments of approximately 757 082- and 454 249-liter (200 000 and 120 000 gallon) capacities. Cost elements for the tank are provided in table 32(c). The MIUS building floor is to form the top of the tank, and this cost is not included; however, the rental cost of forms for supporting pouring of this portion of the MIUS building slab has been included in the cost. For purposes of cost illustration, a proportional part of the total tank cost has been assigned to the HVAC subsystem and to the wastewater subsystem on the basis of the volume required by each subsystem.

Solid-Waste Subsystem

The baseline MIUS costing was based largely on data compiled from vendor telephone quotes. The solid-waste subsystem handles 2721.6 kilograms (6000 pounds) of household wastes and 1814.4 kilograms (4000 pounds) of sludge with a 20-percent solids content. The quantity of residual solid waste is expected to be approximately 907.2 kg/day (1 ton/day) (0.3 to 0.6 cubic meter (10 to 20 cubic feet)). The offsite residual-waste-disposal cost has been estimated at $70/week. The incinerator requires 4955.4 megajoules (4.7×10^6 British thermal units) daily from fuel oil in addition to that from the solid waste. Fuel for the collection tractor was estimated at 1.5 m^3/yr (400 gal/yr). Table 33(a) summarizes the solid-waste subsystem costs excluding labor and electrical power. Operator labor is included in the system operating-crew costs. Table 33(b) provides the component costs and an estimate of the maintenance materials and labor. Table 33(c) provides an estimate of interconnect installation plumbing.

Control/Monitoring Subsystem

The baseline control/monitoring subsystem consists of the central-control room equipment and the sensors and transducers. The cost information for this equipment and its maintenance (tables 34(a) and 34(b)) has been based on a combination of catalog data and vendor quotes.

Baseline MIUS Building Cost

The MIUS building has dimensions of approximately 19.8 by 50.3 meters, 6.1 meters high, (65 by 165 feet, 20 feet high), which include a covered service area. The enclosed floor area of the building is 827.3 square meters (8905 square feet) and includes a shop area and control room/office area at the 3.0-meter (10 foot) level above the shop. A wall 18.3 by 15.2 meters, 3 meters high, (60 by 50 feet, 10 feet high) extends above the 6.1-meter (20 foot) roof of a portion of the building for concealment of the cooling tower, the incinerator stack, and other roof equipment. Although considerable detail has been provided on the design of this building, no effort has been made to cost the specific design.

For the community study, MIUS housing was based on warehouse and office building construction of good quality as described in the 1973 Dodge Building Cost Data (ref. 59), and the same cost data will be used for this cost illustration. Table 35 reflects that description. Cost values given in reference 59 have been escalated by 10 percent to reflect mid-1974 costs. Costs for this construction come to $\$179.65/m^2$ ($\$16.69/ft^2$) (average value not regionally related).

The baseline MIUS building cost will be taken as $148 800. Annual maintenance cost for materials and labor is estimated at 1.5 percent of the original cost, which is $2230/yr.

Trenching and Miscellaneous Costs

A category of miscellaneous costs has been assigned to cover the initial and annual costs that cannot be assigned to a particular subsystem. These costs, together with the MIUS building costs, would typically fall into a general-plant category in an industrial installation cost-accounting scheme. Although the estimates for these costs (table 36(a)) are believed to be reasonable, a detailed assessment and accounting has not been made; rather, the categories have been assigned and the estimates made to complete the cost analysis. Each category is expected to vary with each specific design and the plan and method of accounting for operation and maintenance.

Unit trenching costs in unclassified soil (table 36(b)), based on the 1973 Building Cost File (ref. 54) and escalated by 10 percent, are as follows.

Item	Unit Cost
Trenching by trencher with 0.9-meter (36 inch) bucket or smaller	$\$1.18/m^3$ ($\$0.90/yd^3$)
Backfill by small-tracked bulldozer	$\$0.52/m^3$ ($\$0.40/yd^3$)
95-percent compaction by sheepsfoot roller	$\$1.44/m^3$ ($\$1.10/yd^3$)
Trenching by 0.8-cubic-meter (1 cubic yard) capacity dragline	$\$2.64/m^3$ ($\$2.02/yd^3$)
Sand or bank run gravel	$\$5.05/m^3$ ($\$3.86/yd^3$)

The pneumatic system (table 36(c)) serves for engine start capability, for pneumatic valve actuation for all subsystems, for an air supply for water aeration, and for shop air for cleaning and maintenance. The system consists basically of a service station 1379.0-kN/m^2 (200 psi) unit with an extra 227.1-liter (60 gallon receiver and all tubing, regulators, and valves necessary to complete the system. An annual maintenance cost for the system has been estimated at 5 percent of the initial cost.

No detailed assessment of the tools required for operating and performing routine maintenance on the MIUS has been made. The list in table 36(d) is provided on the type of tools that must be considered, and the total cost estimate has been partly based on the information obtained during a survey of the operation and maintenance of total-energy plants.

No detailed assessment of the spare-parts inventory has been made, and this inventory is an initial cost that must be considered. Preliminary work on the baseline MIUS specification indicated that the control equipment would require the greatest outlay for spare parts. The estimate in table 36(e) for an initial outlay for a spare-parts inventory is provided for completeness of the MIUS cost analysis.

Operating and Maintenance Crew

The size of the baseline MIUS operating crew is estimated at six full-time employees. This crew includes one skilled employee who is responsible for operation of the system and supervision of the O&M crew. Three semi-skilled employees and two helpers provide two shifts of coverage for operating and maintaining the system throughout the year. It has been assumed in this estimate that essentially all maintenance work on the electrical power equipment and the control system equipment would be provided by outside contract. It has further been assumed that approximately one-half of the maintenance labor for the water, wastewater, and firefighting equipment, the HVAC equipment, and the solid-waste equipment would be provided by the O&M crew and that the other one-half would be purchased as required.

The MIUS O&M crew is not responsible for any of the equipment within the apartment buildings, including the plumbing, HVAC equipment, hot-water equipment, and other apartment building equipment.

Table 37(a) provides a summary estimate of the operating-crew costs. Tables 37(b) and 37(c) provide some additional detail on this estimate. Table 37(d) illustrates a possible duty roster for a two-shift operation. Although table 37(d) indicates that 2 employees are used on each of 2 shifts for most of the time, this 2-man/shift coverage will be reduced by 120 shifts/yr because of typical unproductive time. Additional reductions in the two-man/shift coverage can be expected to result from unscheduled maintenance operations.

Adjustment to the Washington, D.C., Area

The initial costing plan for the baseline MIUS was set up to be based on Chicago area costs for three basic reasons: (1) the construction cost indexes of both the 1973 Building Cost File, Central Edition (ref. 54), and the 1973 Building Construction Cost Data (ref. 53) indicate that Chicago costs are near median for the continental United States; (2) the 1973

Building Costs File, Central Edition, includes costs for more components of an MIUS than any of the other standard references; and (3) the other major reference used for component costs, Process Plant Construction Estimating and Engineering Standards (ref. 52), is represented to provide U.S. average costs.

The baseline MIUS was costed from the referenced data sources to a large extent; however, much of the costing information was based on vendor quotes for specific equipment. In some cases, cost information from specific projects was used, if the data seemed appropriate. All historical cost data were adjusted by the appropriate Department of Labor cost index to reflect mid-1974 costs. For the standard references of 1973 cost information, it was assumed that the appropriate Department of Labor cost index would change the same between December 1973 and June 1974 as it changed between June 1973 and December 1973.

The variation with location in diesel fuel cost was assumed to be in the same ratio as the variation in the price of gasoline across the country (excluding State taxes). The base price of diesel fuel was taken from Platt's Oilgram (ref. 63) January 29th average terminal delivery price in the Baltimore area. A 1¢/gal delivery charge was assumed. It was further assumed that diesel oil prices would stabilize at this base for mid-1974.

System cost variations with location were assumed to vary with the composite construction cost index given in reference 54. Costs for maintenance materials and labor (except fuel, purchased raw water, and offsite solid-waste-disposal service) were also assumed to vary with this index. Operating-personnel cost variations were assumed to be in the ratio of the labor construction cost index given in reference 53.

Table 38 summarizes the cost variations. Table 39 illustrates the cost of the baseline MIUS in the Washington, D.C., area.

Comparison with Costs of Conventional Utilities and Services

A comparison of MIUS capital and annual O&M costs has been made with the conventional-utility-system costs, which were determined during the study of a 110 000-population community (ref. 1) conducted in the summer and fall of 1973. The costs for the community-study conventional system are documented in reference 1 (appendix E). Briefly, the community-study conventional utility systems were developed for a community of 110 000 people over a period of 20 years. The community was located in the Washington, D.C., area. Electrical power costs were based on the replacement capital and annual operating cost of the 1319-megawatt coal-burning Homer City, Pennsylvania, plant[5] with transmission, distribution, and general plant facilities as typical for the East Central Power Region. It was

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[5] During the community study, oil, gas, nuclear-fuel and dual-fuel plant costs were also considered. For this comparison study, capital cost based on an oil-burning plant has been used.

assumed that the community would pay for the expansion of this system on an as-required basis as the community developed.

The community-study water supply was from a natural source located 24.1 kilometers (15 statute miles) from the community. The treatment plant was located at the edge of the community, was installed in 15 142-m^3/day (4 000 000 gal/day) units, and had a total capacity of 105 991 530 liters (28 000 000 gallons) at the end of the community buildup period.

The wastewater plant for the conventional community was a tertiary treatment plant installed in units of 7571-m^3/day (2 000 000 gal/day) capacity, with a total capacity of 52 995 765 liters (14 000 000 gallons) at the end of the community development period.

The solid-waste system for the conventional community included typical collection equipment, transport to an offsite incinerator installation, incineration, and landfill of the residue.

Costs for all elements of the conventional community utility systems and services were represented to be mid-1973 costs for the Washington, D.C., area.

For comparison of the MIUS costs to the costs for conventional utilities and services, a proportional part of the community-study conventional system costs for electrical power, water supply, wastewater, and solid waste was taken. These costs - capital, fuel, and other O&M costs - were adjusted to reflect the difference between mid-1973 and mid-1974 costs. A design for conventional HVAC and hot-water equipment was costed separately.

The following loads for conventional utilities located in the Washington, D.C., area were developed, together with the MIUS loads.

Electrical power	671.5 kilowatts (5.882 x 10^6 kWh/yr)
Boiler fuel	587.1 kilowatts (17.561 x 10^9 Btu/yr)
Water supply	137 807.5 m^3/yr (36.405 x 10^6 gal/yr)
Wastewater	122 363.1 m^3/yr (32.325 x 10^6 gal/yr)
Solid waste	2.7 Mg/day (3.0 ton/day)

Two different comparisons are provided in tables 40 and 41. The baseline MIUS costs are represented to be Chicago costs. The community-study costs are represented to be Washington, D.C., area costs. Table 40 compares the baseline MIUS costs to the conventional-system costs without adjustment of the community-study costs for electrical power, water supply, wastewater, and solid waste to the Chicago cost base. Table 41 compares the baseline MIUS costs for Washington, D.C., to the conventional costs for the Washington, D.C., area. Table 42 provides supporting information for each of the conventional-system costs.

Electrical power.- The conventional electrical power costs were based on a large oil-burning central station powerplant with north central region transmission, distribution, and general plant facility costs. All costs were based on the community-study data and were escalated from mid-1973 costs to mid-1974 costs by assuming 35 percent labor and 65 percent materials for the entire system. For tables 41 and 42, it was assumed that fuel costs for the central powerplant were 80 percent of the cost of MIUS fuel.

Water supply.- The conventional water supply system for the community study consisted of a 105 991-m^3/day (28 000 000 gal/day) treatment plant obtaining water from a natural source located 24.1 kilometers (15 statute miles) from the community; community elevated storage; and community distribution. The 1973 capital cost for this system was \$507.21/m^3 (\$1.92/gal) of capacity. It has been assumed that the conventional apartments would buy a proportional part of this system (capital) on the basis of peak requirements, with no adjustment for diversity. The 1973 costs were adjusted to mid-1974 costs as illustrated in table 42(b). It was assumed that water would be purchased on the basis of average requirements, with adjustments to costs from 1973 to 1974. In table 42(b), water system initial costs were assumed to be 20 percent labor and 80 percent materials.

Wastewater.- The conventional wastewater system for the community consisted of a 52 996-m^3/day (14 000 000 gal/day) waste treatment plant located outside the community with a conventional gravity flow and lift station collection system. The total initial cost of this system was \$657.79/m^3 (\$2.49/gal) of capacity. It has been assumed that the conventional apartments would buy a proportional part of this system (capital) on the basis of peak requirements, with no adjustment for diversity. It was assumed that a proportional part of the O&M costs would be paid by the conventional apartments, on the basis of average usage. In table 42(c), the wastewater system costs were assumed to be 20 percent labor and 80 percent materials.

Hot water and HVAC.- Chicago costs for HVAC and hot-water equipment are included in table 42(d). This system, specified for comparison to the MIUS subsystem, is essentially the same as the MIUS subsystem except that all electric compression chillers are used and two 74.6-kilowatt (100 horsepower) boilers provide for domestic hot water and winter space heating.

In addition to the maintenance costs given in table 42(d), it has been estimated that an average 28 hr/week of operator labor and 84 hr/week of helper labor will be required to operate and maintain the system (outside the apartment buildings). By using the same labor rates, overtime quantities, and a 7.7-percent increase for vacation, holidays, and sick leave, the labor costs for operating the conventional HVAC would be as follows.

Component	Annual cost
Operator labor	\$ 8 900
Helper labor	\$18 000
Total	\$26 900

Solid waste.- The costs for a conventional solid-waste system are presented in table 42(e) for comparison to the MIUS subsystem. The conventional apartments generate the same quantity of domestic waste, not including sewage sludge, as the baseline MIUS apartments.

Discounted Costs

To provide an additional mode of cost comparison, discounted cash values for the O&M cost for a 20-year period for the Washington, D.C., MIUS and for conventional utilities have been evaluated. Table 43 provides a comparison of the MIUS cost and the cost of conventional utilities, escalated and discounted. Table 44 provides additional escalated and discounted values on the assumption of a reduced-size crew for the MIUS operation.

Grid Interconnect Costs

It was assumed in the cost analysis of the baseline MIUS that the installation would be independent of a conventional electrical power grid. This independence would cause a cost penalty to be imposed on all other customers of the conventional system for transmission and distribution facilities. If the apartment complex were tied into the conventional grid network for emergency or standby power, a charge would be made to help defray the initial costs and the maintenance of these facilities.

The average cost of distribution equipment for conventional electrical power systems was $175/kW, whereas the cost of the high-density-distribution equipment for the MIUS was only $59.60/kW. As a result of a grid interconnect, the cost difference in the distribution systems, $115.40/kW, or a total of $121 500 should be added to the MIUS electrical subsystem costs.

BASELINE VARIATIONS

The effects on the MIUS system due to location (climate) and size variations of the baseline are discussed in this section. For the location variations, the apartment complex was moved to Minneapolis as a cold climate, to Houston as a hot and wet climate, and to Las Vegas as a hot and dry climate. For the size variations, 300-unit and 1000-unit apartment complexes were chosen as the appropriate size-range limits indicated by marketing studies. The Washington, D.C., climate was used for the size variations.

Model Adjustments

The following changes were made to the facility model used for the baseline.

1. Minneapolis - Devices for warming automobile engines were added to the electrical load and assumed to require a total of 436 kilowatts between 5 and 8 a.m. Double-glazed windows with a U-factor of 0.60 were used as opposed to the use of single-pane glass with a U-factor of 1.06 in all other locations.

2. Washington, 300 units - The low-rise family apartment buildings from the original 500-unit baseline complex were used. These buildings are types 2 and 3 (figs. 6(b) and 6(c)) and actually total 288 units.

3. Washington, 1000 units - This number of units is simply double that of the baseline complex presented in the section entitled "Facility Model"; the actual number is 992 units.

No other changes from the baseline model were made other than the appropriate weather data for Minneapolis, Houston, and Las Vegas.

Loads

Table 45 reflects peak loads based upon the variation models and climate changes in comparison with those for the baseline model. To aid in cost analyses of these variations, prime movers have been selected and installed-air-conditioning capacity has been estimated, as follows.

Model	Prime movers, no.; kW rating type	Installed-air-conditioning capacity, kW (tons)
Washington 500-unit	3; 478 (Fairbanks-Morse 1; 400 (Caterpillar)	2219.1 (631)
Minneapolis 500-unit	3; 478 (Fairbanks-Morse) 1; 400 (Caterpillar)	1916.7 (545)
Houston 500-unit	3; 478 (Fairbanks-Morse) 1; 400 (Caterpillar)	2212.1 (629)
Las Vegas 500-unit	3; 478 (Fairbanks-Morse) 1; 400 (Caterpillar)	2022.2 (575)
Washington 300-unit	4; 400 (Caterpillar)	1325.8 (377)
Washington 1000-unit	4; 956 (Fairbanks-Morse)	4438.2 (1262)

Energy and Consumables Usage Analyses

Analyses of energy and consumables usage were conducted for each of the variation points in the same manner as for the baseline system. (See "Energy and Consumables Usage Analyses" under "Baseline MIUS Design.") A summary of the data for the variation studies is presented in table 46.

More detailed data for each of the variations is presented in the following figures.

Minneapolis 500-unit complex - figures 35, 36(a) to 36(e), and 37

Houston 500-unit complex - figures 38, 39(a) to 39(e), and 40

Las Vegas 500-unit complex - figures 41, 42(a) to 42(e), and 43

Washington 300-unit complex - figures 44, 45(a) to 45(e), and 46

Washington 1000-unit complex - figures 47, 48(a) to 48(e), and 49

For each variation point, the data set is presented in the following order.

Annual summary and comparison to conventional

MIUS energy utilization flow chart - annual

MIUS energy utilization flow chart - winter

MIUS energy utilization flow chart - summer

MIUS energy utilization flow chart - fall

Conventional energy utilization flow chart - annual

The data show that for all the variations in which Fairbanks-Morse engines are used, the energy savings range from 29.2 to 31.9 percent for the Houston 500-unit system and the Washington 1000-unit system, respectively. The larger system in Washington reflects a slightly better comparison because the larger engine provides a slightly greater amount of high-grade waste heat. Among the 500-unit systems, the energy comparison was slightly better for the colder climates because thermal storage provides space heating without cost to the MIUS, whereas the conventional system requires additional fuel. In Minneapolis, on the average winter day, the MIUS made use of all the waste heat available and even required a boiler for a short time period. The relatively low savings of 22.8 percent for the Washington 300-unit system are a reflection of the lower efficiency of the 400-kilowatt Caterpillar engine.

Costs

Capital and annual-operating-cost estimates have been made for the size and location variations discussed in the preceding paragraphs.

First, for the 1000-apartment-unit costing, a detailed assessment of component costs was not generally made as was done for the baseline MIUS; rather, the baseline MIUS costs were scaled according to typical variations in the cost of major subsystem components, with some assessment of specific costs for particular components. Cost variations for the 1000-apartment MIUS, from the Chicago or U.S. median to the Washington, D.C., area, were made according to the indexes of table 38. Table 47 illustrates the cost results for the baseline system and the results for the Washington, D.C., area. Table 48 compares the cost of the 496-apartment MIUS in Washington, D.C., with the 992-apartment MIUS. Table 49 compares the cost of the 992-apartment MIUS to the cost of conventional utilities. The costs of conventional utilities were based on the information given in table 42. Peak capacity requirements and total annual production quantities were obtained from the ESOP. Table 50 illustrates the effects of escalation and discounting of O&M costs over a 20-year period.

No assessment for the costs of a 300-apartment MIUS has been made. The per-dwelling-unit capital and O&M costs for such an MIUS could be expected to be somewhat higher than the costs for the baseline MIUS, and the increased costs would not appear economically attractive when compared to nominal conventional-system costs. Cost assessment for a 300-apartment-unit MIUS would require some basic changes in design and/or hardware selection from the baseline MIUS concept. The baseline MIUS concept uses the smallest Fairbanks-Morse engines available.

The costs of a 496-apartment MIUS located in Minneapolis, Minnesota, Houston, Texas, and Las Vegas, Nevada, were computed from the baseline MIUS costs. Each respective location required unique air-conditioning loads and fuel quantities to compensate for the variations in climatic conditions. The regional load variations used are shown in table 51. The capital costs were computed by proportionately scaling the air-conditioning loads and using a capital cost adjustment index (table 38) for each location. Individual fuel consumption costs were computed on the basis of the quantity required and the unit fuel cost in each region (table 38). Labor costs were scaled directly by using the indexes for adjustment of the baseline MIUS Chicago costs (table 38). Table 52 presents the results of this analysis. The annual maintenance costs include all annual costs not included under the fuel or labor columns.

No consideration has been given in the costing to conventional electrical power grid interconnections as discussed in the subsection entitled "Grid Interconnect Costs."

CONCLUDING REMARKS

The conceptual design study reported herein indicated that an MIUS would be cost competitive with conventional utilities and would require less fossil fuel. For the 496 apartments, with a planned 100-percent occupancy of 1200 residents, the initial outlay in mid-1974 dollars was estimated to be $3540/apartment, with an average monthly utility charge for operations and maintenance of $46.60/apartment. Annual fossil-fuel energy savings, relative to estimated conventional system energy outlays, were 30 percent. Water savings were estimated at approximately 11 percent, and the quantity of solid waste requiring offsite disposal was estimated as 80 percent less than that for the conventional case.

The investigation of design and operating variations for three alternate climate conditions (Las Vegas, Houston, and Minneapolis) indicated no great difference in energy savings. Variations in costs from those for Washington, D.C., were less than 10 percent. An investigation of size-variation effects was not conducted in sufficient depth to permit reliable conclusions.

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National Aeronautics and Space Administration
Houston, Texas, August 1, 1977
386-01-00-00-72

APPENDIX

OTHER HEATING, VENTILATION, AND AIR-CONDITIONING CONSIDERATIONS

By James O. Rippey

During the course of this study, several modifications or supplements to the heating, ventilation, and air-conditioning system were investigated to determine the effect on the baseline performance. These considerations include determining the effect of adjusting indoor thermostat settings for energy conservation, using solar collectors for supplying domestic-hot-water heating, and incorporating evaporative cooling to assist conventional cooling in applicable climates.

Effect of Seasonal Variation of Indoor Temperature Settings for Energy Conservation

Recent energy conservation measures include the adjustment of thermostat settings to 293.2 K (68° F) during heating periods and to 298.7 K (78° F) during cooling periods. A study was made, using the 500-unit apartment complex in Washington, D.C., to determine the effect of these changes from the 296.5-K (74° F) year-round setting used in the baseline study.

Figure 50 shows the hourly effect for the average day and the design day during the winter and summer seasons for the aforementioned temperature settings. The peak design space-heating load was reduced 15.4 percent (from 949.8 to 803.6 kilowatts (3 243 130 to 2 743 910 Btu/hr)), whereas the average winter day's heating was reduced from 8325.3 to 4577.1 kilowatts (28 426 000 to 15 628 000 Btu/hr) for the 24-hour period, a 45-percent reduction. The peak design cooling load was reduced 8.9 percent (from 1906.1 to 1737.3 kilowatts (542 to 494 tons)), and the average daily totals were reduced from 32 073.2 to 24 529.7 kilowatts (9120 to 6975 tons), a 24-percent reduction.

Reductions in peak hourly loads produce direct reductions in the installed capacity of heating and cooling equipment. The reductions in winter daily space-heating totals indicate substantial heating-fuel savings, but the totals are moderated by the domestic-hot-water energy requirements and by the smaller spring, summer, and fall requirements. Similarly, summer daily cooling totals and the differences attributed to the raised thermostat settings are moderated during the fall, winter, and spring. This is indicated in table 53, which shows the seasonal and annual energy requirements for all the utilities furnished to the complex. The annual energy requirements for the conventional utility system are reduced to 2.6 percent because of the revised thermostat settings. The MIUS annual energy savings are reduced 1.6 percent; this result indicates a lesser sensitivity of the MIUS to thermostat setting because of the use of prime-mover and incinerator heat energy.

SOLAR COLLECTION

An investigation into the adaptability of currently available solar flat-plate collectors for the baseline study was performed. Several assumptions were made to accomplish this study, as follows.

1. The collectors would be used only to supply domestic hot water, and thereby more high-grade waste energy for space heating and cooling would be allowed.

2. A storage system would be in conjunction with the collector system.

3. Collectors would be oriented in a year-round fixed position and mounted on building rooftops only.

4. Domestic-hot-water levels above 333.2 K (140° F) can be maintained throughout the average collection period.

5. A simple flat-plate efficiency of 50 percent is reasonable (ref. 64, p. 37, fig. 5).

6. Distribution and storage losses were not considered.

Climatic tables of mean, daily, usable solar radiation data, direct and diffuse, measured on a horizontal surface (ref. 65, p. 69), were corrected for direction and tilt angle of the collectors. The following table shows the building domestic-hot-water requirements and corresponding roof areas.

Building type	Roof area m^2 (ft^2)	Energy requirement for domestic hot water (288.7 to 388.7 K (60° to 150° F)), kW (Btu/day)	Quantity of buildings
1	945.1 (10 173)	22.6 (1 849 085)	3
2	623.4 (6 710)	16.7 (1 368 413)	8
3	550.0 (5 920)	15.0 (1 227 216)	8
4	764.1 (8 225)	63.5 (5 204 777)	1

The total domestic-hot-water energy requirement for all buildings was 384.4 kilowatts (31.5 x 10^6 Btu/day).

The collectors were mounted facing south and initially tilted at 40°, the approximate latitude of the site. Monthly heat gains were calculated, and it was apparent that the minimum performance would be in December. As a result, the heat gains were recalculated for the collectors sloped to

60°, approximately the latitude plus the inclination of the Earth's axis to the orbit plane (23.4°), to optimize the collectors for the winter period. The heat-gain effects are shown in figure 51(a) for the two collector angles. By using the design-month heat gain, it was then possible to calculate the collector area necessary to meet the domestic-hot-water demand for each building. This result is shown in table 54, and the collector output is plotted for the high-rise apartment building in figure 51(b).

It is apparent that solar collectors can adequately be utilized to supply the daily domestic-hot-water demands for each of the buildings on a year-round basis. Sufficient storage would be necessary as a function of probable consecutive cloudy/overcast days, but redundancy could be supplied by the hot-water distribution loop. The desirability of the incorporation of solar collectors in an MIUS design is a function of the year-round excess heat levels provided by other equipment, as well as the heat quality.

Incorporation of solar collectors in the baseline design indicates the following advantages.

1. Although an average winter day has an excess of heat energy from the prime movers and the incinerator, the design winter day with no clouds has a deficiency of 145.2 kilowatts (11.9 x 10^6 Btu/day), an amount that could be made up with thermal storage. If the domestic-hot-water requirement (384.4 kilowatts (31.5 x 10^6 Btu/day)) were furnished by solar collectors, there would be an excess of available energy. The trade-off between storage size and collector area requires an in-depth study and again requires cool-storage considerations.

2. The average summer day uses a total of 9523.5 kilowatts (2708 tons) of absorption cooling and a total of 10 131.9 kilowatts (2881 tons) of compression cooling. Using the high-grade energy normally provided for the domestic hot water would make possible an additional 1994.0 kilowatts (567 tons) of absorption cooling, a 20-percent reduction in the energy consumption attributed to the summer compression cooling, and a 2.7-percent reduction in the total summer electrical consumption.

Extrapolation to other locations where more heating or more cooling is required indicates that incorporation of flat-plate collectors into the MIUS design is a very desirable contribution to energy savings.

EVAPORATIVE COOLING

An investigation was performed to determine the supplemental effects of evaporative cooling in conjunction with the more conventional compression cooling. Evaporative cooling is an attractive consideration in hot and dry climates because the energy consumption compared to that of compression cooling is very small. Weather data revealed the major city with the most representative environment of the hot and dry extremes to be Las Vegas, Nevada. Figure 52 is a psychrometric chart for the area showing average seasonal conditions based on eight 3-hour periods. Also shown is the summer design point (the hourly maximum that is two standard deviations above the mean day's peak) and the selected indoor design point (296.5 K (74° F), 50 percent relative humidity) with respect to the ASHRAE comfort zone.

Evaporative cooling was effected by reducing the average-summer data points along the constant wet-bulb temperature diagonals to either a 296.5-K (74° F) dry-bulb temperature or a 285.4-K (54° F) dewpoint temperature, whichever was reached first. This procedure would provide the effect of a controlled evaporative cooler in the outside air ventilation intake. Although this system does not lower the internal energy (enthalpy), it does produce a significant proportion to the desired indoor conditions with a minimum capital cost.

With use of the revised temperature and humidity conditions, the energy to lower the hourly temperatures still above 296.5 K (74° F) to the indoor design temperatures was calculated for sensible cooling. The totals were compared with total sensible cooling energy from the original average-summer conditions. These values in kilowatts (and in tons) of cooling for the baseline apartment complex ventilation load are shown in figure 53. The daily total for the cooling load without the ventilation load is 20 594.4 kilowatts (5 856 tons). Sensible cooling only of the ventilation intake would add 4353.8 kilowatts (1 238 tons), whereas sensible cooling after evaporative precooling would add 1610.7 kilowatts (458 tons), a 37-percent reduction in ventilation load and an 11-percent reduction in the total average-summer cooling load. However, this simple, open-system evaporative cooler is not the best solution. It is evident that an enclosed evaporative system that is used to precool the incoming air before a measured amount of humidity is added could feasibly eliminate the entire average-summer ventilation load, in which case the total cooling load would be reduced by 17.5 percent.

In the MIUS application, the compression-air-conditioning electrical demand is 16 percent of the total electrical demand for the summer. Therefore, the summertime reduction of electrical energy consumption due to the open evaporative cooling system in the illustrated case is 6 percent and could be as much as 16 percent with the enclosed evaporative system. The average-summer conditions represent the only period of the year in which evaporative cooling would have a significant effect, and the savings based on annual electrical consumption are approximately 3 percent and 4.7 percent, respectively. These potential savings suggest incorporation of evaporative precooling in applicable climates.

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TABLE 1.- SITE DESCRIPTION

Unit count	496
Total area, km^2 (acres)	0.05 (11.18)
Densities	
Units/km^2 (units/acre)	10 946.8 (44.3)
Persons/km^2 (person/acre)	26 316.7 (106.5)
Parking	
Car space count	740
Spaces/unit	1.5
Irrigated green space, m^2 (ft^2)	8832.3 (95 070)
Pool count	2
Pool volume	
Pool number 1, m^3 (ft^3)	621.0 (21 930)
Pool number 2, m^3 (ft^3)	175.6 (6 200)

TABLE 2.- BUILDING VOLUMES

Building type	No. of buildings	Conditioned volume in each building, m^3 (ft^3)
Low-rise; singles	3	7 777.4 (274 657)
Low-rise; family	8	5 130.2 (181 170)
Low-rise; family	8	4 526.2 (159 840)
High-rise; singles	1	24 338.7 (859 512)

TABLE 3.- UNIT DESCRIPTION FOR 496-UNIT COMPLEX

Unit type	No. of units	Building type	Apartment type/ no. of bedrooms	No. of people/ unit	Area, m^2 (ft^2)
A	36	Low-rise; singles	Efficiency	1	40.6 (437)
B	36	Low-rise; singles	1	1.5	69.7 (750)
C	36	Low-rise; singles	2	2	92.9 (1000)
D	120	Low-rise; family	1	2	74.3 (800)
E	120	Low-rise; family	2	3.5	92.9 (1000)
F	48	Low-rise; family	3	4.5	116.1 (1250)
G	20	High-rise; singles	Efficiency	1	41.8 (450)
H	40	High-rise; singles	1	1.5	65.0 (700)
J	10	High-rise; singles	1	1.5	69.7 (750)
K	30	High-rise; singles	2	2	92.9 (1000)

TABLE 4.- APARTMENT VERTICAL DIMENSIONS

(From ref. 2)

(a) Low-rise

Floors, no.	3
Floor-to-floor height, m (ft)	2.7 (9.0)
Floor-to-ceiling height, m (ft)	
Living units	2.4 (8.0)
Corridors	2.1 (7.0)

(b) High-rise

Floors, no.	11
Floor-to-floor height, m (ft)	
First floor	3.7 (12.0)
Each remaining floor	2.6 (8.5)
Floor-to-ceiling height, m (ft)	
First floor	2.9 (9.5)
Each remaining floor	2.4 (8.0)
Corridors	2.1 (7.0)

TABLE 5.- BUILDING MATERIALS DESCRIPTION

Glazing, m^2 (ft^2),	
50-percent operable glass/unit	3.9 (42)
100-percent operable glass/bedroom	1.1 (12)
U-factors (heat-transfer coefficients)	
Walls	0.07
Roof	0.05
Glazing	1.06

TABLE 6.- EQUIPMENT

(a) Kitchen equipment

Description	No./unit
Cooking range with vent hood	1
Oven	1
Refrigerator-freezer	1
Dishwasher	1
Disposal unit	1

(b) Laundry equipment

Building type	Description	Total no.
Low-rise	Washer	56
	Double-load-capacity dryer	28
High-rise	Washer	14
	Double-load-capacity dryer	7

TABLE 7.- DAILY ELECTRICAL PROFILE INPUT TO THE ESOP FOR A 496-UNIT APARTMENT COMPLEX

Time of day	Electrical demand, kW	
	Domestic[a]	Auxiliary[b] (for 2σ summer day)
12 p.m.	510	120
1 a.m.	435	100
2 a.m	392	97
3 a.m.	318	90
4 a.m.	318	88
5 a.m.	318	84
6 a.m.	318	88
7 a.m.	371	93
8 a.m.	445	97
9 a.m.	414	98
10 a.m.	382	100
11 a.m.	382	108
12 m.	382	112
1 p.m.	382	115
2 p.m.	382	119
3 p.m.	382	124
4 p.m.	382	130
5 p.m.	465	135
6 p.m.	615	140
7 p.m.	742	144
8 p.m.	844	150
9 p.m.	844	150
10 p.m.	844	150
11 p.m.	685	140

[a] Domestic electrical load includes range, refrigerator, dishwasher, disposal, lighting (outdoor and hallway), small appliances, and air-handler motor loads.

[b] Does not include chiller power. Chiller power is developed in the ESOP.

TABLE 8.- TOTAL DOMESTIC ELECTRICAL DEMAND ACCORDING TO BUILDING TYPE

(Washington, D.C.; 2σ summer; no cloud cover)

Time of day	Total electrical demands, kW			
	Bldg. type 1	Bldg. type 2	Bldg. type 3	Bldg. type 4
12 p.m.	67.6	201	174	68.0
1 a.m.	57.7	171	148	58.0
2 a.m.	52.0	154	133	52.3
3 a.m.	42.2	125	108	42.4
4 a.m.	42.2	125	108	42.4
5 a.m.	42.2	125	108	42.4
6 a.m.	42.2	125	108	42.4
7 a.m.	49.2	146	126	49.5
8 a.m.	59.0	175	151	59.4
9 a.m.	54.9	163	141	55.2
10 a.m.	50.6	150	130	51.0
11 a.m.	50.6	150	130	51.0
12 m.	50.6	150	130	51.0
1 p.m.	50.6	150	130	51.0
2 p.m.	50.6	150	130	51.0
3 p.m.	50.6	150	130	51.0
4 p.m.	50.6	150	130	51.0
5 p.m.	61.6	183	158	62.0
6 p.m.	81.5	242	209	82.0
7 p.m.	98.4	292	252	99.0
8 p.m.	112.0	332	287	112.6
9 p.m.	112.0	332	287	112.6
10 p.m.	112.0	332	287	112.6
11 p.m.	90.8	270	233	91.4

TABLE 9.- AVERAGE DAILY DOMESTIC WATER DEMANDS BY BUILDING TYPE

Type of water demand	Quantity of water demand, m^3/day (gal/day)			
	Building type 1	Building type 2	Building type 3	Building type 4
Daily hot water	28.0 (7 388)	55.2 (14 575)	49.5 (13 071)	26.2 (6 930)
Kitchen	7.5 (1 976)	11.8 (3 110)	11.2 (2 959)	7.0 (1 839)
Laundry	10.3 (2 727)	13.8 (3 636)	13.8 (3 636)	9.6 (2 525)
Bath	10.2 (2 685)	29.6 (7 829)	24.5 (6 476)	9.7 (2 566)
Daily cold water	24.0 (6 329)	64.0 (16 913)	53.8 (14 217)	22.8 (6 021)
Kitchen	.9 (238)	2.4 (634)	2.0 (533)	.9 (226)
Laundry	4.0 (1 053)	5.3 (1 404)	5.3 (1 404)	3.7 (975)
Bath	4.4 (1 150)	12.7 (3 355)	10.5 (2 776)	4.2 (1 100)
Toilet	14.7 (3 888)	43.6 (11 520)	36.0 (9 504)	14.1 (3 720)
Daily total water	52.0 (13 717)	119.2 (31 488)	103.3 (27 288)	49.0 (12 951)
Kitchen	8.4 (2 214)	14.2 (3 744)	13.2 (3 492)	7.8 (2 065)
Laundry	14.3 (3 780)	19.1 (5 040)	19.1 (5 040)	13.2 (3 500)
Bath	14.5 (3 835)	42.3 (11 184)	35.0 (9 252)	13.9 (3 666)
Toilet	14.7 (3 888)	43.6 (11 520)	36.0 (9 504)	14.1 (3 720)

TABLE 10.- 496-UNIT DESIGN CASE

ELECTRICAL LOADS PROFILE

(Washington, D.C.; with thermal storage; summer 2σ)

Time of day	Electrical demand, kW
12 p.m.	630
1 a.m.	535
2 a.m.	489
3 a.m.	408
4 a.m.	406
5 a.m.	402
6 a.m.	406
7 a.m.	464
8 a.m.	541
9 a.m.	512
10 a.m.	482
11 a.m.	490
12 m.	494
1 p.m.	497
2 p.m.	501
3 p.m.	506
4 p.m.	512
5 p.m.	600
6 p.m.	755
7 p.m.	886
8 p.m.	994
9 p.m.	994
10 p.m.	994
11 p.m.	825

TABLE 11 - SPECIFICATIONS FOR FAIRBANKS-MORSE DIESEL GENERATOR

(Model 38D8 1/8, 4 cylinders; 478 kW (rated) at 75.4 rad/sec (720 rpm))

Load, kW	Portion of full load, percent	Specific fuel consumption, J/J (Btu/kWh)	Heat recovered hourly, MJ (Btu)			Electrical conversion efficiency, percent	Thermal efficiency, percent
			Water jacket (394.3 K (250° F))	Exhaust (394.3 K (250° F))	Lube oil (358.2 K (185° F))		
120	25	4.1 (13-924)	168.70 (0.16x10⁶)	94.89 (0.09x10⁶)	295.22 (0.28x10⁶)	24	55
239	50	3.2 (10 921)	231.96 (.22)	295.22 (.28)	411.20 (.39)	31	65
359	75	3.0 (10 239)	316.31 (.30)	537.72 (.51)	611.52 (.58)	33	71
478	100	3.0 (10 239)	421.74 (.40)	854.02 (.81)	759.13 (.72)	33.4	73
526	110	3.0 (10 375)	485.00 (.46)	1001.63 (.95)	854.02 (.81)	33	74

TABLE 12.- POWER GENERATION EQUIPMENT LIST

Item	Quantity
Diesel generator, model 38D 1/8, rated at 478 kW, 75.4 rad/sec (720 rpm)	3
Diesel generator, model D379B, rated at 400 kW, 125.7 rad/sec (1200 rpm)	1
Vapor-phase heat-recovery unit, model VP-4860	3
Condensate tank	1
Airblast heat exchanger (for lube-oil heat-recovery bypass)	1
Heat exchanger (for lube-oil heat recovery)	1
Prime-mover oil-cooler heat exchanger	3
Prime-mover water-jacket circulating pump	3
Condensate pump, 0.25 kW (0.33 hp)	2

TABLE 13.- HVAC MAJOR EQUIPMENT SELECTION

Item	Design requirement	Selection		
		Size of unit	No. of units	Type of unit
Chillers				
Absorption, kW (tons)	776.9 (220.9)	777.2 (221)	1	
Compression, kW (tons)	1406.7 (400)	703.4 (200)	2	
Cooling tower, m^3/min (gal/min)	7.07 (1867)	[a]7.16 (1892)	1	4-cell[a]
Boiler/incinerator burner	None required	Not applicable	Not applicable	Not applicable
Thermal-storage tank, m^3 (ft^3)	124.6 (25 590)	728.9 (25 740)	1	Rectangular, concrete, underground

[a] Reference 30.

TABLE 14.- SOLID-WASTE SUBSYSTEM COMPONENTS

Item	Quantity
Small tractor for transporting carts to incinerator	1
Consumat loader, model ML375D, for incinerator loading[a]	1
Consumat incinerator, model C-225	1
Automatic ash-removal system	1
Heat-recovery boiler	1
Oil burner	3
Flame sensor	3
Loader fire-control fog system	1
Storage container for ashes, 7645 liters (10 yd^3)	1
Wheeled collection cart	48
Gravity-chute charging station	76
Gravity chute	23
Sludge holding tank	1
Auger	1

[a] Reference 31.

TABLE 15.- WASTEWATER TREATMENT PLANT

EFFLUENT-QUALITY REQUIREMENTS

Charasteristic	Requisite effluent quality
Turbidity, Jackson turbidity units	<1
Alkalinity (calcium carbonate), p/m	<245
Hardness (calcium carbonate), p/m	<200
Hydrogen-ion concentration, pH	6.9 to 7.1
Biological oxygen demand, p/m	<5
Chemical oxygen demand, p/m	<15
Total nitrogen, p/m	<3
Sulfates, p/m	<15
Chlorides, p/m	<55
Phosphates, p/m	<1
Total solids, p/m	<1000
Coliform, most probable no.[a]	<2

[a] Reference 22, page 211.

TABLE 16.- POWER DISTRIBUTION EQUIPMENT LIST

Item	Quantity
600-kVA switchgear at 460 V (rms), 3-phase	4
1700-kVA transformer at 460 V (rms), 3-phase	1
1700-kVA switchgear at 4160 V (rms), 3-phase	1
250-kVA switchgear at 4160 V (rms), 3-phase	1
240-kVA switchgear at 4160 V (rms), 3-phase	2
200-kVA switchgear at 4160 V (rms), 3-phase	1
150-kVA switchgear at 4160 V (rms), 3-phase	1
80-kVA transformer at 4160/240/120 V (rms), 1-phase	9
70-kVA transformer at 4160/240/120 V (rms), 1-phase	3
50-kVA transformer at 4160/240/120 V (rms), 1-phase	3

TABLE 17.- INSTRUMENTATION AND CONTROL REQUIREMENTS

Subsystem or functional area	No. of control valves				No. of monitor points, bilevel and analogs
	2-way throttle	3-way throttle	2-way solenoid	3-way solenoid	
Prime movers, generator, and heat recovery	11	0	1	0	123
Incinerator heat recovery	1	0	1	0	8
Fire-fighting-water storage tank	0	0	0	0	20
Water distribution, boiler makeup	0	0	8	0	24
HVAC - 3 chillers and thermal storage	1	2	0	3	58
Steam/condensate distribution	9	0	0	0	15
HVAC - hot-water thermal storage and domestic hot water	0	3	0	3	12
Water and liquid-waste treatment	0	0	2	2	51
Totals	22	5	12	8	311

TABLE 18 - DISTRIBUTION OF CONTROL VALVES

Functional area	No of 2-way throttle valves of size -						No of 3-way throttle valves of size -					No of 2-way solenoid valves of size -			No of 3-way solenoid valves of size -		
	1 3 to 2 5 cm (0 5 to 1 in)	5 1 cm (2 in)	7 6 cm (3 in)	10 2 cm (4 in)	15 2 cm (6 in)	20 3 cm (8 in)	7 6 cm (3 in)	10.2 cm (4 in)	15 2 cm (6 in)	20 3 cm (8 in)	30 5 cm (12 in)	1 3 cm (0 5 in)	2 5 cm (1 in.)	5 1 cm (2 in)	1 3 cm (0 5 in)	2 5 cm (1 in)	5 1 cm (2 in.)
Prime mover	0	11	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Incinerator	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0
Firefighting-water storage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water distribution	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0
HVAC - chillers	0	0	0	0	0	1	0	0	0	5	0	0	0	0	0	0	0
Steam/condensate distribution	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0
HVAC - hot water	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0
Water and liquid-waste treatment	0	0	1	0	1	0	1	0	0	0	0	0	0	1	0	0	0
Totals	0	11	1	0	11	1	1	0	0	11	0	0	0	11	0	0	0

TABLE 19.- FEDERAL REGULATIONS CONCERNING ATTAINMENT OF NATIONAL AIR QUALITY STANDARDS

(a) Pollutant priorities

Air Quality Control Region	Standards-attainment priority assigned to -				
	Particulate matter	Sulfur oxides	Nitrogen oxides	Carbon monoxide	Photochemical oxidants
National Capital Interstate	I	I	I	I	I

(b) Achievement dates

Air Quality Control Region	Standards-attainment achievement date assigned to -							
	Particulate matter		Sulfur oxides		Nitrogen oxides		Carbon monoxide	Photochemical oxidants
	Primary	Secondary	Primary	Secondary	Primary	Secondary		
National Capital Interstate	[a]June 1975	[a]June 1975	[a]June 1975	[a]June 1975	[a]June 1975	[a]June 1975	[b]May 31, 1977	[b]May 31, 1977

[a] Prescribed by the Administrator because the plan did not provide a specific date or the date provided was not acceptable.

[b] Transportation or land use control strategy to be submitted no later than April 15, 1973.

TABLE 20.- POLLUTION PRIORITY LEVELS

Pollutant	Concentration, g/m^3 (p/m by volume)[a]		
	Priority I	Priority II	Priority III
Sulfur oxides			
Annual arithmetic mean	>100 (0.04)	60 to 100 (0.02 to 0.04)	<60 (0.02)
24-hr max.	>455 (.17)	260 to 455 (0.10 to 0.17)	<260 (.10)
3-hr max.	--	1300 (0.50)	<1300 (.50)
Particulate matter			
Annual geometric mean	>95	60 to 95	<60
24-hr max.	>325	150 to 325	<150
Carbon monoxide			
1-hr max.	≥55 (48)	--	<55 (48)
8-hr max.	≥14 (8)	--	<14 (8)
Nitrogen dioxide			
Annual arithmetic mean	≥110 (.06)	--	<110 (.06)
Photochemical oxidants			
1-hr max.	≥195 (.10)	--	<195 (.10)

[a] Paragraphs 51.3 (a) (1) (6) and 51.3 (b) i of reference 35: "Ambient concentration limits expressed as micrograms per cubic meter and parts per million by volume (p/m in parentheses)."

TABLE 21.- NATIONAL AIR QUALITY STANDARDS

Pollutant	Standard, $\mu g/m^3$ (p/m)	
	Primary	Secondary
Sulfur oxides (sulfur dioxide)		
Annual arithmetic mean	80 (0.03)	--
24-hr max. (1/yr)	365 (.14)	--
3-hr max. (1/yr)	--	1300 (0.5)
Particulates		
Annual geometric mean	75	60
24-hr max. (1/yr)	260	150
Carbon monoxide		
8-hr max. (1/yr)	10 (9)	10 (9)
1-hr max. (1/yr)	40 (35)	40 (35)
Photochemical oxidants		
1-hr max. (1/yr)	160 (.08)	160 (.08)
Hydrocarbons		
3-hr max. (6 to 9 a.m.) (1/yr)	160 (.24)	160 (.24)
Nitrogen dioxide		
Annual arithmetic mean	100 (.05)	100 (.05)

TABLE 22.- EXISTING POLLUTION LEVELS COMPARED TO AIR QUALITY STANDARDS

Pollutant	Existing pollution level, p/m (μg/m3)	Ratio existing level to primary standard	Ratio existing level to secondary standard
Sulfur oxides			
Annual arithmetic mean	0.05	1.67	--
24-hr max. (1/yr)	.23	1.64	--
3-hr max. (1/yr)	.46	--	0.92
Particulates			
Annual geometric mean	(104)	1.38	1.73
24-hr max. (1/yr)	[a](360)	1.38	2.40
Carbon monoxide			
8-hr max. (1/yr)	25	2.78	2.78
1-hr max. (1/yr)	44	1.26	1.26
Photochemical oxidants			
1-hr max. (1/yr)	.24	3.0	3.0
Hydrocarbons			
3-hr max.	.4	1.67	1.67
Nitrogen oxides			
Annual arithmetic mean	.07	1.40	1.40

[a] Estimated by author.

TABLE 23.- COMPILATION OF CONTROL STRATEGY EFFECTS FOR THE MARYLAND PORTION OF THE NATIONAL CAPITAL INTERSTATE REGION ON MAY 31, 1977

Emission and recuction categories	Carbon monoxide		Hydrocarbons	
	Mg (ton) per peak period	Percent of total reduction required	Mg (ton) per peak period	Percent of total reduction required
Stationary source emissions without control strategy	70.8 (78)	--	13.0 (14.3)	--
Expected reduction from:				
Dry-cleaning-vapor recovery	0	0	1.0 (1.1)	8.7
Gasoline-handling-vapor recovery	0	0	4.5 (5.0)	39.4
Other stationary source rule strengthening	0	0	0	0
Stationary emissions remaining	70.8 (78)	--	7.5 (8.2)	--
Mobile emissions from highway light- and heavy-duty vehicles without control strategy	449.1 (495)	--	17.5 (19.3)	--
Expected reduction from:				
Vehicle inspection and maintenance	23.6 (26)	28.0	1.4 (1.5)	11.8
Vacuum spark advance disconnect retrofit before 1968 cars	2.7 (3)	3.2	.4 (.4)	3.1
Catalytic retrofit of fleet light-duty vehicles	4.5 (5)	5.4	.2 (.2)	1.6
Mass transit improvements	19.1 (21)	22.6	2.4 (2.7)	21.3
Heavy-duty-vehicle peak-hour delivery ban	24.5 (27)	29.0	.9 (1.0)	7.9
Aircraft model program	10.0 (11.0)	11.8	.7 (.8)	6.3
Mobile emissions remaining	364.7 (402)	--	11.5 (12.7)	--
Total emissions without strategy	519.9 (573)	--	30.5 (33.6)	--
Total reductions	84.4 (93)	100.0	11.5 (12.7)	100.1
Total emissions remaining	435.5 (480)	--	19.0 (20.9)	--

TABLE 24.- CARBON MONOXIDE AND HYDROCARBON EMISSIONS FROM THE MIUS USING DIESEL FUEL

(a) Minimum, average, and maximum

Season	Carbon monoxide emissions, g/hr			Hydrocarbon emissions, g/hr		
	Min.	Av.	Max.	Min.	Av.	Max.
Spring	342	465	706	120	164	250
Summer, av.	333	492	706	118	174	250
Summer, 2σ	508	590	706	179	208	250
Fall	343	466	706	121	164	250
Winter	330	449	706	116	159	250

(b) Additional data

Time period	Days/time period	Carbon monoxide emissions		Hydrocarbon emissions	
		g/hr	g/time period[a] (tons/time period)[b]	g/hr	g/time period[a] (tons/time period)[b]
Spring	92	465	1 026 720 (1.13)	164	362 112 (0.40)
Summer	92	492	1 086 336 (1.20)	174	384 192 (0.42)
Fall	91	466	1 017 744 (1.12)	164	358 176 (0.40)
Winter	90	449	969 840 (1.07)	159	343 440 (0.38)
Whole year	365	--	4 100 640 (4.52)	--	1 447 920 (1.60)

[a] Grams per hour times hours per day times days per time period.

[b] Grams per time period divided by grams per ton.

TABLE 25.- PROJECTED ANNUAL EMISSIONS FOR THE ENTIRE MARYLAND AREA AND THE FRACTIONAL PART DUE TO THE MIUS

Carbon monoxide			Hydrocarbons		
Total, Mg/yr (ton/yr)	MIUS contribution, Mg/yr (ton/yr)	Fractional part due to the MIUS, percent	Total, Mg/yr (ton/yr)[a]	MIUS contribution, Mg/yr (ton/yr)	Fractional part due to the MIUS, percent
117 050.4 (129 026)	4.10 (4.52)	0.0035	5092.0 (5613)	1.45 (1.60)	0.0285

[a] Estimated from ratio of total hydrocarbon emission (peak period) to total carbon monoxide emission (peak period); 20.9/480 = 0.0435.

TABLE 26.- BASELINE MIUS CAPITAL AND ANNUAL O&M COST SUMMARY

(1974 dollars)

Item	Capital cost	Annual operating cost	Annual maintenance cost	Remarks
Electrical power	$ 396 710	$108 600	$23 100	Total - no cost for electricity to subsystems
Water supply	223 300	2 950	1 490	Conventional water system
Wastewater and firefighting water	434 700	5 400	20 120	Excluding outfall
HVAC	238 260	--	7 760	Excluding apartment building equipment
Solid waste	108 100	6 860	5 300	Including offsite disposal costs
Controls	144 860	--	18 250	Contract maintenance
MIUS housing	148 800	--	2 230	
Miscellaneous costs	58 600	--	550	
System operating crew	--	75 100	--	Direct wages and payroll taxes
System totals	$1 753 330	$198 910	$78 800	

TABLE 27.- BASELINE MIUS UNIT-COST SUMMARY

(1974 dollars)

Item	Cost
Initial cost per apartment	$3540.00
Average total monthly utility cost per apartment	46.60
Average monthly utility component cost per apartment	
Electrical power and HVAC (including all operating personnel, housing, and control costs)	39.53
Water	.75
Wastewater and firefighting water	4.28
Solid waste	2.04

TABLE 28.- BASELINE MIUS ELECTRICAL POWER SUBSYSTEM COST ANALYSIS

(a) Cost summary - 1974 dollars

Item	Initial cost[a]
Electrical subsystem	
1434 kW with heat recovery at $195/kW	$279 640
400 kW without heat recovery at $99/kW	39 720
Distribution at $34/kW	62 930
Fuel supply at $8/kW	14 420
Total subsystem capital at $216/kW	$396 710
Annual operating cost (no operator labor)	
Fuel at $67.36/m^3 (25.5¢/gal) or 5.35 mills/MJ (19.25 mills/kWh)	$104 500
Lubrication oil at 0.21 mill/MJ (0.75 mill/kWh)	4 080
Annual maintenance cost (including labor)	
Engine repair and other generation plant at 1.12 mills/MJ (4.02 mills/kWh)	$ 21 800
Distribution at 0.06 mill/MJ (0.23 mill/kWh)	1 260
Fuel system at 0.003 mill/MJ (0.01 mill/kWh)	70
Total subsystem O&M (exluding operators) at 6.74 mills/MJ (24.26 mills/kWh)	$131 710

[a] To nearest $10.

TABLE 28.- Continued

(b) Component costs - 1974 dollars

	Component	Cost[b]
Generation		
3	Fairbanks-Morse D38D 1/8 engine-generator sets, including engines, internal lube-oil heat exchangers, engine accessories, installation, generators, terminal lugs and cables, and external lube-oil equipment, at $72 430 each[c]	$217 290
3	exhaust silencer heat-recovery units at $6750 each[d]	20 250
1	lube-oil-to-water heat exchanger[e]	1 200
1	airblast heat exchanger[d]	2 000
1	condensate tank (and pump)[e]	1 200
1	3-engine mechanical hardware equipment and installation[f]	37 700
1	D379B Caterpillar 400-kW engine-generator[g]	39 720
	Subtotal generation	$319 360
Fuel		
2	75 708.2-liter (20 000 gal) underground fuel storage tanks[h]	$ 11 120
1	378.5-liter (100 gal) day tank	300
4	0.25-kW (0.33-hp) fuel pumps plus plumbing installed	3 000
	Subtotal fuel	$ 14 420
Electrical distribution[i]		
1	1700-kVA transformer, 3-phase, 460/4160 V	$ 12 500
4	600-kVA switchgear units, 460 V, at $3300 each	13 200
1	1700-kVA switchgear unit, 4160 V	3 700
1	250-kVA switchgear unit, 4160 V	2 300
2	240-kVA switchgear units, 4160 V, at $2300 each	4 600
1	200-kVA switchgear unit, 4160 V	2 300
1	150-kVA switchgear unit, 4160 V	2 100
9	80-kVA transformers at $1300 each	11 700
3	70-kVA transformers at $1220 each	3 660
3	50-kVA transformers at $1080 each	3 240
	2094 m (6870 ft) AWG no. 8 underground at 98.4¢/m (30¢/ft)	2 060
	759 m (2490 ft) AWG no. 10 underground at 67.9¢/m (20.7¢/ft)	515
	146 m (480 ft) AWG no. 12 underground at 55.4¢/m (16.9¢/ft)	80
	991 m (3250 ft) AWG no. 8 neutral at 98.4¢/m (30¢/ft)	975
	Subtotal distribution	$ 62 930
	Total electrical subsystem	$396 710

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[b] To nearest $5.

[c] All equipment except the engines is based on the Jersey City total energy installation escalated to mid-1974. See table 28(c).

[d] Based on the Jersey City total energy installation escalated to mid-1974.

[e] Based on reference 52.

[f] Component parts estimated from installation sketch and costed from reference 52. See table 28(d).

[g] Based on Jersey City installation, adjusted for size, and escalated to mid-1974. See table 28(c).

[h] Based on means (ref. 53) and adjusted for Chicago area and mid-1974 estimate.

[i] Transformers and switchgear based on reference 52; wire and installation based on building cost file (ref. 54) and current nonferrous metals index (ref. 55).

TABLE 28.- Continued

(c) Engine accessory and generator cost basis

Engine-generator material and installation[j] contract item	Cost, Dec. 1970 dollars		Cost, mid-1974 dollars
Caterpillar D398 engine	$26 032	$26 772	$30 250
Freight	740		
Start-stop kit	1 303	4 196	4 740
Wiring harness	114		
Lube-oil control	338		
Mounting rails	142		
Lube pump	154		
Smoke eliminator	71		
Voltage regulator (335)	NC[k]		
Series booster (195)	NC		
Fuel and oil pressure regulators	200		
Air-pressure regulator	109		
Overspeed alarm (89)	NC		
Temperature alarm	40		
Fuel filter	8		
Lube-oil filters (5 each)	11		
Lube-oil fill	71		
First oil change	71		
Governor	1 215		
Temperature sensor ports	349		
600-kW generator	7 968	8 733	9 340
Electric lug set	200		
Electric cable 3/0, 304.8 m (1000 ft), $1.85/m ($0.565/ft)	565		
Direct labor	1 029	12 855	15 350
Service labor	6 062		
Load bank	1 755		
Travel	259		
Bonds, warranty, and manuals	3 750		
Totals		$52 556	$59 680

[j] Based on the Jersey City Summit Apartments total-energy installation (ref. 56).

[k] NC = no cost.

TABLE 28.- Continued

(d) Engine-heat-recovery installation hardware[l]

Item	Installed cost	Annual maintenance material[m]	
		Percent	Cost
Per engine			
2 20.3-cm (8 in.) flex joints, 10.2-cm (4 in.) travel, flanged, at $379 each	$758	5	$38
2 20.3-cm (8 in.) schedule 40 elbows at $199 each	398	.5	2
2 20.3-cm (8 in.) 68.0-kg (150 lb) flanges at $157 each	314	.5	2
1 20.3-cm (8 in.) custom wye section (estimated)	500	.5	2
3.0 m (10 ft) of 20.3-cm (8 in.) schedule 40 pipe spools at $77.62/m ($23.66/ft)	237	.5	1
1 15.2-cm (6 in.) flex joint, 10.2-cm (4 in.) travel, flanged	344	5	17
1 15.2-cm (6 in.) flex joint, 5.1-cm (2 in.) travel	255	5	13
1.5 m (5 ft) of 15.2-cm (6 in.) schedule 40 pipe spools at $61.45/m ($18.73/ft)	94	.5	2
6 15.2-cm (6 in.) flanges at $80 each (not including valve flanges)	480	.5	2
3 15.2-cm (6 in.) elbows at $149 each	447	.5	2
3 5.1-cm (2 in.) isolation valves (threaded) at $96 each	288	3	9
3 5.1-cm (2 in.) control valves with mating flanges and controller at $722 each	2166	10	217
1 15.2-cm (6 in.) check valve (flanged with mating flanges)	578	3	17
1 15.2-cm (6 in.) isolation valve (flanged with mating flanges)	622	3	19
1 3.8-cm (1.5 in.) blowdown valve (threaded)	51	3	1
8.5-m (28 ft) equivalent of 20.3-cm (8 in.) 3.8-cm (1.5 in.) thick single-layer insulation at $15.26/m ($4.65/ft)	130	.5	1
13.7-m (45 ft) equivalent of 15.2-cm (6 in.) 3.8-cm (1.5 in.) thick single-layer insulation at $12.96/m ($3.95/ft)	178	.5	1
13.7-m (45 ft) equivalent of 5.1-cm (2 in.) 3.8-cm (1.5 in.) thick single-layer insulation at $9.02/m ($2.75/ft)	124	.5	1
Total, each engine	$7964		$347

[l] Based on reference 52; no profit.

[m] This column is for illustration only; valve, heat-recovery, and plumbing maintenance is assumed to be included with the powerplant maintenance costs taken from the American Society of Mechanical Engineers (ASME) data - reference table 28(e).

TABLE 28.- Continued

(d) Continued

Item	Installed cost	Annual maintenance material[m]	
		Percent	Cost
Common to 3-engine installation			
9.1 m (30 ft) of 20.3-cm (8 in.) schedule 40 stack pipe at \$77.62/m (\$23.66/ft)	\$ 710	0.5	\$ 4
21.3 m (70 ft) of 15.2-cm (6 in.) schedule 40 pipe spools at \$61.45/m (\$18.73/ft)	1 310	.5	7
61.0 m (200 ft) of 5.1-cm (2 in.) schedule 40 pipe spools at \$23.46/m (\$7.15/ft)	1 430	.5	7
12.2 m (40 ft) of 3.8-cm (1.5 in.) schedule 40 pipe at \$9.38/m (\$2.86/ft)	114	.5	1
42.7 m (140 ft) of 2.5-cm (1 in.) schedule 40 pipe at \$7.41/m (\$2.26/ft)	316	.5	2
3 20.3-cm (8 in.) flanges at \$99 each	297	.5	1
1 15.2-cm (6 in.) gate valve (with mating flanges)	622	3	19
1 15.2-cm (6 in.) back-pressure regulator (local control)	1 699	10	170
1 reducer (15.2 cm to 5.1 cm (6 in. to 2 in.))	107	.5	1
4 15.2-cm (6 in.) T's at \$229 each	916	.5	5
13 15.2-cm (6 in.) elbows at \$149 each	1 940	.5	10
2 7.6-cm (3 in.) isolation valves (threaded) at \$125 each	250	3	8
3 7.6-cm (3 in.) flanges (all 7.6-cm (3 in.) pipe costed with the water subsystem) at \$40 each	120	.5	1
6 5.1-cm (2 in.) isolation valves (threaded) at \$96 each	576	3	17
1 5.1-cm (2 in.) throttle valve with controller and mating flanges	722	10	72

[m] This column is for illustration only; valve, heat-recovery, and plumbing maintenance is assumed to be included with the powerplant maintenance costs taken from the ASME data - reference table 28(e).

TABLE 28.- Continued

(d) Concluded

Item	Installed cost	Annual maintenance material[m]	
		Percent	Cost
Common to 3-engine installation			
13 5.1-cm (2 in.) T's at $81 each	$ 1 153	.5	$ 6
15 5.1-cm (2 in.) schedule 40 elbows at $52 each	780	.5	4
5 2.5-cm (1 in.) isolation valves (threaded) at $39 each	195	.5	1
9.1 m (30 ft) of 2.5-cm (1 in.) steam-clean hose with nozzle	120	5	6
9.1 m (30 ft) of 20.3-cm (8 in.) 3.8-cm (1.5 in.) thick insulation at $15.26/m ($4.65/ft)	140	.5	1
42.1-m (138 ft) equivalent of 15.2-cm (6 in.) 3.8-cm (1.5 in.) thick insulation at $12.96/m ($3.95/ft)	545	.5	3
103.9-m (341 ft) equivalent of 5.1-cm (2 in.) 2.5-cm (1 in.) thick insulation at $7.05/m ($2.15/ft)	735	.5	4
Subtotal - common to 3-engine installation	$14 797		$ 350
3 engines at $7964 each	23 892		1041
Totals	[n]$38 700		[n]$1400

[m] This column is for illustration only; valve, heat-recovery, and plumbing maintenance is assumed to be included with the powerplant maintenance costs taken from the ASME data - reference table 28(e).

[n] To nearest $100.

TABLE 28.- Continued

(e) Operating and maintenance cost basis[o]

Plant no.	No. of engines	Power, kW	Energy consumption, MJ (kWh)	Run factor	Cost, mills/MJ (mills/kWh)			
					Lubrication	Operators and supervision	Engine repair	Engine repair, supplies, and miscellaneous
316	4	5750	44 353 440 (12 320 400)	69.8	0.05 (0.18)	1.18 (4.24)	0 70 (2.51)	0.73 (2 64)
104	4	4940	31 928 040 (8 868 900)	57.8	.13 (.46)	1.44 (5.18)	--	.27 (.97)
166	4	3901	31 674 600 (8 798 500)	67.2	.07 (.27)	.66 (2.36)	--	1 13 (4.06)
1411	4	3600	24 429 960 (6 786 100)	58.2	.01 (.05)	1.06 (3.82)	1.41 (5 09)	1.46 (5.25)
1412	4	2361	12 692 556 (3 525 710)	83.7	.09 (.33)	2 22 (7.98)	.27 (.96)	.47 (1.69)
148	5	3413	28 838 592 (8 010 720)	69.3	.11 (.39)	1.20 (4 31)	--	2 25 (8.10)
411	5	4563	29 314 980 (8 143 050)	68.0	.09 (.31)	1.03 (3.71)	.11 (.40)	.27 (.98)
190	5	3792	26 506 080 (7 362 800)	66.3	.09 (.32)	1.49 (5.38)	--	1.36 (4.91)
136	5	4996	41 168 880 (11 435 800)	67 4	.11 (.38)	80 (2.88)	--	.11 (.40)
--	--	--	--	--	[p].08 (.30)	[p]1.23 (4 43)	--	[p]89 (3.22)

[o] Small-baseload municipal powerplant operating data (1970) from the 1972 ASME report on diesel- and gasoline-engine power costs (ref. 57).

[p] 1970 average. Mid-1974 estimates: lube oil, 1970 value times 2.5; other, 1970 value times 1.25.

TABLE 28 - Concluded

(f) Maintenance cost factors

Distribution area	Maintenance and repair, annual percent of initial cost
Substation (outdoor)	2.02
Substation (indoor)	1.57
Underground wiring	1.67
Interior wiring	2.46

TABLE 29.- CONVENTIONAL WATER SUPPLY COSTS[a]

(1974 dollars)

Item	Initial cost
Water supply	
420.5 m^3/day (111 077 gal/day) peak capacity at $530.99/$m^3$ ($2.01/gal)[b]	$223 300
Annual operating cost	
Chemicals at 0.78¢/m^3 (2.95¢/1000 gal)	$ 950
Electricity[c] at 0.96¢/m^3 (3.62¢/1000 gal)	1 160
Labor and miscellaneous at 0.68¢/m^3 (2.57¢/1000 gal)	830
Subtotal at 2.41¢/m^3 (9.14¢/1000 gal)	$2 950
Annual maintenance materials and labor at 1.22¢/m^3 (4.60¢/1000 gal)	$1 490
Total annual O&M cost at 3.63¢/m^3 (13.74¢/1000 gal)	$4 440

[a] Based on the community study for the Washington, D.C., area.

[b] A proportional part of a 105 991-m^3/day (28 000 000 gal/day) system.

[c] Electrical power cost based on the community study conventional fuel-oil powerplant.

TABLE 30.- BASELINE MIUS WATER SUPPLY SUBSYSTEM COST ANALYSIS

(a) Cost summary - 1974 dollars

Item	Initial cost
Water supply subsystem	
Supply pumps, packaged Waterboy, chlorinator, and storage tank	\$41 100
Distribution (no trenching)	7 100
Total subsystem capital at \$0.12/liter (\$0.45/gal) capacity	\$48 200
Annual operating cost (no operators or electricity)	
Purchase raw water at 2.6¢/m^3 (10.0¢/1000 gal)	\$3 230
Chlorine at 0.2¢/m^3 (0.6¢/1000 gal)	170
Alum at 1.2¢/m^3 (4.6¢/1000 gal)	1 480
Polyelectrolyte at 0.2¢/m^3 (0.6¢/1000 gal)	170
Annual maintenance materials and labor[a] at 1.5¢/m^3 (5.7¢/1000 gal)	1 880
Total subsystem O&M (excluding electricity and operators) at 5.7¢/m^3 (21.5¢/1000 gal)	\$6 930

[a] Approximately one-half the maintenance labor is provided by the operating crew.

TABLE 30.- Continued

(b) Component costs - 1974 dollars

Item	Initial cost[b]	Maintenance materials	
		Percent	Cost
2 raw-water pumps, 0.3-m^3/min (78 gal/min), 343.7-kN/m^2 (115 ft) head pressure[c]	$ 2 560	~3.2	$ 82
Packaged treatment plant - Waterboy model WB-133, 0.4-m^3/min (100 gal/min)[d]	23 100	5	1155
Chlorinator[e]	1 300	5	65
Distribution (no trenching)			
73.2 m (240 ft) of 7.6-cm (3 in.) schedule 40 polyvinyl chloride (PVC) pipe at $13.71/m ($4.18/ft)[f]	1 000	.5	5
780.3 m (2560 ft) of 5.1-cm (2 in.) schedule 40 PVC pipe at $7.81/m ($2.38/ft)	6 100	.5	30
113 562-liter (30 000 gal) underground steel tank[g]	8 640	.5	43
2 pressure boost pumps (same as raw-water pumps)	2 560	3.2	82
Interconnect plumbing (table 30(c))	5 000	1.8	88
Total capital	$50 260		
Annual maintenance materials			$1550
(Annual maintenance labor)			($ 770)

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[b] To nearest $10.

[c] Richardson's 15028-2 pump (ref. 52), based on Ingersoll-Rand single-stage horizontal centrifugal pump at $1282 each.

[d] Vendor quote of $21 000 based on September 1972 prices escalated to mid-1974 by 10 percent.

[e] Based on reference 52.

[f] 1973 Building Cost File (ref. 54) escalated by 10 percent to mid-1974.

[g] Based on Means (ref. 53) 0.953-centimeter, 2.4- by 7.6-meter (8 by 25 foot) underground steel; tank exterior coating, excavation, and fittings included.

TABLE 30.- Continued

(c) Interconnect plumbing - 1974 dollars

Item	Initial cost	Annual maintenance materials	
		Percent	Cost
30.5 m (100 ft) of 7.6-cm (3 in.) schedule 40 pipe spools (no detailed evaluation) at $35.99/m ($10.97/ft)	$1097	0.5	$ 5
15.2 m (50 ft) of 5.1-cm (2 in.) schedule 40 pipe spools (no detailed evaluation) at $23.46/m ($7.15/ft)	358	.5	2
4 7.6-cm (3 in.) flanges at $40 each	160	.5	1
4 7.6-cm (3 in.) elbows at $72 each	288	.5	1
5 7.6-cm (3 in.) T's at $111 each	555	.5	3
8 7.6-cm (3 in.) isolation valves (threaded) at $125 each	1000	3	30
1 5.1-cm (2 in.) nipple (to 7.6-cm (3 in.) pipe) at $55	55	.5	1
2 5.1-cm (2 in.) elbows at $51 each	102	.5	1
1 5.1-cm (2 in.) T at $81	81	.5	1
7 5.1-cm (2 in.) isolation valves (threaded) at $96 each	672	3	20
2 5.1-cm (2 in.) check valves at $127 each	254	3	8
1 7.6-cm (3 in.) solenoid valve at $280	280	5	14
Total interconnect plumbing	$4902		
Total annual maintenance material			$87

TABLE 30.- Concluded

(d) Annual operating cost (excluding labor and electricity) - 1974 dollars

Item	Cost
Purchased raw water at [h]2.6¢/m^3 (10¢/1000 gal)	$3230
Chlorine (based on 4 mg/liter) at [i]33.1¢/kg (15¢/lb) (471.6 kg (1040 lb))	$ 156
Alum, 100 p/m, 13 426.3 kg (14.8 tons) at $0.11/kg ($100/ton)	$1480
Polyelectrolyte, 1 p/m, 131.5 kg (290 lb) at $1.30/kg ($0.59/lb)	$ 171

[h] This amount does not represent a U.S. average or a value for any specific site. Purchase of raw water is not believed to be a typical method of operation for small treatment plant installations. In 1970, the City of Houston sold Texas City untreated surface water at 1.1¢/m^3 (4¢/1000 gal), which was possibly below cost.

[i] Based on reference 58.

TABLE 31.- BASELINE MIUS WASTEWATER AND FIREFIGHTING-WATER SUBSYSTEM COST ANALYSIS

(a) Cost summary - 1974 dollars

Item	Initial cost
Wastewater subsystem	
Collection	$ 27 800
Processing plant	367 700
Firefighting water	39 200
(Outfall - 1.6 km (1 s. mi.))	(100 800)
Total subsystem capital at $0.97/liter ($3.69/gal) of capacity	$434 700
Annual operating cost (no operators or electricity) -	
Chemicals at 4.4¢/m3 (16.7¢/1000 gal)	$ 5 400
Annual maintenance materials and labor cost[a]	
Collection	180
Processing plant	19 120
Firefighting water	820
(Outfall)	(500)
Total subsystem O&M (excluding operators and electricity) at 20.9¢/m3 (79.3¢/1000 gal)	$ 25 520

[a] Approximately one-half of the maintenance labor is provided by the operating crew.

TABLE 31.- Continued

(b) Component costs - 1974 dollars

Item	Capital cost	Maintenance materials	
		Percent	Cost
2 raw-wastewater pumps, 3.7-kW (5 hp), 447 m^3/day (118 000 gal/day), 0.3 m^3/min (82 gal/min), complete with float switches and cast-iron basins, at $1900 each[b]	$ 3 800	3.2	$ 122
Preliminary/primary Siemag Claritower[c]	28 600	3	858
Flow-equalization tank, 113 562-liter (30 000 gal), underground[d]	9 840	.5	49
3-stage Autotrol Bio-Disk process[e]	42 500	3	1 275
2 75 708-liter (20 000 gal) tanks at $5150 each[f]	10 300	.5	52
2 pumps between flow-equalization tank and Bio-Disk unit (same as raw-wastewater pump without basin) at $1440 each	2 880	3.2	92
Secondary clarification based on Garver clarifier-reactor[g]	14 100	3	423

[b] Richardson's 15028-62 vertical nonclog sewage pump (ref. 52).

[c] Vendor quote: Siemag Systems, Inc., 111 Eucalyptus, El Segundo, Calif. 90245, plus $600 for ventilation system.

[d] Based on Means (ref. 53).

[e] Vendor quote: Autotrol Corp., Bio-Systems Div., 5855 N. Glen Park Rd., Milwaukee, Wis. 53209, 414-228-9100.

[f] Based on Means (ref. 53).

[g] Based on Richardson's (ref. 52) Garver Water-Conditioning Co. clarifier-reactor.

TABLE 3.1.- Continued

(b) Continued

Item	Capital cost	Maintenance materials	
		Percent	Cost
Met-Pro integrated physical-chemical advanced wastewater treatment system			
2 189-m^3/day (50 000 gal/day) units[h]	\$129 800	5	\$6 490
1 94.6-m^3/day (25 000 gal/day) unit	52 800	5	2 640
Holding tank, 454 248-liter (120 000 gal)[i]	16 800	.5	84
2 sludge pumps, 0.1-m^3/min (30 gal/min) at 44.8-kN/m^2 (15 foot) head pressure[j]	1 150	10	115
Sludge thickening based on Garver clarifier-reactor[k]	10 200	3	306
Vacuum filter, 2.6-m^2 (28 ft^2)[l]	22 200	10	2 220
15 141.6-liter (4000 gal) pressurized tank for makeup[m]	4 800	1	48
2 effluent-discharge pumps (same as Bio-Disk) at \$1440 each	2 880	3.2	92

[h] Vendor quote: Met-Pro Systems Div., 5th St. and Mitchell Ave., Lansdale, Pa., 215-368-1671.

[i] Proportional part of concrete tank beneath MIUS building. See the HVAC system for description of this tank.

[j] Richardson's 15028-41, 0.09-m^3/min (25 gal/min) at 137.9 kN/m^2 (20 psi), \$578 each (ref. 52).

[k] Based on Garver clarifier-reactor volume of 16.7 cubic meters (4400 gallons), 2.7 meters (9 feet) diameter by 4.6 meters (15 feet) high.

[l] Based on Richardson's stainless steel vacuum rotary dryer (ref. 52).

[m] Based on prefabricated propane tanks from Richardson's (ref. 52) (1723.7-kN/m^2 (250 psi) rating, ASME).

TABLE 31.- Continued

(b) Continued

Item	Capital cost	Maintenance materials	
		Percent	Cost
15 141.6-liter (3000 gal) pressurized tank for firefighting-water storage	$ 4 200	1	$ 42
Interconnect plumbing (table 31(c))	10 800	--	324
Subtotal - wastewater processing	[n]$367 700		
Subtotal - maintenance materials			[n]$15 300
(Subtotal - maintenance labor at 50 percent of material cost)			($ 7 650)
Wastewater collection: 809.2 m (2655 ft) of 15.2-cm (6 in.) cast-iron piping installed, no trenching, at $34.32/m ($10.46/ft)[o]	$ 27 771	.5	$ 139
Subtotal - wastewater collection	[n]$ 27 800		
Subtotal - maintenance materials			$ 139
(Subtotal - maintenance labor)			($ 70)
(Wastewater outfall: 1609.3 m (5280 ft) of 15.2-cm (6 in.) cast-iron pipe, including trenching, backfilling, and compaction, at $62.43/m ($19.03/ft))	($100 478)	.5	($ 502)
(Subtotal - wastewater outfall)	[n]($100 500)	--	[n]($ 500)

[n] To nearest $100.

[o] Based on Building Cost File (ref. 54) with a price increase of 13.5 percent, mid-1973 to mid-1974.

TABLE 31.- Continued

(b) Concluded

Item	Capital cost	Maintenance materials	
		Percent	Cost
Firefighting equipment (not including storage)			
3 pumps, 11.4-m^3/min (3000 gal/min) at 689.5 kN/m^2 (100 psi), with reduced-voltage starters and circuit breakers, at $8670 each[p]	$ 26 010	1.6	[q]$ 416
495.3 m (1625 ft) of monoline 30.5-cm (12 in.) pipe, no trenching, at $75.46/m ($23/ft)[r]	37 375	.5	187
Interconnect plumbing (table 31(c))	9 500	--	213
Subtotal - firefighting equipment	[n]$ 72 900		
Subtotal - maintenance materials			$ 800
(Subtotal - maintenance labor at 50 percent of materials)			($ 400)
Total wastewater collection and processing and firefighting (excluding outfall and trenching)	[n]$468 400		
Annual maintenance materials			[s]$16 250
(Annual maintenance labor)			($ 8 125)
Annual operating labor	(t)		
Annual operating materials and supplies (not including electrical power)			[s]$ 5 400

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[n] To nearest $100.

[p] Based on Richardson's 15028-2 (ref. 52).

[q] One-half of the typical maintenance materials cost for pump-motor installations has been assumed for the firefighting-water pumps.

[r] Vendor quote.

[s] To nearest $50.

[t] System-level operating crew.

TABLE 31.- Concluded

(c) Interconnect plumbing, processing, and collection hardware - 1974 dollars

Item	Initial cost	Annual maintenance materials	
		Percent	Cost
10 15.2-cm (6 in.) isolation valves with mating hardware at $622 each	$ 6 220	3	$187
17 7.6-cm (3 in.) isolation valves (threaded) at $125 each	2 125	3	64
1 7.6-cm (3 in.) 3-way valve with positioner and mating hardware	899	10	90
2 7.6-cm (3 in.) solenoid valves at $280 each	560	5	28
Miscellaneous interconnect piping and fittings (not evaluated in detail)	1 000	.5	5
Subtotal - capital	$10 804		
Subtotal - maintenance materials			$374
Firefighting			
21.3 m (70 ft) of 30.5-cm (12 in.) firefighting water pipe spools at $111.61/m ($34.02/ft)	$ 2 381	.5	$ 12
3 30.5-cm (12 in.) flanges at $167 each	501	.5	3
1 30.5-cm (12 in.) isolation valve	1 586	3	48
6 20.3-cm (8 in.) isolation valves with mating hardware at $838 each	5 028	3	151
Subtotal - capital	$ 9 496		
Subtotal - maintenance materials			$214

TABLE 32.- BASELINE MIUS HVAC SUBSYSTEM COST ANALYSIS

(a) Cost summary - 1974 dollars

Item	Initial cost
HVAC subsystem	
2183.9 kW (621 tons) with thermal storage at \$86.44/kW (\$304/ton) of capacity	\$189 700
Hot-water/chilled-water distribution (external to MIUS building) at \$22.18/kW (\$78/ton) of capacity	48 560
Total subsystem capital[a] at \$108.62/kW (\$382/ton) of capacity	\$238 260
Annual operating cost	(b)
Annual maintenance cost at \$4.12/kW (\$14.50/ton)	
Materials	\$ 6 210
Labor[c]	1 550
Total annual maintenance	\$ 7 760

[a] Excluding apartment building equipment.

[b] Operating labor included in the composite crew; operating materials included with the maintenance costs.

[c] One-half of the typical maintenance labor is assumed to be provided by the operating crew.

TABLE 32.- Continued

(b) Equipment costs (MIUS building) - 1974 dollars

Item	Quantity	Capital cost			Maintenance cost		
		Material unit	Labor unit	Total	Materials[d]		Total[c]
					Percent	Cost	
777.2-kW (221 ton) absorption chiller	1	$23 800	$1646	$ 25 446	3.5	$ 833	
703.4-kW (200 ton) centrifugal chiller	2	19 550	1320	41 740	3.5	1369	
Cooling tower, 7.2-m^3/min (1892 gal/min)	1	15 900	1250	17 150	5.05	803	
Pump, 7.6-m^3/min (2000 gal/min), 149.4-kN/m^2 (50 ft) head, turbine	2	975	390	2 730	3.3	64	
Pump, 4.5-m^3/min (1200 gal/min), 538.0-kN/m^2 (180 ft) head, centrifugal	2	1 518	500	4 036	3.3	100	
Pump, 0.9-m^3/min (250 gal/min), 747.2-kN/m^2 (250 ft) head, turbine	2	1 260	83	2 686	3.3	83	
Electric motors, 460-V, 3-phase							
29.8-kW (40 hp) vertical, 371.8-rad/sec (3550 rpm)	2	1 120	111	2 462	5.0	112	
56.0-kW (75 hp) horizontal, 183.3-rad/sec (1750 rpm)	2	980	128	2 216	5.0	98	
22.4-kW (30 hp) vertical, 371.8-rad/sec (3550 rpm)	2	952	44	1 992	5.0	95	
Starter, size 3	4	640	---	2 560	5.0	128	
Starter, size 4	2	1 209	--	2 418	5.0	121	
724 567-liter (191 411 gallon) thermal storage system (TSS) tank (table 32(c))	1			28 000	5	140	
Heat exchanger, 2.3-m^3/min (600 gal/min), 2-pass, 45 7-cm (18 in.) shell by 111 8 cm (44 in.) long	1	3 060	750	3 810	3.1	95	
Heat exchanger, 0.8-m^3/min (210 gal/min), 2-pass, 30.5-cm (12 in.) shell by 196.9 cm (77.5 in.) long	1	1 326	300	1 626	3.1	41	
Subtotals				[e]$138 870		[e]$4080	[e]$5100

[c] One-half of the typical maintenance labor is assumed to be provided by the operating crew.

[d] Maintenance materials cost based on initial cost of materials only

[e] To nearest $10.

TABLE 32.- Continued

(b) Continued

Item	Quantity	Capital cost			Maintenance cost		
		Material unit	Labor unit	Total	Materials^d		Total^c
					Percent	Cost	
A120 black steel pipe, schedule 40							
30.5-cm (12 in.) welded joint, 9.1 m (30 ft) at $111.61/m ($34.02/ft)	1	(f)	(g)	$ 1 021	0.5	$ 46	
20.3-cm (8 in.) welded joint, 15.2 m (50 ft) at $77.62/m ($23.66/ft)	1	(f)	(g)	1 183			
15.2-cm (6 in.) welded joint, 57.9 m (190 ft) at $61.45/m ($18.73/ft)	1	(f)	(g)	3 559			
12.7-cm (5 in.) welded joint, 18.3 m (60 ft) at $61.45/m ($18.73/ft)	1	(f)	(g)	1 124			
7.6-cm (3 in.) threaded joint, 27.4 m (90 ft) at $35.99/m ($10.97/ft)	1	(f)	(g)	987			
5.1-cm (2 in.) threaded joint, 18.3 m (60 ft) at $23.46/m ($7.15/ft)	1	(f)	(g)	429			
Pipe insulation, 1.91-cm (0.75 in.) thick fiberglass							
20.3-cm (8 in.), 6.1 m (20 ft) at $15.26/m ($4.65/ft)	1	(f)	(g)	93			
15.2-cm (6 in.), 45.7 m (150 ft) at $12.96/m ($3.95/ft)	1	(f)	(g)	593			
7.6-cm (3 in.), 15.2 m (50 ft) at $10.33 m ($3.15/ft)	1	(f)	(g)	158			

[c] One-half of the typical maintenance labor is assumed to be provided by the operating crew

[d] Maintenance materials cost based on initial cost of materials only.

[e] To nearest $10.

[f] Included under "Item."

[g] Included in material unit cost.

TABLE 32.- Continued

(b) Continued

Item	Quantity	Capital cost			Maintenance cost		
		Material unit	Labor unit	Total	Materials[d]		Total[c]
					Percent	Cost	
No. 125 control valves with operator, controller, flanges, and gaskets							
7.6-cm (3 in.)	1	$ 932	(g)	$ 932	5	$1074	
5.1-cm (2 in.)	1	722	(g)	722			
15.2-cm (6 in.)	5	1 683	(g)	8 415			
20.3-cm (8 in.)	2	2 343	(g)	4 686			
12.7-cm (5 in.)	4	1 683	(g)	6 732			
No. 150 valve with handwheel, flanges, and gaskets							
5.1-cm (2 in.) threaded	5	96	(g)	480	3	606	
10.2-cm (4 in.) threaded	10	168	(g)	1 680			
15.2-cm (6 in.) flanged	12	622	(g)	7 464			
20.3-cm (8 in.) flanged	8	838	(g)	6 704			
7.6-cm (3 in.) threaded	16	125	(g)	2 000			
12.7-cm (5 in.) flanged	3	622	(g)	1 866			
Subtotals (mechanical room)				[e]$189 700		[e]$5810	[e]$7260

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[c] One-half of the typical maintenance labor is assumed to be provided by the operating crew.

[d] Maintenance materials cost based on initial cost of materials only.

[e] To nearest $10

[g] Included in material unit cost

TABLE 32 - Continued

(b) Concluded

Item	Quantity	Capital cost			Maintenance cost		
		Material unit	Labor unit	Total	Materials[d]		Total[c]
					Percent	Cost	
Tar-coated uninsulated A120 galvanized steel pipe, schedule 40							
8.9-cm (10.2 cm) (3.5 in. (4 in.))	320	$ 3.56	$ 4.62	$ 2 618	0.5	$ 211	
7.6-cm (3 in.)	3030	2.37	3.08	16 514			
6.4-cm (2.5 in.)	370	1.84	2.45	1 587			
5.1-cm (2 in.)	810	1.13	2.31	2 786			
3.8-cm (1.5 in.)	480	.85	2.06	1 397			
3.18-cm (1 25 in.)	4740	.66	1.85	11 897			
2.5-cm (1 in.)	670	.51	1.69	1 474			
1.91-cm (0 75 in.)	760	.39	1.43	1 383			
1.3-cm (0.5 in.)	1590	.35	1.23	2 512			
Gate valves, threaded joint							
Iron body, 8 9-cm (10.2-cm) (3.5 in. (4 in.)), 861 8-kN/m2 (125 psi)	20	110	58	3 360	3	192	
Bronze body, 3.8-cm (1.5 in.), 861 8-kN/m2 (125 psi)	2	19	32	102			
Bronze body, 3.18-cm (1 25 in), 861.8-kN/m2 (125 psi)	38	16	30	1 748			
Bronze body, 1.3-cm (0.5 in.), 861.8-kN/m2 (125 psi)	38	7	24	1 178			
Subtotal distribution				[e]$ 48 560		$ 403	$ 504
Total HVAC initial cost				$238 260		[e]$6210	[e]$7760

[c] One-half of the typical maintenance labor is assumed to be provided by the operating crew.

[d] Maintenance materials cost based on initial cost of materials only.

[e] To nearest $10

TABLE 32.- Continued

(c) Thermal storage tank (and wastewater holding tank) costs - 1974 dollars

Item	Cost
Bulk excavation, 1529.1 m^3 at \$1.31/m^3 (2000 yd^3 at \$1.00/yd^3)	\$ 2 000
Haul or grade excavated material at \$0.65/m^3 (\$0.50/yd^3)	1 000
Backfill and tamp, 321.1 m^3 at \$1.31/m^3 (420 yd^3 at \$1.00/yd^3)	420
Trim and level bottom by hand at \$3.23/m^2 (\$2.70/yd^2)	100
15.2-cm (6 in.) sand base in place, 14.5 m^3 at \$5.05/m^3 (19 yd^3 at \$3.86/yd^3)	73
Wall forms (based on 5 uses), 749.7 m^2 at \$16.58/m^2 (8070 ft^2 at \$1.54/ft^2)	12 428
20 684.3-kN/m^2 (3000 psi) concrete 27.9-cm (11 in.) walls and bottom, 189.6 m^3 at \$47.03/m^3 (248 yd^3 at \$35.96/yd^3)[h]	8 918
Reinforcing steel, 29.7 kg/m^3 (50 lb/yd^3) concrete at \$0.61/kg (\$550/ton) in place (5624.5 kg (6.2 tons))	3 410
12 30.5-cm (12 in.) by 6.1-m (20 ft) support piles, 27 579.0-kN/m^2 (4000 psi) concrete, containing 118.6 kg/m^3 (200 lb/yd^3) steel	1 685
Break ties, plug holes, and patch sidewalls; 418.1 m^2 (4500 ft^2) at \$3.59/m^2 (33.33¢/ft^2)	1 500
Bottom, steel trowel, 2 passes; 255.5 m^2 (2750 ft^2) at \$2.80/m^2 (26¢/ft^2)	715
Subtotal	\$32 249

[h] Design wall thickness is actually 25.4 centimeters (10 inches); 27.9 centimeters (11 inches) for material thickness was used to account for concrete in buttresses.

TABLE 32.- Concluded

(c) Concluded

Item	Cost
Interior coating, vinyl plastic, sprayed on to a thickness of 0.6 to 1.0 mm (25 to 40 mils); 673.5 m^2 (7250 ft^2) at \$9.47/m^2 (88¢/ft^2)	\$ 6 380
Form rental for pouring building slab (based on 5 uses), 279.5 m^2 (20.4 by 13.7 m) (3015 ft^2 (67 by 45 ft)) at \$20.13/m^2 (\$1.87/ft^2)	5 638
2 4.6-m (15 ft) steel ladders in place at (\$52.49/m (\$16/ft)	480
Total tank cost	[e]\$44 750
Cost charged to HVAC subsystem (five-eighths)	[i]\$28 000
Cost charged to wastewater subsystem (three-eighths)	[i]\$16 800

[e] To nearest \$10.

[i] To nearest \$100.

TABLE 33.- BASELINE MIUS SOLID-WASTE SUBSYSTEM COST ANALYSIS

(a) Cost summary - 1974 dollars

Item	Initial cost
Collection and incineration equipment with heat recovery at $24.03/kg ($21 800/ton) capacity	$108 100
Annual operating cost (no operator labor or electricity)	
Incinerator fuel at 6.7¢/liter (25.5¢/gal)	$ 3 120
Gasoline at 0.40¢/kg ($3.67/ton)	100
Offsite disposal	3 640
Annual maintenance cost (including purchase labor), no replacement, at 0.31¢/kg ($2.82/ton)	5 300
Total subsystem O&M cost (excluding operators and electricity) at 0.72¢/kg ($6.49/ton)	$12 160

TABLE 33.- Continued

(b) Component costs - 1974 dollars

Item	Quantity	Factory cost	Installed cost	Maintenance materials		Useful life, yr	Annual replacement cost
				Percent	Cost		
Tractor	1	--	$ 2 000	2	$ 40	10	$ 200
ML375D Consumat loader	1	$10 011	10 300	3	309	20	515
C-225 incinerator	1	20 963	21 000	3	630	20	1050
Automatic ash-removal unit	1	5 284	5 300	3	159	20	265
Heat-recovery boiler	1	--	40 000	5	2000	20	2000
Oil burner	3	488	500	20	100	5	0
Flame sensor	3	498	500	20	100	5	0
7.6-m^3 (10 yd^3) ash storage container	1	--	1 200	5	6	20	60
Wheeled collection cart	48	20 544	20 600	3	618	10	2060
Gravity-chute charging station, 23 chutes, 3 floors ($300/floor)	78	--	NC	--	--	40	--
Sludge-holding tank (5.9 m^3, 5678.1 liters (210 ft^3, 1500 gal))	1	--	700	5	4	20	35
Auger (with drive)	1	--	1 200	3	36	20	60
Loader fire-control fog system	1	323	400	3	12	10	40
Installation hardware (table 33(c))			4 400		200	30	147
Total capital			$108 100				
Annual maintenance materials (no replacement)					[a]$4220		
Annual maintenance labor[b]					[a]$1060		

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[a] To nearest $10.

[b] One-half of the typical maintenance labor is assumed to be provided by the operating crew.

TABLE 33.- Concluded

(c) Heat-recovery interconnect plumbing - 1974 dollars

Item	Initial cost	Annual maintenance materials	
		Percent	Cost
12.2 m (40 ft) of 15.2-cm (6 in.) schedule 40 pipe spools at $61.45/m ($18.73/ft)	$ 749	0.5	$ 4
2 15.2-cm (6 in.) flanges (and bolt-ups) at $126 each	252	.5	1
1 15.2-cm (6 in.) 45° elbow	52	.5	1
2 15.2-cm (6 in.) 90° elbows at $149 each	298	.5	1
23.5 m (77 ft) of equivalent 15.2-cm (6 in.), 3.8-cm (1.5 in.) insulation at $12.96/m ($3.95/ft)	304	.5	2
12.2 m (40 ft) of 5.1-cm (2 in.) feed-water pipe at $11.09/m ($3.38/ft)	135	.5	1
1 15.2-cm (6 in.) back-pressure regulator (local control)	1699	10	170
1 15.2-cm (6 in.) isolation valve (flanged)	622	3	19
1 5.1-cm (2 in.) isolation valve (threaded)	96	3	3
1 3.8-cm (1.5 in.) blowdown valve (threaded)	51	3	2
12.2 m (40 ft) of 3.8-cm (1.5 in.) schedule 40 pipe at $9.38/m ($2.86/ft)	114	.5	1
Total initial cost	$4372		
Annual maintenance materials			$205

TABLE 34.- BASELINE MIUS CONTROL AND MONITORING SUBSYSTEM COST ANALYSIS

(a) Cost summary - 1974 dollars

Item	Initial cost
Control and monitoring capital cost	
Control-room equipment	$ 75 100
Sensors and transducers	69 760
Total capital cost	$144 860
Annual operating cost	(a)
Annual maintenance cost	
Control-room equipment	$ 11 270
Sensors and transducers	6 980
Total annual maintenance cost	$ 18 250

[a] No separate annual operating cost.

(b) Component and maintenance costs - 1974 dollars

Item	Quantity	Installed cost	Annual maintenance	
			Percent	Cost
Control console computer	1	$ 65 000	15	[b]$11 270
CRT with keyboard	1	3 000		
Typewriter/printer	1	1 700		
Cassette tape recorder	1	5 400		
Temperature sensors	124	4 960	10	6 980
Analog sensors	94	54 400		
Pressure transducers	17	10 400		
Totals		$144 860		$18 250

[b] Contract.

TABLE 35.- BASELINE MIUS BUILDING DESCRIPTION

(From ref. 59)

Item	Description
Structure	Reinforced-concrete foundation, footings, walls, and slabs. Exterior walls: all perimeter walls, brick and block; office walls, brick and block or curtain wall panels of plate glass, aluminum extrusions, porcelain enamel panels, or precast aggregate-finish wall panels. Interior structural framing: grid layout, structural steel framing of columns and beams. Roof structure: steel-bar open-web joists, metal deck. Built-up roof and insulation. Office area finished with resilient flooring, ceramic tile toilets, and suspended acoustical ceilings.
Plumbing	Two toilets for office area, toilet and locker room for warehouse. Water coolers, utility, and service sinks.
Heating and ventilation	Rooftop combination heating and air-conditioning units, gas- or oil-fired furnace or electric baseboard heating system for office area. Suspended unit heaters in warehouse.
Electrical	Combination fluorescent and incandescent lighting system: open strip in warehouse; built-in panels set into suspended ceilings in office, complete with diffusers. Fire alarm system.
Special feature	Sprinkler system in all areas.

TABLE 36.- BASELINE MIUS TRENCHING AND MISCELLANEOUS COSTS

(a) Cost summary - 1974 dollars

Item	Cost
Trenching and miscellaneous costs	
Trenching	$27 100
Pneumatic system	6 300
Tools	5 000
Spare-parts inventory	10 000
Initial fuel loading (151.4 m3 (40 000 gal))	10 200
Total initial cost	$58 600
Annual operating cost	(a)
Annual maintenance cost	
Pneumatic system	$ 300
Tools	250
Total annual O&M costs	$ 550

[a] No separate operating cost.

TABLE 36.- Continued

(b) Trenching costs - 1974 dollars

Item	Cost
Trenching along sidewalk: 792.5 m (2600 ft) long, 0.8 m (2.5 ft) wide, 1.1 m (3.5 ft) deep, by trenching machine; backfill by bulldozer; 95-percent compaction by sheepsfoot roller; unclassified soil	$ 2 080
Trenching for common sewer and firefighting water: 824.5 m (2705 ft) long, 3.7 m (12 ft) deep (av), 0.9 m (3 ft) wide at bottom, 45o sides, by 0.8-m^3 (1 yd^3) dragline; backfill by bulldozer; compaction by sheepsfoot roller; unclassified soil	23 200
Additional trenching for firefighting water: 173.7 m (570 ft) long, 1.4 m (4.5 ft) deep, 0.6 m (2 ft) wide; backfill	570
Sand and gravel: 249 m^3 (326 yd^3)	1 260
Total (excluding sewer outfall)	$27 110

TABLE 36.- Continued

(c) Pneumatic system - 1974 dollars

Item	Total cost
Ingersoll-Rand T 301-1/2 TM air compressor, 1.1-kW (1.5 hp), 0.14-m^3/min (5.07 ft^3/min)	$ 890
Electrical	90
Extra 227.1-liter (60 gal) receiver	125
7 regulators at $40 each	280
4 1.3-cm (0.5 in.) relief valves at $12 each	48
10 1.3-cm (0.5 in.) valves at $10 each	100
2 check valves at $10 each	20
30 0.64-cm (0.25 in.) valves at $10 each	300
40 0.64-cm (0.25 in.) solenoid valves at $45 each	1800
152.4 m (500 ft) of 1.3-cm (0.5 in.) schedule 40 pipe at $5.31/m ($1.62/ft) (includes fittings)	810
304.8 m (1000 ft) of 0.64-cm (0.25 in.) tubing at $3.97/m ($1.21/ft)	1210
Miscellaneous installation, electrical and mechanical, 40 man-hours at $15/hr	600
Total system	[b]$6270

[b]To nearest $10.

(d) Tools - 1974 dollars

Item	Cost
Total initial cost Welding, cutting, and soldering equipment and supplies Complete mechanics and plumbing tools including torque wrenches, dial indicators, pipe wrenches, jacks, grinder, hoists, and similar equipment Electrical test equipment and tools Pressure and temperature test equipment Cleaning and printing equipment	$5000
Annual maintenance and replacement at 5 percent of initial cost	$ 250

TABLE 36.- Concluded

(e) Spare-parts inventory - 1974 dollars

Item	Cost
Control system equipment components at 5 percent of initial subsystem cost	$ 7 000
Gaskets, valve packing, filters, pneumatic valve actuators and components, solenoid valves, electrical components, and plumbing fittings	3 000
Total initial inventory	$10 000
Annual maintenance	(c)

[c] Included in annual maintenance costs.

TABLE 37.- BASELINE MIUS OPERATING-CREW COSTS

(a) Employee salaries - 1974 dollars

Item	Annual cost[a]
One skilled employee[b]	$20 800
Three semiskilled employees[c]	34 200
Two service employees[d]	15 060
Overtime allocation[e]	5 040
Total	$75 100

[a] Including payroll taxes.

[b] Class V engineer as reported in Department of Labor statistics table 104 escalated from mid-1971 to 1974 by 15 percent.

[c] Monthly labor review, Department of Labor December 1973 labor rate table for utility workers and assuming the same increase will occur between December 1973 and June 1974 as occurred between June 1973 and December 1973.

[d] Service workers rate with the same increases as in footnote (c).

[e] Estimated at 100 hr/yr per employee.

TABLE 37.- Continued

(b) Subsystem O&M task hour estimates[f] - daily basis

Task	Effort, man-hr/day					
	Electrical plant	Water and wastewater	HVAC	Solid waste	Subtotals	Other[g]
Supervision Monitoring Data logging, records, clerical Inspection	0.5	6.5	1.3	--	8.3	
Operations Inspection Data logging Monitoring Servicing Adjustments	.5	10.6	2.3	4.5	17.9	
Preventive maintenance - Schedule maintenance, equipment replacement, and unscheduled equipment repairs[h]	1.0	4.9	.5	.5	6.9	
Custodial service	--	2.3	.3	--	2.6	
Totals	2.0	24.3	4.4	5.0	35.7	4.0
Total with additional					39.7	

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[f] Allocation of man-hours for integrated system operation is not expected to be according to this table; however, these man-hour estimates have been used, in part, to establish system operating-crew size.

[g] Control system, MIUS housing, and auxiliary equipment.

[h] See table 37(e) for estimate of additional maintenance labor.

TABLE 37.- Continued

(c) Subsystem O&M task hour estimates - weekly basis

Supervision, operation, and maintenance, man-hr/week	278
Nonproductive time at 7.7 percent[i], man-hr/week	21
Total time required, man-hr/week	299
20-percent reduction in time for integrated operations, man-hr/week	60
Adjusted total, man-hr/week[h]	239
Number of full-time employees	6

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[h] See table 37(e) for estimate of additional maintenance labor.

[i] Based on 5 paid holidays, 5 days paid sick leave, and 10 days paid vacation per employee per year.

(d) Example of regular shift pattern with five employees[j] on two shifts[k]

Day	First shift		Second shift	
	Assignment	Total	Assignment	Total
1	B,H	2	A	1
2	B,H	2	A,H	2
3	C,H	2	A,H	2
4	C,H	2	A,H	2
5	C,H	2	B,H	2
6	C	1	B,H	2
7	C,A	2	B	1
8	A,H	2	B	1
9	A,H	2	B,H	2
10	A,H	2	C,H	2
11	A,H	2	C,H	2
12	B,H	2	C,H	2
13	B	1	C,H	2
14	B	1	C,A	2
15	B,H	2	A	1
16	B,H	2	A,H	2
17	C,H	2	A,H	2
18	C,H	2	A,H	2

[j] A, B, C = semiskilled; H = helper.

[k] Time off for holidays, sick leave, vacation, and other reasons will require variations in regular shift pattern.

TABLE 37.- Continued

(d) Concluded

Day	First shift		Second shift	
	Assignment	Total	Assignment	Total
19	C,H	2	B,H	2
20	C	1	B,H	2
21	C,A	2	B	1
22	A,H	2	B	1
23	A,H	2	B,H	2
24	A,H	2	C,H	2
25	A,H	2	C,H	2
26	B,H	2	C,H	2
27	B	1	C,H	2
28	B	1	C,A	2
29	B,H	2	A	1
30	B,H	2	A,H	2
31	C,H	2	A,H	2
32	C,H	2	A,H	2
33	C,H	2	B,H	2
34	C	1	B,H	2
35	C,A	2	B	1
36	A,H	2	B	1

TABLE 37.- Concluded

(e) Additional maintenance labor not provided by the full-time O&M personnel -

1974 dollars

Item	Cost	
	Materials and labor	Labor only
Electrical power equipment	$23 100	[l]$ 7 700
Engine-generators		
Heat recovery		
Switchgear and transformers		
Distribution wiring		
Fuel-supply equipment		
Water, wastewater, and firefighting equipment		[m]4 020
HVAC equipment		[m]1 500
Solid-waste equipment		[m]1 060
Control system equipment	18 300	[l]6 100
Total maintenance labor not provided by operating crew		[n]$20 400

[l] Based on one-third for labor and two-thirds for material.

[m] Based on component estimates.

[n] To nearest $50.

TABLE 38.- INDEXES FOR ADJUSTMENT OF THE BASELINE MIUS CHICAGO COSTS

MIUS location	Fuel cost, \$/m^3 (¢/gal)[a]	Relative cost index		
		System and O&M[b]	Fuel oil and lube oil[a]	Operating labor[c]
Chicago, Ill.	67.36 (25.5)	100.0	100.0	100.0
Washington, D.C.	64.72 (24.5)	92.8	96.0	90.7
Minneapolis, Minn.	71.85 (27.2)	96.3	106.5	95.5
Houston, Tex.	60.23 (22.8)	87.7	89.5	79.6
Las Vegas, Nev.	71.85 (27.2)	101.0	106.5	98.1

[a] Based on Platt's Oilgram (ref. 63) and the variation of gasoline prices, exclusive of sales taxes.

[b] Based on the 1973 Building Cost File (ref. 54) composite construction cost index - labor and materials.

[c] Based on Robert Means' 1973 construction labor cost index (ref. 53).

TABLE 39.- COMPARISON OF THE BASELINE MIUS COSTS WITH THE MIUS COSTS IN WASHINGTON, D.C.

(1974 dollars)

Item	Baseline MIUS costs		Washington, D.C., MIUS costs	
	Capital	Annual O&M	Capital	Annual O&M
Electrical power	$ 396 710	$131 700	$ 368 100	$125 600
Water supply[a]	223 300	4 440	223 300	4 440
Wastewater, firefighting	434 700	25 520	404 000	23 680
HVAC and hot water	238 260	7 760	220 000	7 050
Solid waste	108 100	12 160	101 000	11 660
Controls	144 860	18 250	134 400	16 760
MIUS housing	148 800	2 230	138 000	2 070
Miscellaneous costs	58 600	550	54 400	510
System operating crew	--	75 100	--	68 100
Totals	$1 753 330	$277 710	$1 643 200	$259 870

[a] Conventional water supply costed for the Washington, D.C., area.

TABLE 40.- COMPARISON OF THE BASELINE MIUS COST TO THE COST OF CONVENTIONAL UTILITIES AND SERVICES

(1974 dollars)

Item	Baseline MIUS costs		Conventional utilities costs[a]		Conventional utilities costs[b]	
	Capital	Annual O&M	Capital	Annual O&M	Capital	Annual O&M
Electrical power	$ 396 710	$131 700	$ 711 500	$142 950	$ 711 500	$118 750
Boiler fuel	--	--	5 050	32 050	5 050	32 050
Water supply[c]	223 300	4 440	246 900	5 000	246 900	5 000
Wastewater	434 700	25 520	304 000	16 500	304 000	16 500
HVAC and hot water	238 260	7 760	201 100	6 920	201 100	6 920
Solid waste	108 100	12 160	75 400	22 600	75 400	22 600
Controls	144 860	18 250	--	--	--	--
MIUS housing	148 800	2 230	(d)	(d)	(d)	(d)
Miscellaneous costs	58 600	550	(e)	(e)	(e)	(e)
System operating crew	--	75 100	--	[f]26 900	--	[f]26 900
Totals	$1 753 330	$277 710	$1 543 950	$252 920	$1 543 950	$228 720

[a] All costs except boiler, boiler fuel tank, and HVAC equipment and maintenance are based on the conventional utility system of the community study. For capital, it was assumed that capacity would be purchased on the basis of peak requirements. All community-study 1973 costs were adjusted to reflect 1974 costs, but the costs were not adjusted to the Chicago base. The conventional electrical power system fuel costs were assumed the same as the baseline MIUS fuel costs.

[b] Same as footnote (a), except central powerplant fuel at 80 percent of the cost of MIUS fuel.

[c] Conventional water supply system costs for the MIUS are based on the community-study data.

[d] The HVAC mechanical-room costs have not been evaluated.

[e] Tools, pneumatic system, and spare-parts-inventory requirements have not been evaluated.

[f] HVAC.

TABLE 41.- COMPARISON OF THE COST OF THE BASELINE LOCATED IN WASHINGTON, D.C.,

TO THE COST OF CONVENTIONAL UTILITIES AND SERVICES

(1974 dollars)

Item	Washington, D.C., MIUS costs		Conventional utilities costs[a]	
	Capital	Annual O&M	Capital	Annual O&M
Electrical power	$ 368 100	$125 600	$ 711 500	$114 950
Boiler fuel	--	--	4 680	30 850
Water supply	223 300	4 440	246 900	5 000
Wastewater	404 000	23 680	304 000	16 500
HVAC and hot water	220 000	7 050	186 500	6 420
Solid waste	101 000	11 660	75 400	22 600
Controls	134 400	16 760	--	--
MIUS housing	138 000	2 070	(b)	(b)
Miscellaneous costs	54 400	510	(c)	(c)
System operating crew	--	68 100	--	[d]24 400
Totals	$1 643 200	$259 870	$1 528 980	$220 720

[a] All equipment costs except the boiler fuel tank and HVAC have been based on the community-study conventional system. For capital, it was assumed that capacity would be purchased on the basis of peak requirements. All community-study 1973 costs were adjusted to reflect 1974 costs. A special adjustment was made for the fuel requirements of the solid-waste system. Fuel costs for the central powerplant are at 80 percent of the fuel costs for the MIUS.

[b] The HVAC mechanical-room costs have not been evaluated.

[c] Tools, pneumatic system, and spare-parts-inventory requirements have not been evaluated.

[d] HVAC.

TABLE 42.- CONVENTIONAL UTILITIES COSTS FOR COMPARISON TO THOSE OF THE WASHINGTON MIUS

(a) Electrical power

Contract construction labor increase from June 1973 to June 1974, percent	11.2
Electrical machinery and equipment increase from June 1973 to June 1974, percent	2.3
Total system cost (mid-1973), \$/kW	435
Conventional apartments peak capacity (no adjustment for diversity - 2σ + 6 percent requirement), kW	1501
Conventional system capital cost (\$474/kW times 1501 kW), dollars	711 500
Conventional system O&M costs, not including fuel, escalated to mid-1974 - conventional apartments requirement, 21.175 TJ (5.882×10^6 kWh) at 1.01 mills/MJ (3.63 mills/kWh), dollars	21 350
Fuel cost - delivered efficiency of the central system, 3.3 J/J (11 360 Btu/kWh), dollars	
Fuel at 1.7 mills/TJ (\$1.75/10^{12} Btu) (baseline Washington MIUS cost)	116 900
Fuel at 1.3 mills/TJ (\$1.40/10^{12} Btu) (80 percent baseline Washington MIUS cost)	93 600

TABLE 42.- Continued

(b) Water supply

Contract construction labor increase, mid-1973 to mid-1974, percent	11.2
Miscellaneous machinery and equipment increase, mid-1973 to mid-1974, percent	3.2
1974 replacement cost of conventional water system, \$/m^3 (\$/gal)	530.99 (2.01)
Peak requirements of conventional apartments, m^3/day (gal/day)	465 (122 850)
System capital cost (465 m^3 times \$530.99/m^3 (122 850 gal times \$2.01/gal)), dollars	≈246 900
Av requirements of conventional apartments, m^3/yr (gal/yr)	137 807 (36.4x10^6)
1973 conventional system O&M costs, not including electricity, ¢/m^3 (¢/1000 gal)	2.5 (9.4)
1974 conventional system O&M costs, ¢/m^3 (¢/1000 gal)	[a]2.68 (10.15)
1974 electricity cost, ¢/m^3 (¢/1000 gal)	0.96 (3.62)
1974 conventional apartments direct costs based on av requirements, dollars	5000

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[a] Escalated from 1973 by a factor of 1.08.

TABLE 42.- Continued

(c) Wastewater

Contract construction labor increase, mid-1973 to mid-1974, percent	11.2
Miscellaneous machinery and equipment increase, mid-1973 to mid-1974, percent	3.2
1974 replacement cost of conventional system, \$/m3 (\$/gal)	692.13 (2.62)
Peak requirements of conventional apartments, m3/day (gal/day)	446.7 (118 000)
System capital cost (446.7 m3 times \$692.13/m3 (118 000 gal times \$2.62/gal)), dollars	309 200
Av requirements for conventional apartments, m3/yr (gal/yr)	122 363 (32.3×10^6)
1973 conventional system O&M costs, ¢/m3 (¢/1000 gal)	12.7 (48)
1974 conventional system O&M costs, ¢/m3 (¢/1000 gal)	[a]13.7 (51.8)
1974 conventional apartments direct costs based on av requirements, dollars	16 500

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[a] Escalated from 1973 by a factor of 1.08.

TABLE 42.- Continued

(d) HVAC

Item	Quantity	Capital, 1974 dollars		Maintenance, 1974 dollars			
		Cost/unit	Total	Materials		Labor[b]	Total[b]
				Percent	Cost		
1090.2-kW (310 ton) compression chiller	2	$26 750	$ 53 500	3.5	$1872	$310	$2182
Cooling tower, 6 3-m^3/min (1675 gal/min) 2 11.2-kW (15 hp) fans 2 18.7-kW (25 hp) fans	1	13 000	13 000	5.05	657	110	767
Boiler, 74.6-kW (100 hp)	2	7 120	14 240	3	427	72	499
Pump (tower), 6 8-m^3/min (1800 gal/min), 149.4-kN/m^2 (50 ft) head	2	3 680	7 360	[c]3.3	305	50	355
Pump (cold water), 388.6-kN/m^2 (130 ft) head	2	3 890	7 780		323	53	376
Pump (hot water), 0.9-m^3/min (250 gal/min), 747.2-kN/m^2 (250 ft) head	2	2 976	5 952		247	40	287
Subtotal			$101 832				
Piping same as MIUS[d]			99 300		2120	350	2470
Totals			[e]$201 130				[b,e]$6940

[b] One-half of normal maintenance labor is provided by the operating crew.

[c] 5 0 percent for motors and starter/circuit breakers.

[d] See table 32(b) for details.

[e] To nearest $10.

TABLE 42.- Concluded

(e) Solid waste

Capital cost, \$/kg-day (\$/ton-day)	[f]26.79 (24 300)
1973 cost for conventional apartments, at 2721.6 kg/day (3 tons/day), dollars	72 900
Mid-1974 cost for conventional apartments, dollars	975 400
1973 O&M costs, at 1.91¢/kg (\$17.29/ton) (for 993 367.3 kg (1095 tons)), dollars	18 920
Mid-1974 O&M costs, dollars	[a]20 400
Heating value of solid waste handled, MJ/kg (Btu/ton)	[h]2.46 (2.12x10^{6})
Delta fuel cost assigned for this comparison, [i]mill/TJ (\$/10^{12} Btu)	0.69 (0.73)
Adjusted fuel cost for 993 367.3 kg (1095 tons), dollars	1695
Total 1974 O&M cost of solid-waste disposal, dollars	22 600

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[a] Escalated from 1973 by a factor of 1.08.

[f] This amount yielded by the conventional community-study (1974) data.

[g] Escalated from 1973 by a factor of 1.032.

[h] Requirement of the conventional solid-waste system of the community study.

[i] Fuel costs increased for the Washington, D.C., area from an estimated 0.97 mill/TJ (\$1.02/10^{12} Btu) to 1.66 mills/TJ (\$1.75/10^{12} Btu) in mid-1974.

TABLE 43.- COST COMPARISONS OF THE WASHINGTON, D.C., MIUS AND THE CONVENTIONAL UTILITIES

(1974 dollars)

Item	Conventional utilities costs[a]	MIUS costs
Total capital outlay	$1 529 000	$1 643 200
Total fuel and lube cost (20 yr)	2 567 000	2 146 000
Other O&M costs (20 yr)	1 847 000	3 052 000
Total outlay (20 yr)	$5 943 000	$6 841 000
Escalated and discounted outlay[b] (20-yr totals)	$3 363 000	$3 752 000
Escalated and discounted outlay[c] (20-yr totals)	$3 471 000	$3 930 000
Escalated and discounted outlay[d] (20-yr totals)	$4 005 000	$4 376 000

[a] Fuel cost for central powerplant at 80 percent of the cost for MIUS fuel.

[b] Fuel escalated at 5 percent/yr; all other costs at 3 percent/yr discounted at 15 percent/yr to mid-1974.

[c] All costs escalated at 5 percent/yr; dicounted at 15 percent/yr to mid-1974.

[d] Fuel escalated at 10 percent/yr; all other costs at 5 percent/yr discounted at 15 percent/yr to mid-1974.

TABLE 44.- COST COMPARISONS OF THE WASHINGTON, D.C., MIUS WITH A FOUR-MAN CREW[a] AND THE CONVENTIONAL UTILITIES

(1974 dollars)

Item	Conventional utilities costs[b]	MIUS costs
Total capital outlay	$1 529 000	$1 643 200
Total fuel and lube cost (20 yr)	2 567 000	2 146 000
Other O&M costs (20 yr)	1 847 000	2 672 000
Total outlay (20 yr)	$5 943 000	$6 461 000
Escalated and discounted outlay[c] (20-yr totals)	$3 363 000	$3 607 000
Escalated and discounted outlay[d] (20-yr totals)	$4 005 000	$4 208 000

[a] Two operators, one helper, and an engineer.

[b] Fuel cost for central powerplant at 80 percent of the cost of MIUS fuel.

[c] Fuel escalated at 5 percent/yr; all other costs at 3 percent/yr discounted at 15 percent/yr to mid-1974.

[d] Fuel escalated at 10 percent/yr; all other costs at 5 percent/yr discounted at 15 percent/yr to mid-1974.

TABLE 45.- PEAK LOAD VARIATIONS

Parameter	Peak loads at -					
	Baseline, Washington, D C., 500-unit	Minneapolis 500-unit	Houston 500-unit	Las Vegas 500-unit	Washington, D C., 300-unit	Washington, D.C., 1000-unit
Electric power, kW	994	994	994	994	800	1988
HVAC cooling, kW (tons)	1906.1 (542)	1667 0 (474)	1923 7 (547)	1758.4 (500)	1153.5 (328)	3812.2 (1084)
HVAC space heating, kW (Btu/hr)	951.8 (3 25x10^6)	1440 9 (4 92x10^6)	582.8 (1 99x10^6)	749 8 (2 56x10^6)	459.8 (1.57x10^6)	1900.8 (6.49x10^6)
Solid waste, kg/day (lb/day)	2721.6 (6000)	2721.6 (6000)	2721 6 (6000)	2721 6 (6000)	1995.8 (4400)	5443 1 (12 000)
Sludge, kg/day (lb/day)	1814 4 (4000)	1814 4 (4000)	1814 4 (4000)	1814.4 (4000)	1315.4 (2900)	3628 7 (8000)
Total incinerated, kg/day (lb/day)	4535 9 (10 000)	4535.9 (10 000)	4535 9 (10 000)	4535 9 (10 000)	3311.2 (7300)	9071.8 (20 000)
Potable water, m^3/day (gal/day)	420 2 (111 000)	420.2 (111 000)	420.2 (111 000)	420.2 (111 000)	291 5 (77 000)	840.4 (222 000)
Wastewater, m^3/day (gal/day)	446 7 (118 000)	442.9 (117 000)	454.2 (120 000)	446 7 (118 000)	306.6 (81 000)	893.4 (236 000)

TABLE 46 - VARIATIONS SUMMARY

Annual comparisons	Minneapolis 500-unit	Houston 500-unit	Las Vegas 500-unit	Washington, D C, 300-unit	Washington, D C, 1000-unit	Baseline, Washington, D C, 500-unit
MIUS fuel, GJ (Btu)	63 574 (60 297x10^6)	66 272 (62 856x10^6)	64 025 (60 725x10^6)	47 201 (44 768x10^6)	121 407 (115 149x10^6)	62 334 (59 121x10^6)
Conventional fuel, GJ (Btu)	92 671 (87 894x10^6)	93 662 (88 834x10^6)	91 176 (86 476x10^6)	61 109 (57 959x10^6)	178 274 (169 084x10^6)	89 082 (84 490x10^6)
Savings, percent	31 4	29.2	29 8	22 8	31 9	30 0
MIUS water, m^3 (gal)	123 177 (32 540x10^6)	123 177 (32 540x10^6)	123 177 (32 540x10^6)	84 274 (22 263x10^6)	246 354 (65 08x10^6)	123 177 (32 54x10^6)
Conventional water, m^3 (gal)	133 761 (35 336x10^6)	149 334 (39 450x10^6)	152 578 (40 307x10^6)	94 949 (25 083x10^6)	276 629 (73 078x10^6)	137 807 (36 405x10^6)
Savings, percent	8	18	19	11	11	11
MIUS wastewater effluent, m^3 (gal)	110 235 (29 121x10^6)	98 950 (26.140x10^6)	94 366 (24 929x10^6)	73 494 (19 415x10^6)	214 083 (56 555x10^6)	107 392 (28 370x10^6)
Conventional wastewater effluent, m^3 (gal)	120 819 (31 917x10^6)	125 107 (33 050x10^6)	123 767 (32 696x10^6)	84 168 (22 235x10^6)	244 355 (64 552x10^6)	122 022 (32 235x10^6)
Savings, percent	9	21	24	12	12	12
MIUS trash effluent, kg (tons)	197 766 (218)	197 766 (218)	197 766 (218)	146 057 (161)	394 625 (435)	197 766 (218)
Conventional trash effluent, kg (tons)	987 924 (1089)	987 924 (1089)	987 924 (1089)	728 469 (803)	1 974 941 (2177)	987 924 (1089)
Savings, percent	80	80	80	80	80	80

TABLE 47.- 1000-APARTMENT-MIUS CAPITAL AND O&M COST SUMMARY

(1974 dollars)

Item	Chicago (U.S. median) costs			Washington, D.C., costs		
	Capital	Annual operating	Annual maintenance	Capital	Annual operating	Annual maintenance
Electrical power	$ 751 600	$216 700	$ 46 630	$ 697 000	$208 180	$ 43 240
Water supply[a]	446 600	5 900	2 980	446 600	5 900	2 980
Wastewater/firefighting	616 600	10 800	27 740	573 000	10 000	25 800
HVAC	475 250	--	17 260	441 000	--	16 020
Solid waste	173 200	13 720	8 440	161 000	13 460	7 830
Controls	144 900	--	18 260	134 400	--	16 760
Miscellaneous	95 870	--	550	89 600	--	510
MIUS housing	178 500	--	2 680	165 600	--	2 480
System operating crew	--	90 200	--	--	81 800	--
System totals	$2 882 520	$337 320	$124 540	$2 708 200	$319 340	$115 620

[a] Conventional water supply system costs based on the community-study data (Washington, D.C., area costs).

TABLE 48.- COMPARISON OF THE MIUS COSTS FOR 496 APARTMENTS AND 1000 APARTMENTS IN WASHINGTON, D.C.

(1974 dollars)

Item	496-apartment-MIUS costs		1000-apartment-MIUS costs	
	Capital	Annual O&M	Capital	Annual O&M
Electrical power	$ 368 100	$125 600	$ 697 000	$251 420
Water supply	223 300	4 440	446 600	8 880
Wastewater/fire-fighting	404 000	23 680	573 000	35 800
HVAC and hot water	220 000	7 050	441 000	16 020
Solid waste	101 000	11 660	161 000	21 290
Controls	134 400	16 760	134 400	16 760
MIUS housing	138 000	2 070	165 600	2 480
Miscellaneous	54 400	510	89 600	510
System operating crew	--	68 100	--	81 800
Totals	$1 643 200	$259 870	$2 708 200	$434 960

TABLE 49.- COMPARISON OF THE COST OF THE 1000-APARTMENT MIUS LOCATED IN WASHINGTON, D.C., TO THE COST OF CONVENTIONAL UTILITIES AND SERVICES

(1974 dollars)

Item	Washington, D.C., MIUS costs		Conventional utilities costs[a]	
	Capital	Annual O&M	Capital	Annual O&M
Electrical power	$ 697 000	$251 420	$1 424 000	$230 710
Boiler fuel	--	--	7 020	71 290
Water supply[b]	446 600	8 880	493 800	10 000
Wastewater	573 000	35 800	608 000	33 000
HVAC and hot water	441 000	16 020	406 500	15 360
Solid waste	161 000	21 290	150 800	41 260
Controls	134 400	16 760	--	--
MIUS housing	165 600	2 480	(c)	(c)
Miscellaneous costs	89 600	510	(d)	(d)
System operating crew	--	81 800	--	[e]24 400
Totals	$2 708 200	$434 960	$3 090 120	$426 020

[a] All equipment costs except the boiler fuel tank and HVAC have been based on the community-study conventional system. For capital, it was assumed that capacity would be purchased on the basis of peak requirements. All community-study 1973 costs were adjusted to reflect 1974 costs. A special adjustment was made for the fuel requirements of the solid-waste system. Fuel costs for the central powerplant are at 80 percent of the fuel costs for the MIUS.

[b] Conventional water supply system costs based on the community-study data.

[c] The HVAC mechanical-room costs have not been evaluated.

[d] Tools, pneumatic system, and spare-parts-inventory requirements have not been evaluated.

[e] HVAC.

TABLE 50.- COST COMPARISON OF THE WASHINGTON, D.C., 1000-APARTMENT MIUS AND THE CONVENTIONAL UTILITIES

(1974 dollars)

Item	Conventional utilities costs[a]	MIUS cost
Total capital outlay	$ 3 090 100	$ 2 708 200
Total fuel and lube cost (20 yr)	5 345 000	4 288 000
Other O&M costs (20 yr)	3 069 000	4 411 000
Total outlay (20 yr)	$11 504 100	$11 407 200
Escalated and discounted outlay[b] (20-yr totals)	$ 6 613 000	$ 6 278 000
Escalated and discounted outlay[c] (20-yr totals)	$ 6 791 000	$ 6 534 000
Escalated and discounted outlay[d] (20-yr totals)	$ 7 903 000	$ 7 426 000

[a] Fuel cost for central powerplant at 80 percent of the cost for MIUS fuel.

[b] Fuel escalated at 5 percent/yr; all other costs at 3 percent/yr; discounted at 15 per/yr to mid-1974.

[c] All costs escalated at 5 percent/yr; discounted at 15 percent/yr to mid-1974.

[d] Fuel escalated at 10 percent/yr; all other costs at 5 percent/yr; discounted at 15 percent/yr to mid-1974.

TABLE 51.- REGIONAL LOAD VARIATIONS FOR THE BASELINE MIUS

MIUS location	Electricity, GJ (kWh)	Powerplant fuel, GJ (Btu)	Incinerator fuel, GJ (Btu)
Washington, D.C.	19 612.8 (5.44×10^{6})	62 334.2 (59.121×10^{9})	1794.5 (1.702×10^{9})
Minneapolis, Minn.	19 728.0 (5.480)	63 573.1 (60.296)	1794.5 (1.702)
Houston, Tex.	20 991.6 (5.831)	66 272.2 (62.856)	1794.5 (1.702)
Las Vegas, Nev.	20 239.2 (5.622)	64 025.4 (60.725)	1794.5 (1.702)

TABLE 52.- BASELINE MIUS COST VARIATIONS WITH LOCATION

(Mid-1974 dollars)

MIUS location	System initial cost	Annual fuel and lube cost	Annual labor cost	Other operating costs	Annual maintenance cost	Total annual O&M cost
Washington, D.C.	$1 643 200	$110 400	$68 100	$8400	$73 000	$259 900
Minneapolis, Minn.	1 704 000	126 200	71 600	8700	75 700	282 200
Houston, Tex.	1 553 000	109 100	59 800	7900	69 000	245 800
Las Vegas, Nev.	1 790 000	127 200	73 700	9100	79 500	289 500

TABLE 53 - EFFECT OF CONTROLLING INDOOR TEMPERATURE FROM 296 5 K (74° F) to 298 7 K (78° F) DURING COOLING PERIODS AND TO 293.2 K (68° F) DURING HEATING PERIODS ON THE SEASONAL ENERGY REQUIREMENTS

Controlled indoor temperature, K (°F)	Seasonal energy requirements, GJ (Btu)				
	Winter	Spring	Summer	Fall	Annual
			Conventional		
296.5 (74)	22 057.0 (20.920x10^9)	21 315.8 (20.217x10^9)	24 450.4 (23.190x10^9)	21 259.9 (20.164x10^9)	89 083.1 (84 491x10^9)
293.2 (68)	21 103.9 (20.016)	21 762.8 (20.641)	25 487.9 (24.174)	21 786.0 (20 663)	--
298.7 (78)	22 906.8 (21.726)	21 156.6 (20.066)	23 474.0 (22.264)	21 030 1 (19 946)	--
Best, 293.2/298.7 (68/78)	21 103.9 (20.016)	21 156 6 (20.066)	23 474.0 (22.264)	21 030.1 (19 946)	86 764.6 (82 292)
			MIUS		
296.5 (74)	15 093.0 (14.315x10^9)	15 185.8 (14.403x10^9)	17 329.3 (16.436x10^9)	15 061.4 (14 285x10^9)	62 668.5 (59.438x10^9)
293.2 (68)	14 907.5 (14.139)	15 350.3 (14.559)	18 089.5 (17 157)	15 320 8 (14.531)	--
298 7 (78)	15 321 8 (14 532)	15 160.5 (14.379)	16 582.8 (15.728)	15 007.6 (14.234)	--
Best, 293.2/298.7 (68/78)	14 907 5 (14.139)	15 160.5 (14.379)	16 582.8 (15.728)	15 007 6 (14.234)	61 658 4 (58.480)

TABLE 54.- SOLAR COLLECTOR HEAT GAINS

AS A FUNCTION OF SURFACE TILT

Building type	Collector area, m^2 (ft^2)	Collector portion of roof area, percent
40° tilt, 50-percent efficiency, December (8205.3 kJ/m^2 (723 Btu/ft^2))		
1	237.6 (2558)	25
2	175.9 (1893)	28
3	156.0 (1679)	29
4	688.8 (7199)	88
60° tilt, 50-percent efficiency, December (9635.2 kJ/m^2 (849 Btu/ft^2))		
1	202.3 (2178)	22
2	149.8 (1612)	24
3	134.2 (1445)	24
4	569.5 (6130)	75

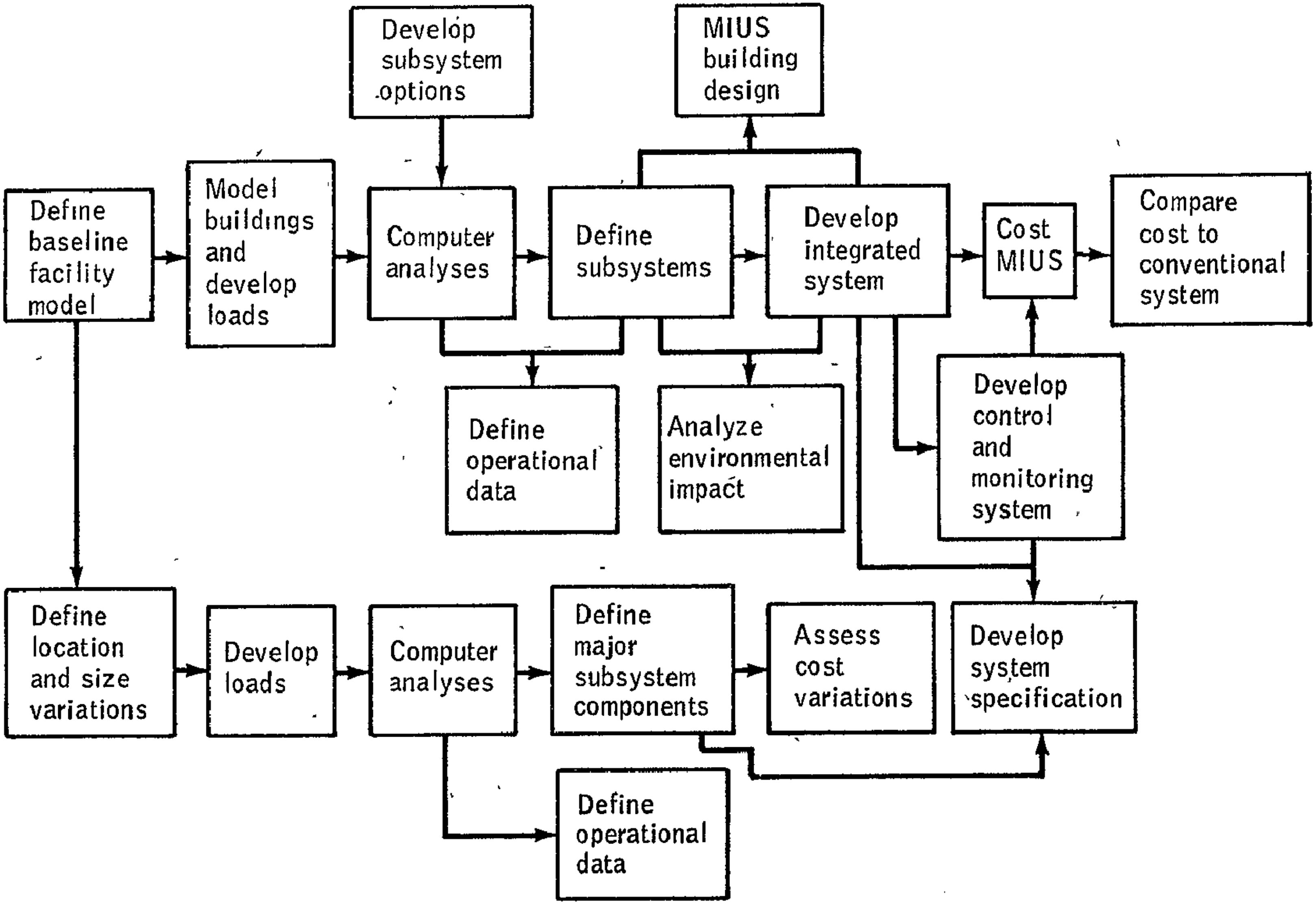


Figure 1.- Preliminary design study logic.

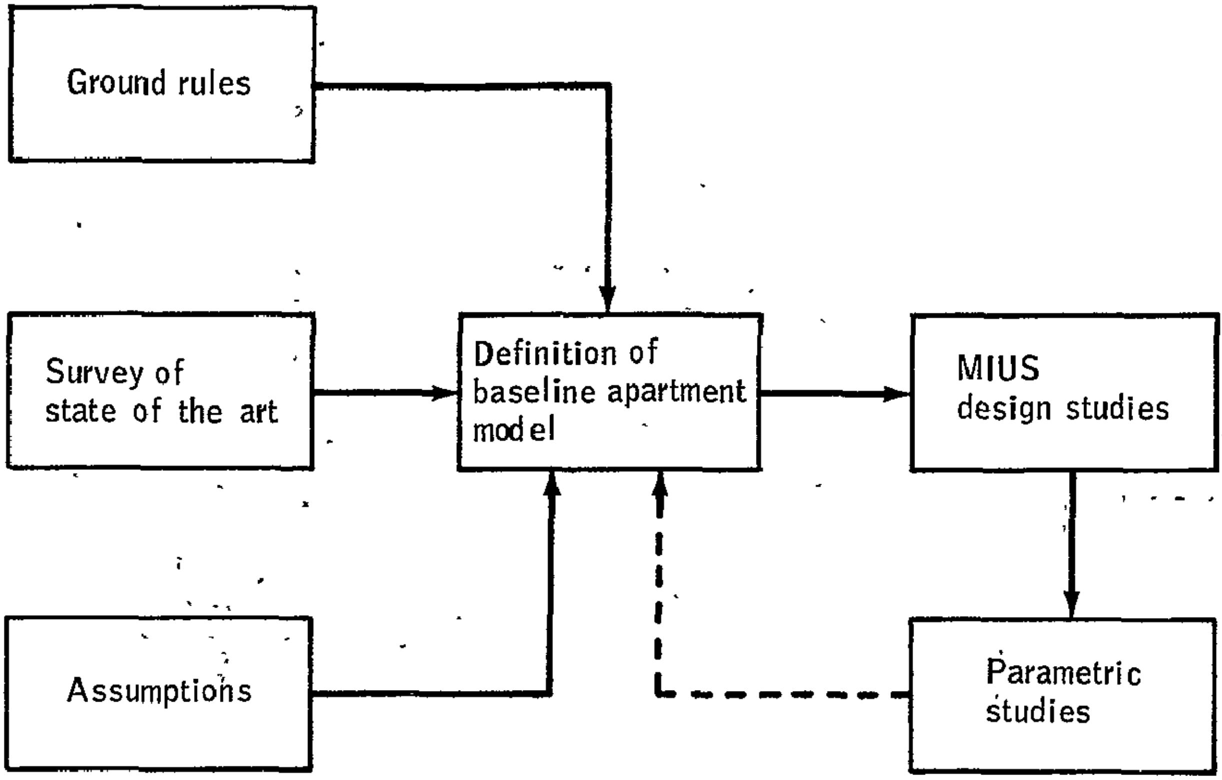


Figure 2.- Task logic for baseline apartment model definition.

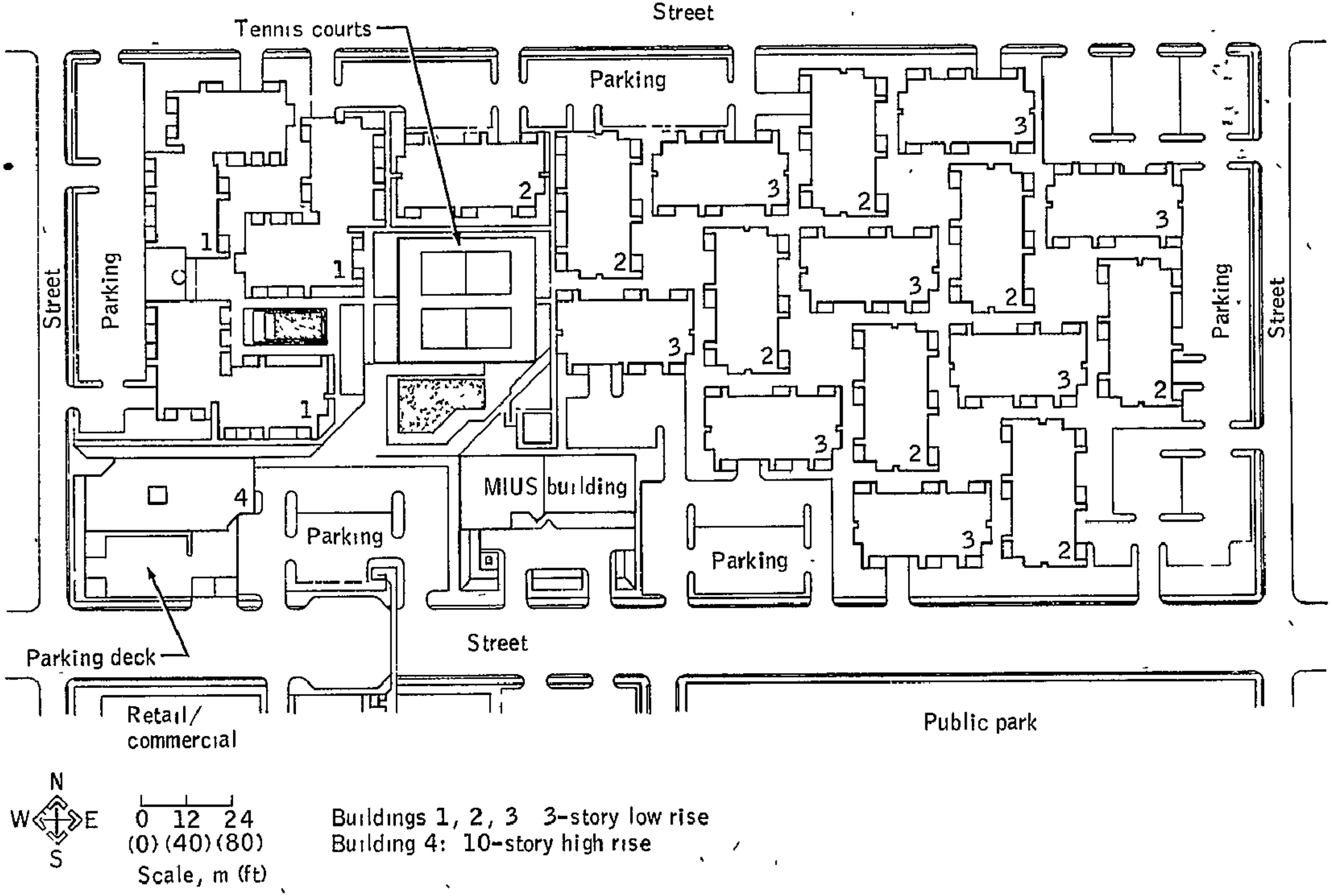
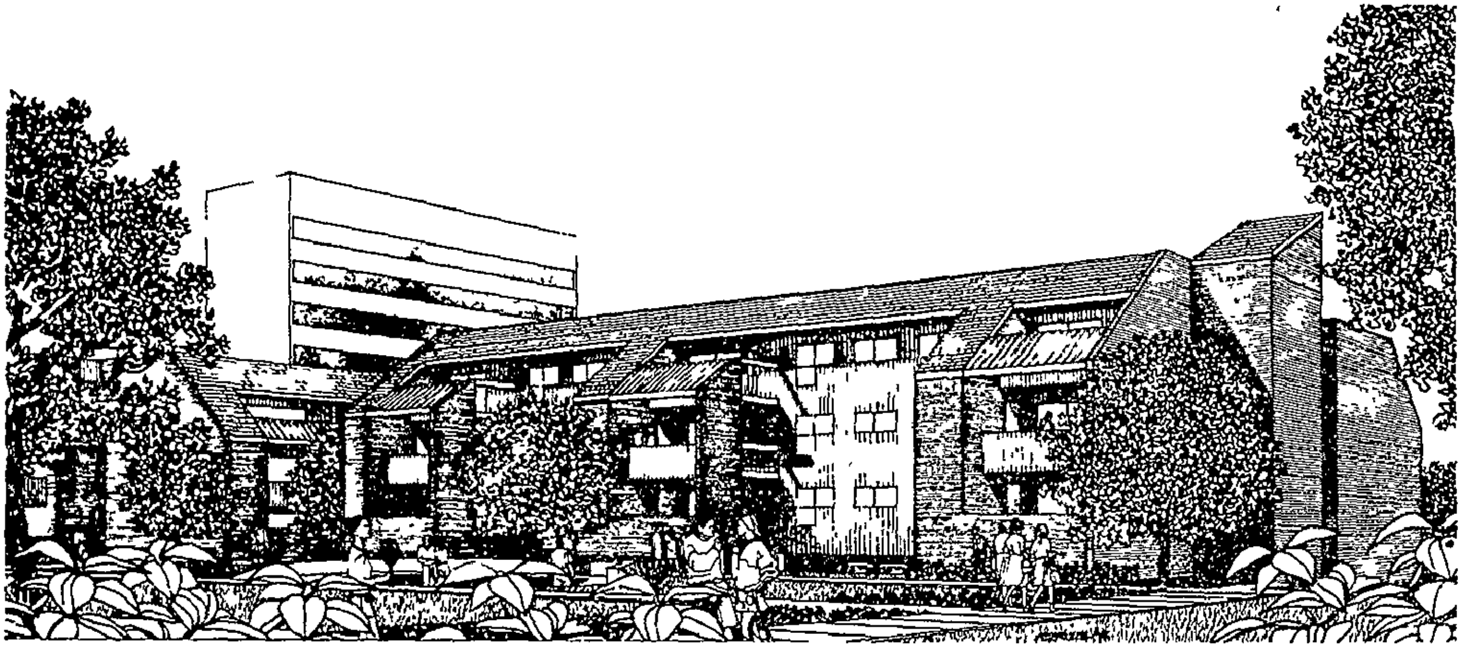
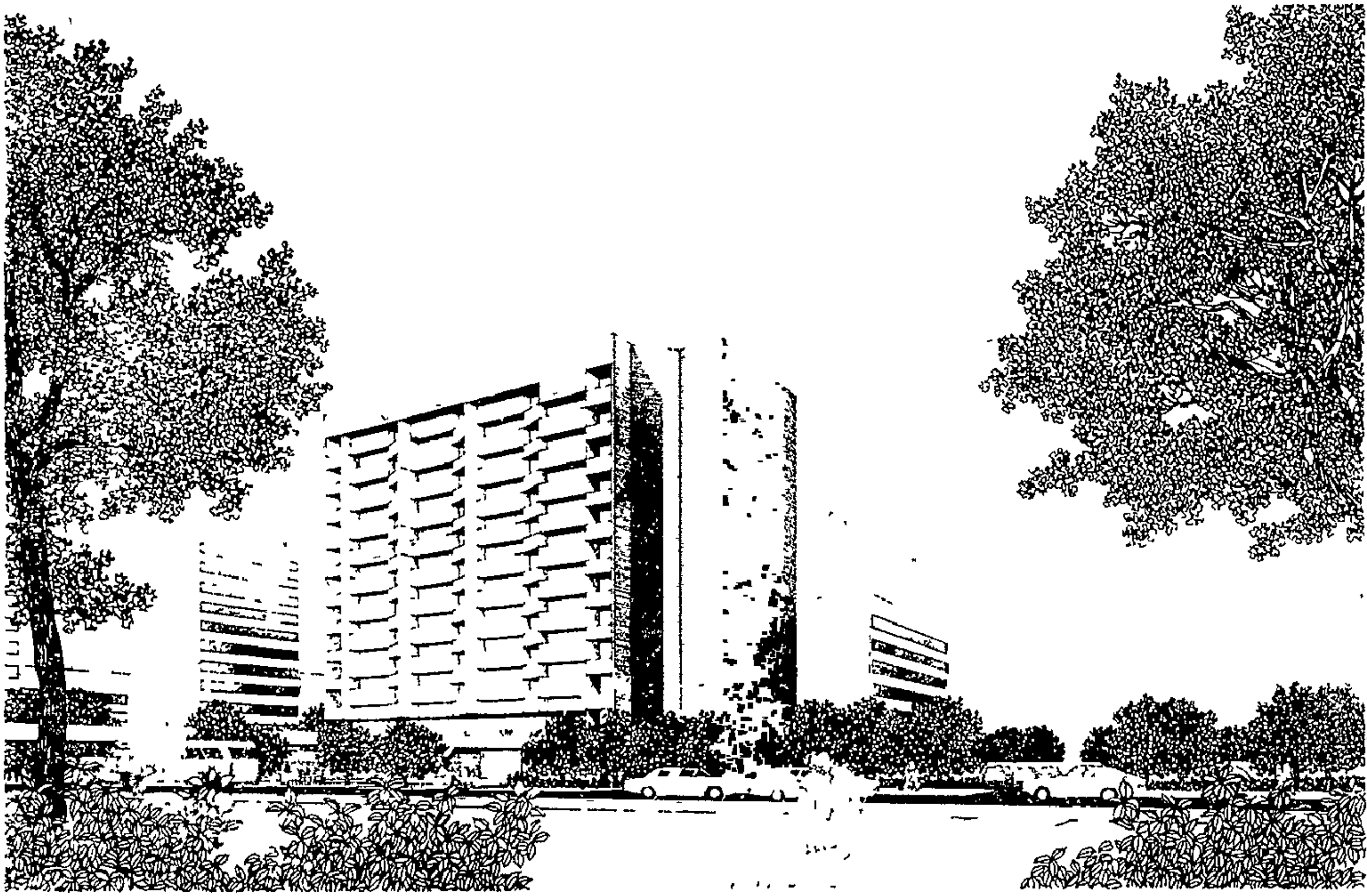


Figure 3.- Site plan.



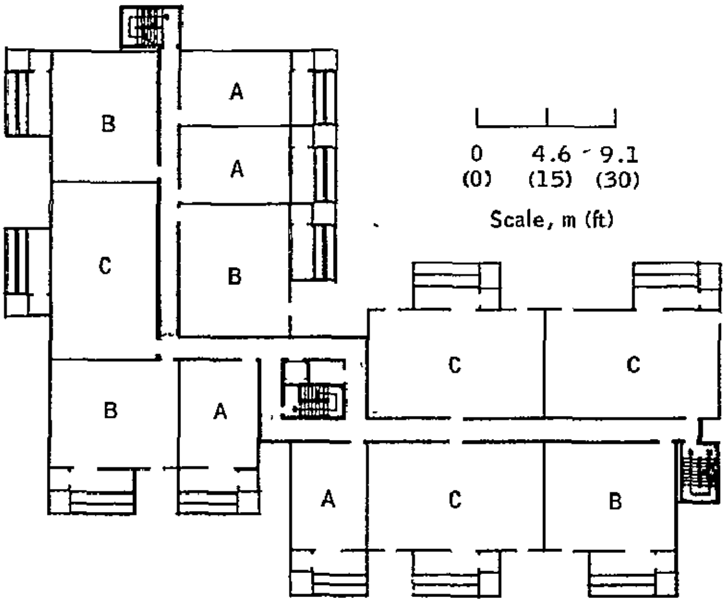
(a) Low-rise.

Figure 4.- Illustration of apartment-complex buildings.



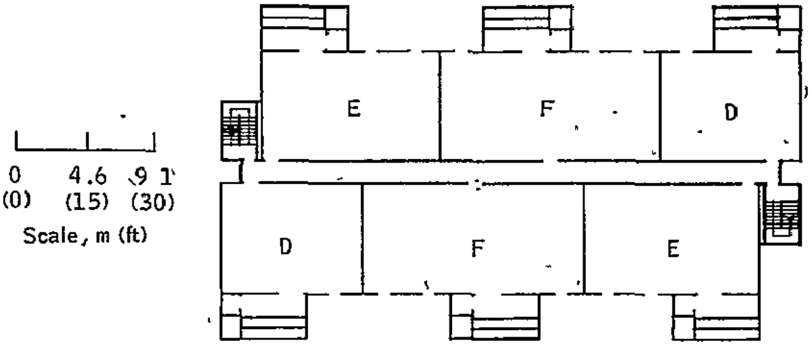
(b) High-rise.

Figure 4.- Concluded.

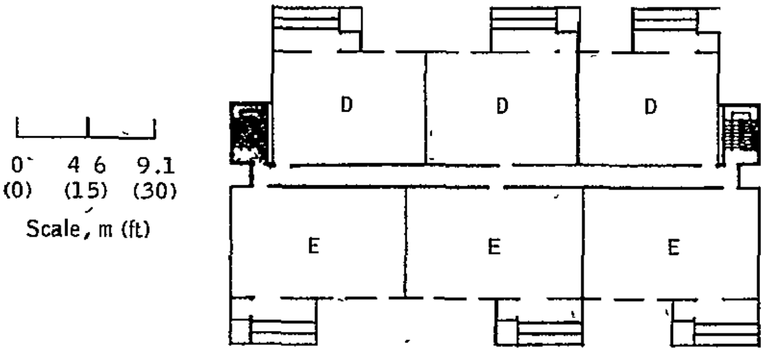


(a) Floor plan: building type 1.

Figure 5.- Floor plans and cross sections of apartment-complex buildings.

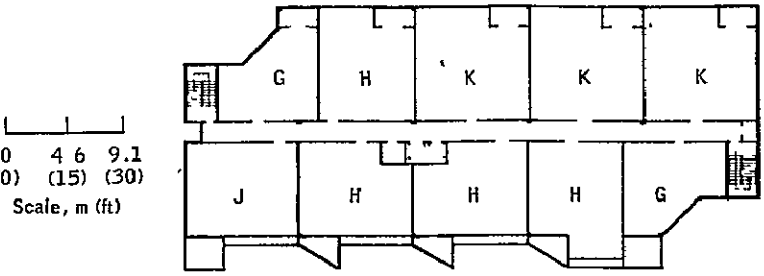


(b) Floor plan: building type 2.

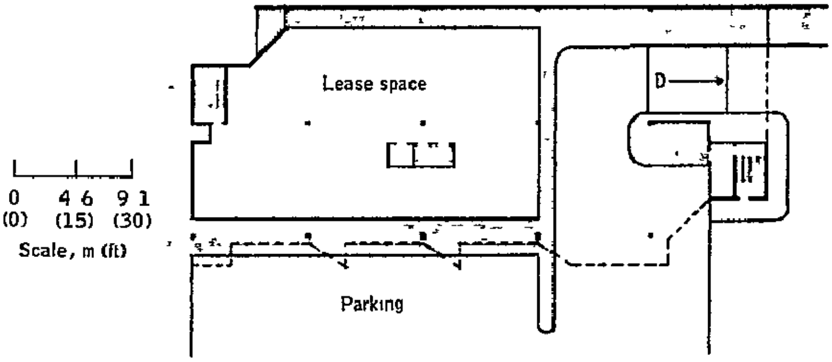


(c) Floor plan: building type 3.

Figure 5.- Continued.

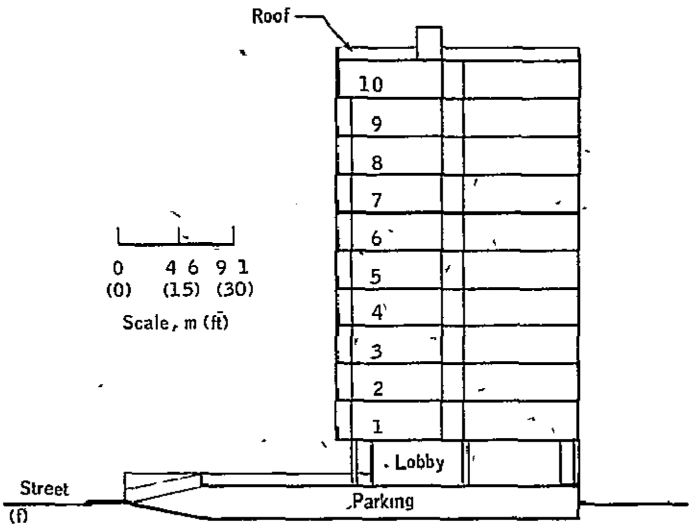


(d) Typical floor plan: building type 4.



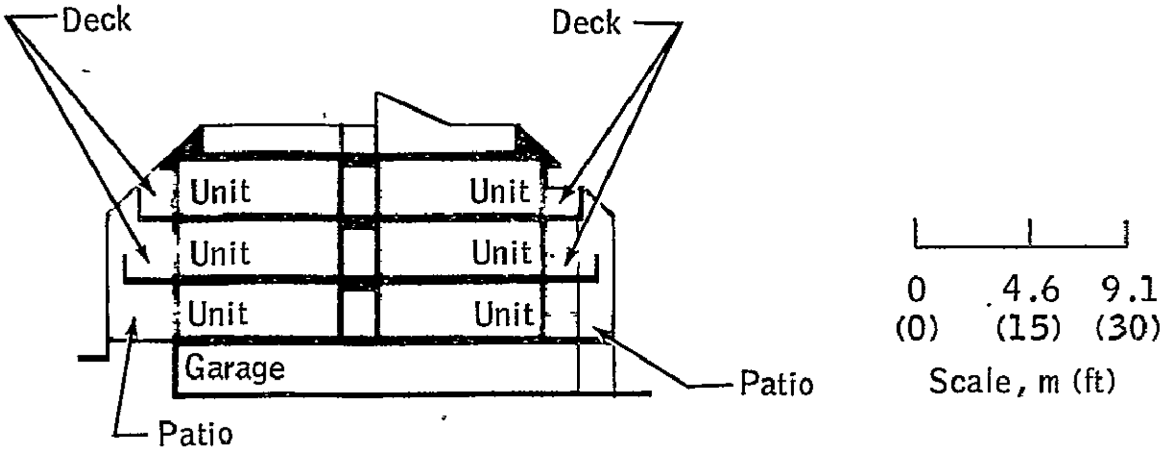
(e) Lobby floor plan: building type 4.

Figure 5.- Continued.

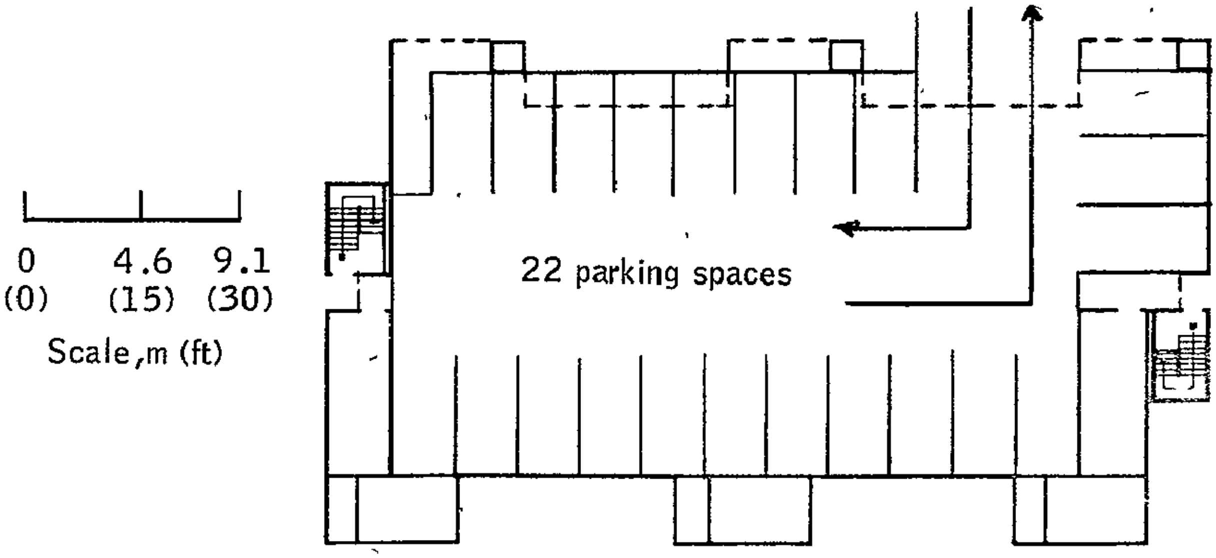


(f) Section through building 4.

Figure 5.- Continued.

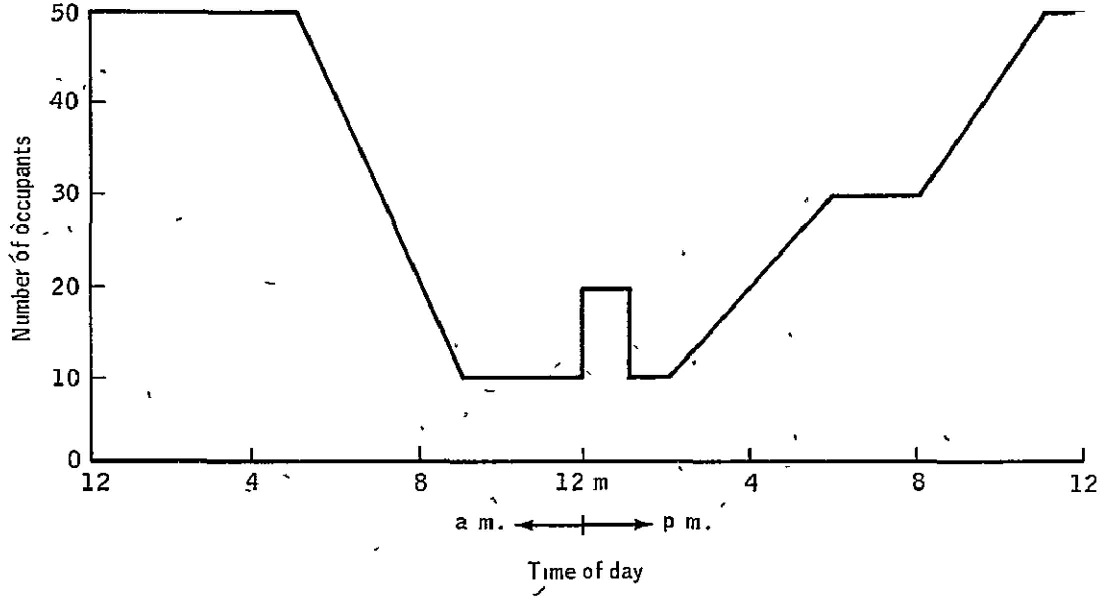


(g) Building 4 cross section with garage.

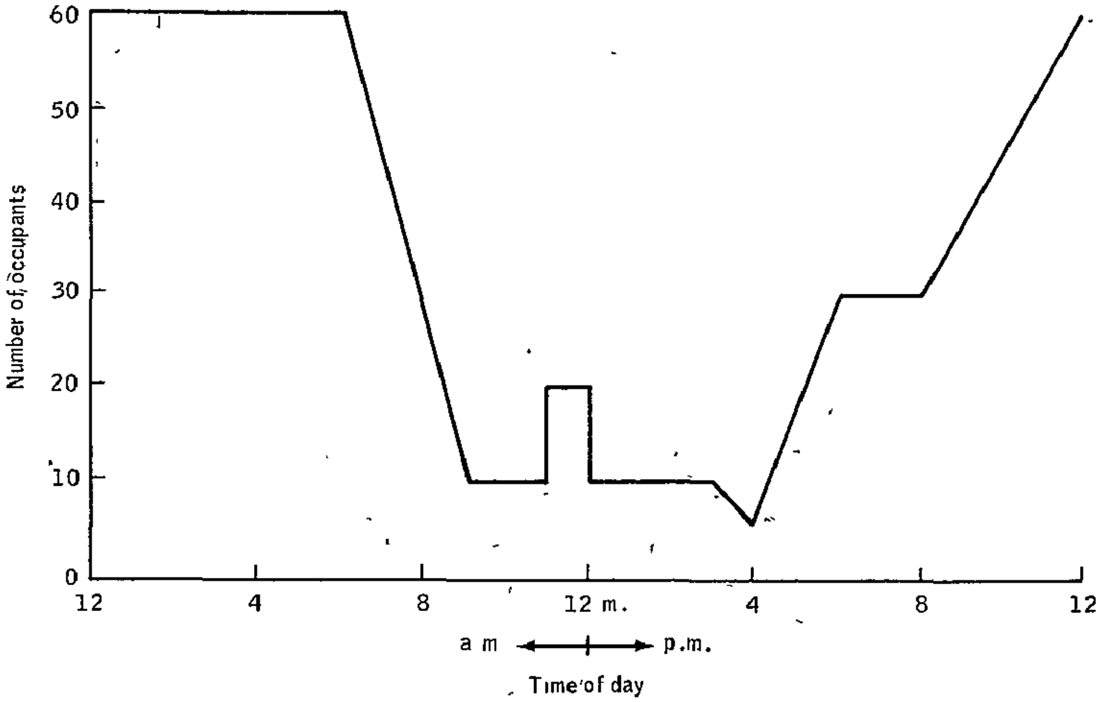


(h) Building 4 garage plan.

Figure 5.- Concluded.

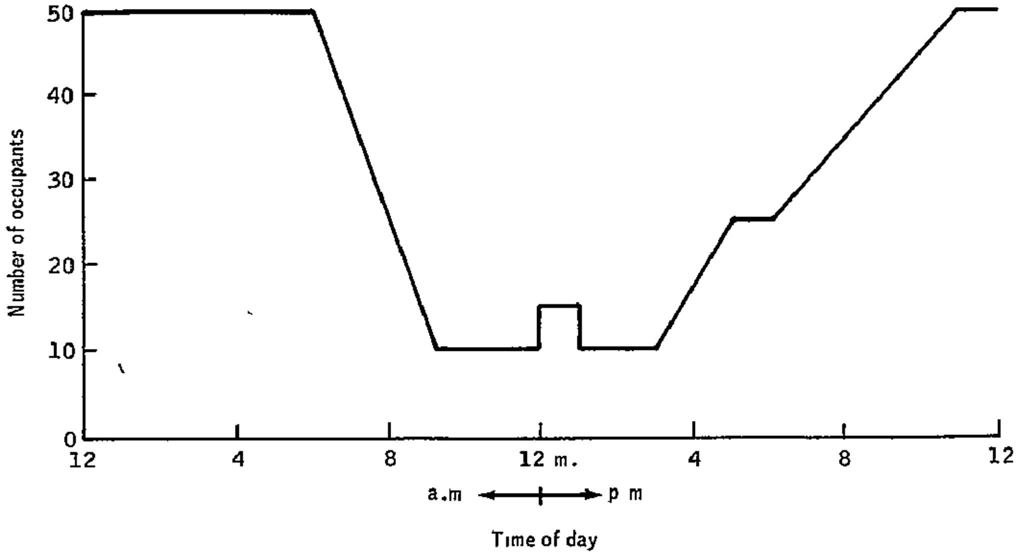


(a) Building type 1.

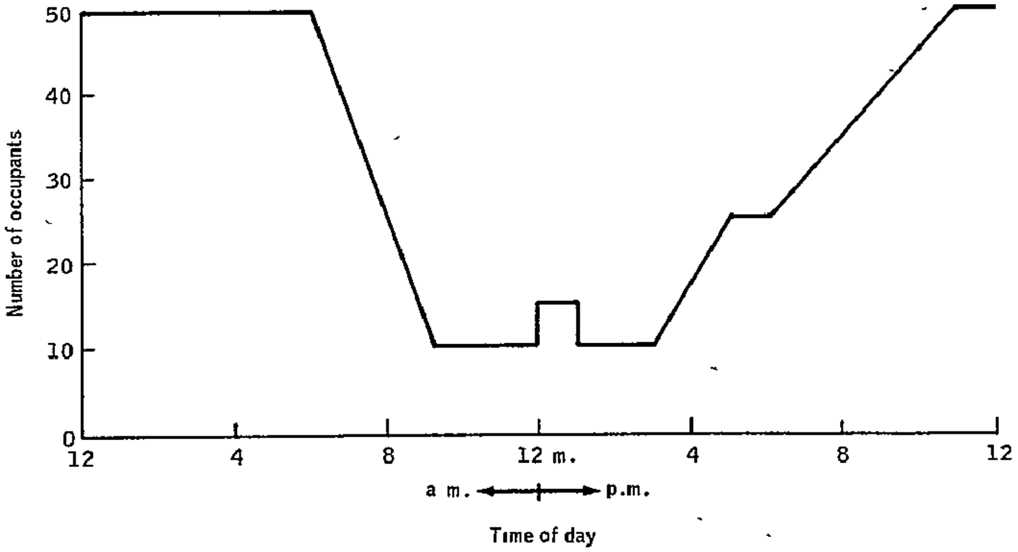


(b) Building type 2.

Figure 6.- Estimated occupancy profile.



(c) Building type 3.



(d) Building type 4.

Figure 6.- Concluded.

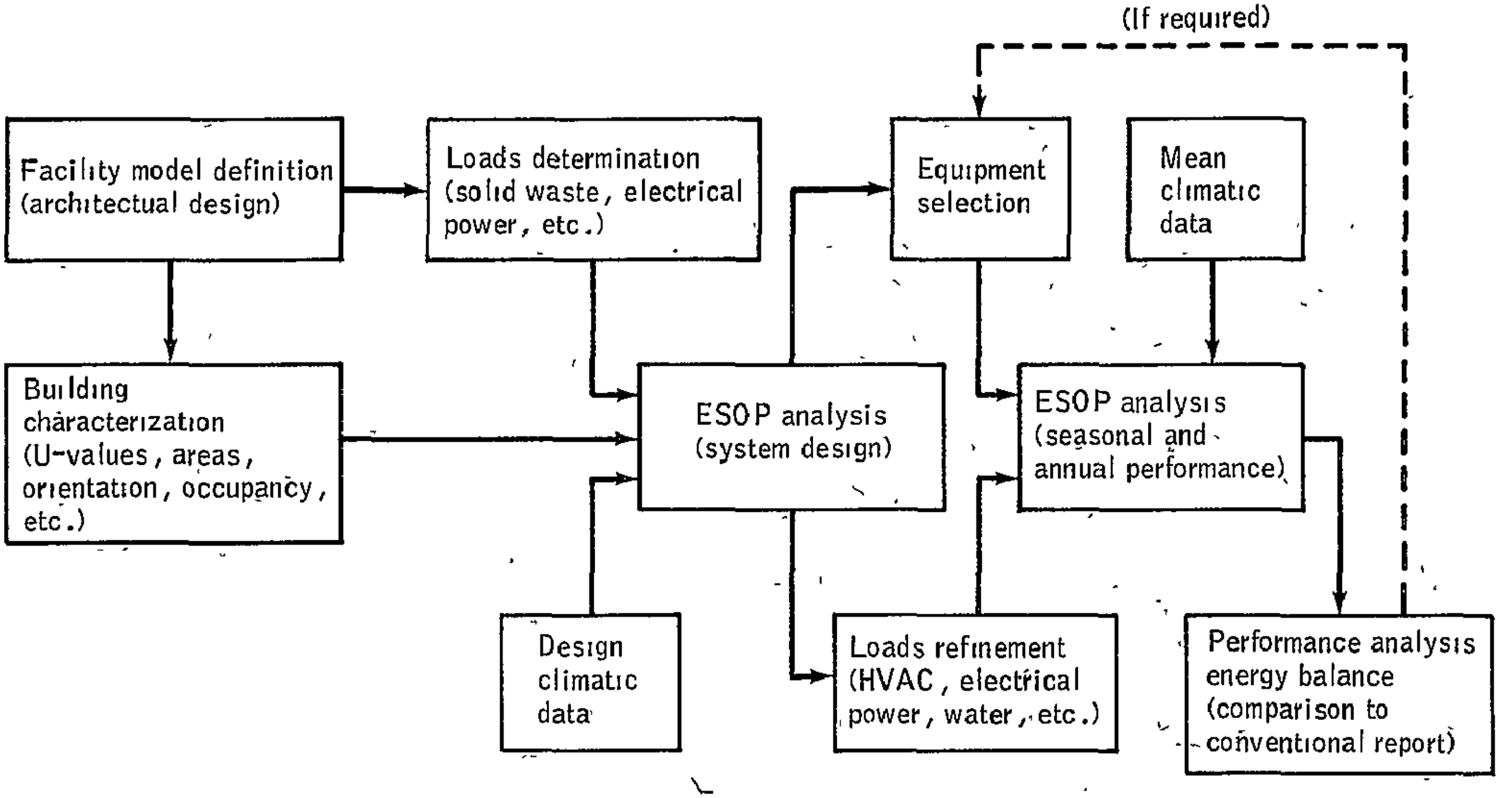


Figure 7.- Design procedure.

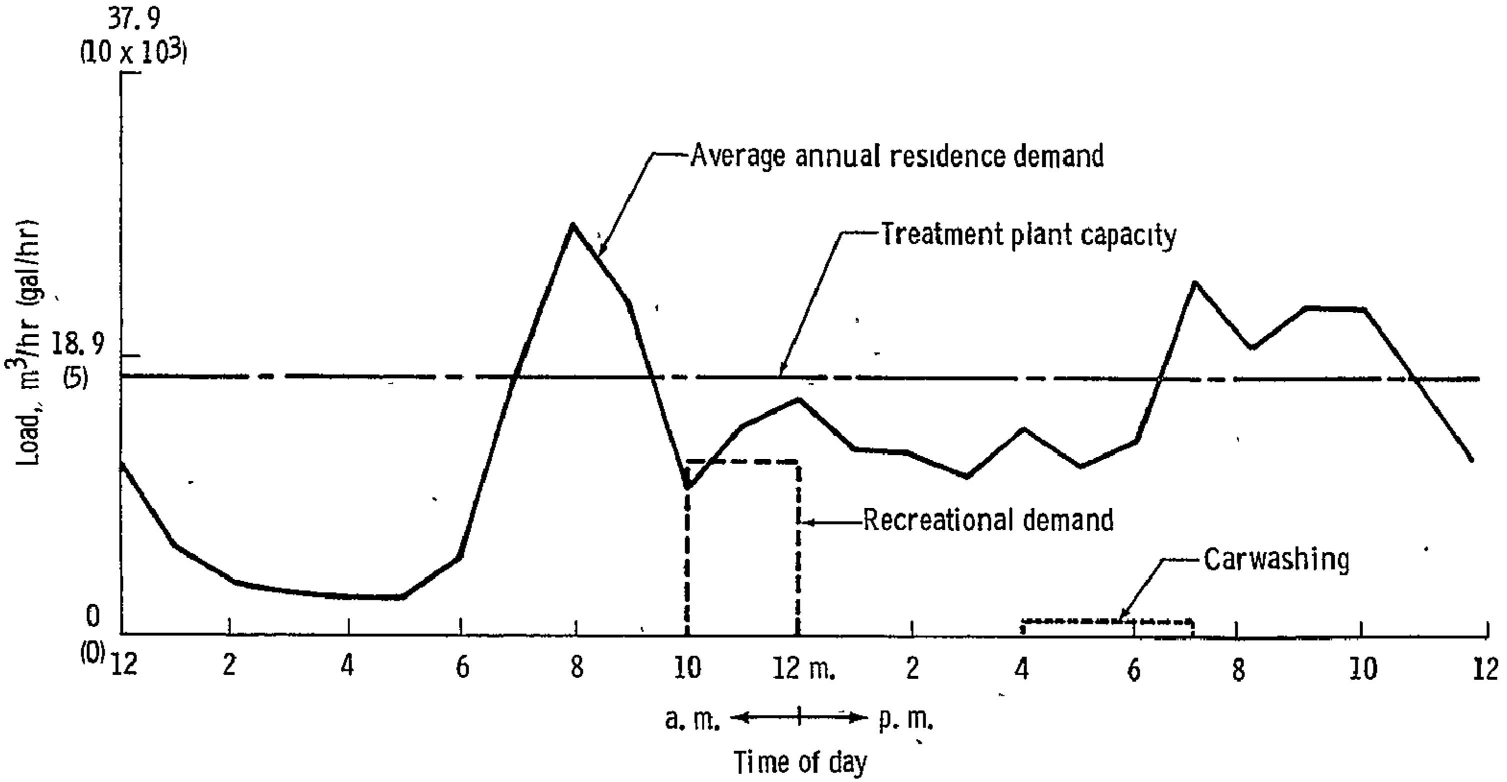


Figure 8.- Load profiles, potable-water subsystem.

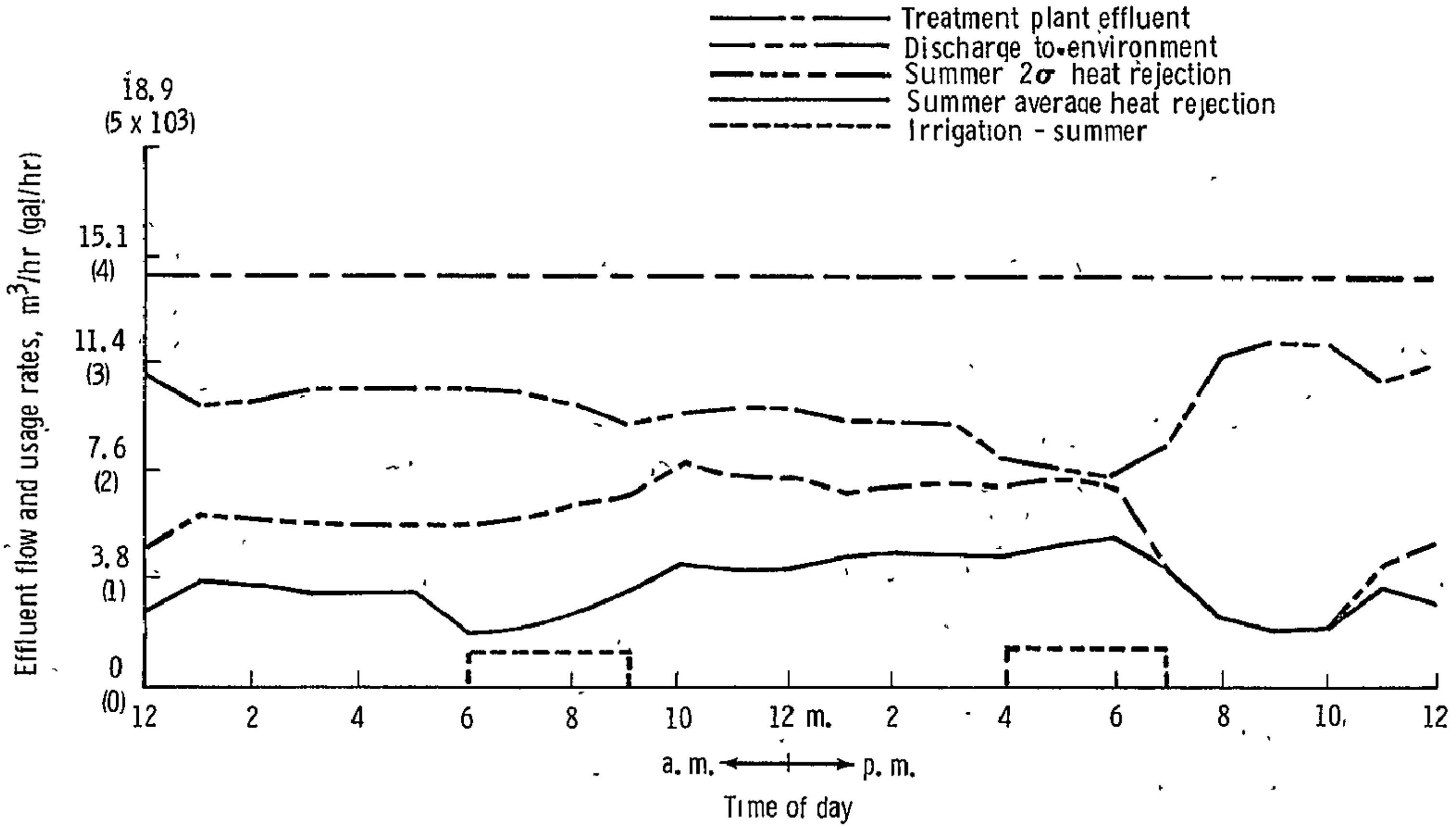


Figure 9.- Wastewater treatment plant effluent and summer usage profiles.

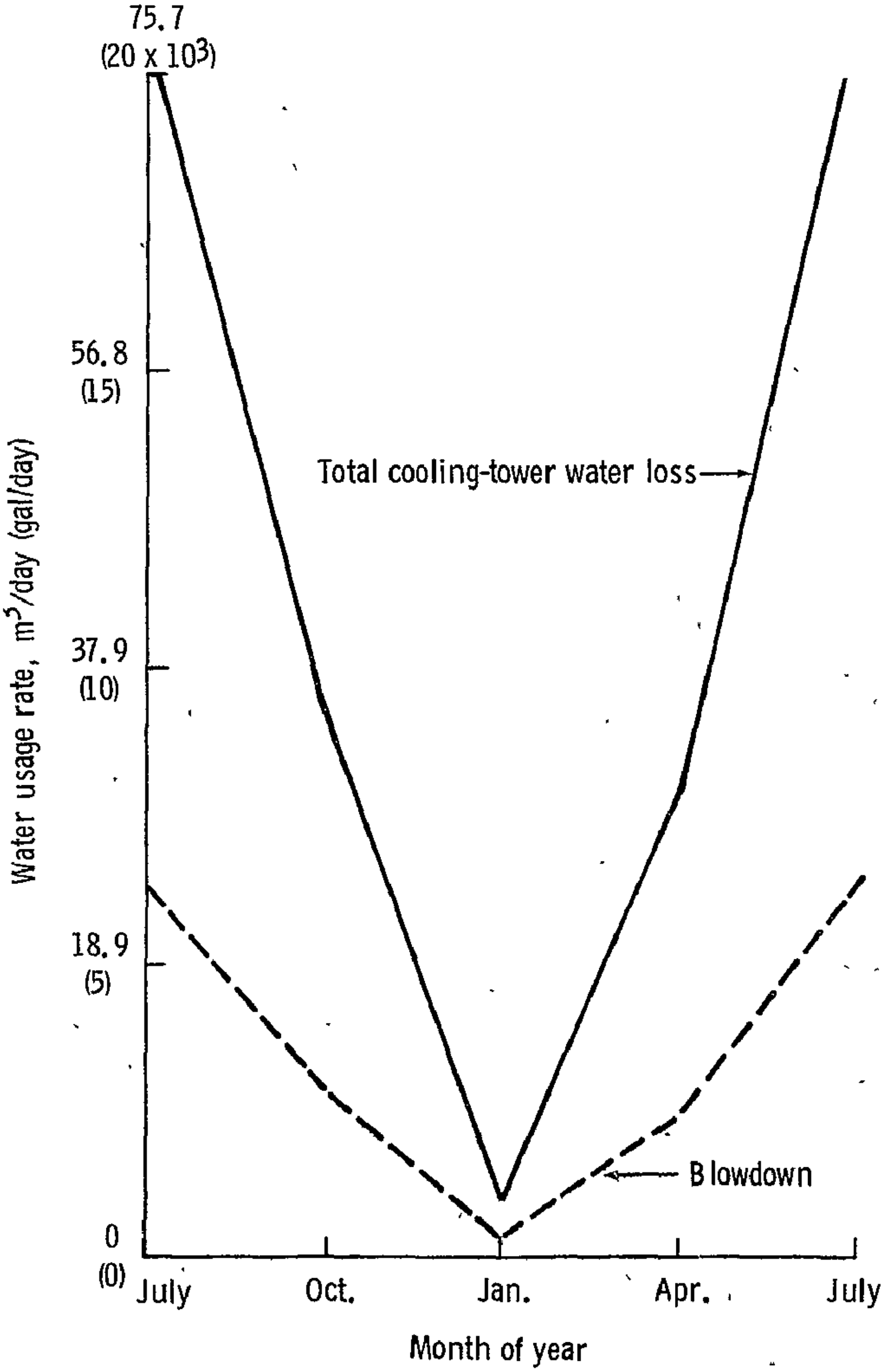


Figure 10.- Heat-rejection-system water requirements.

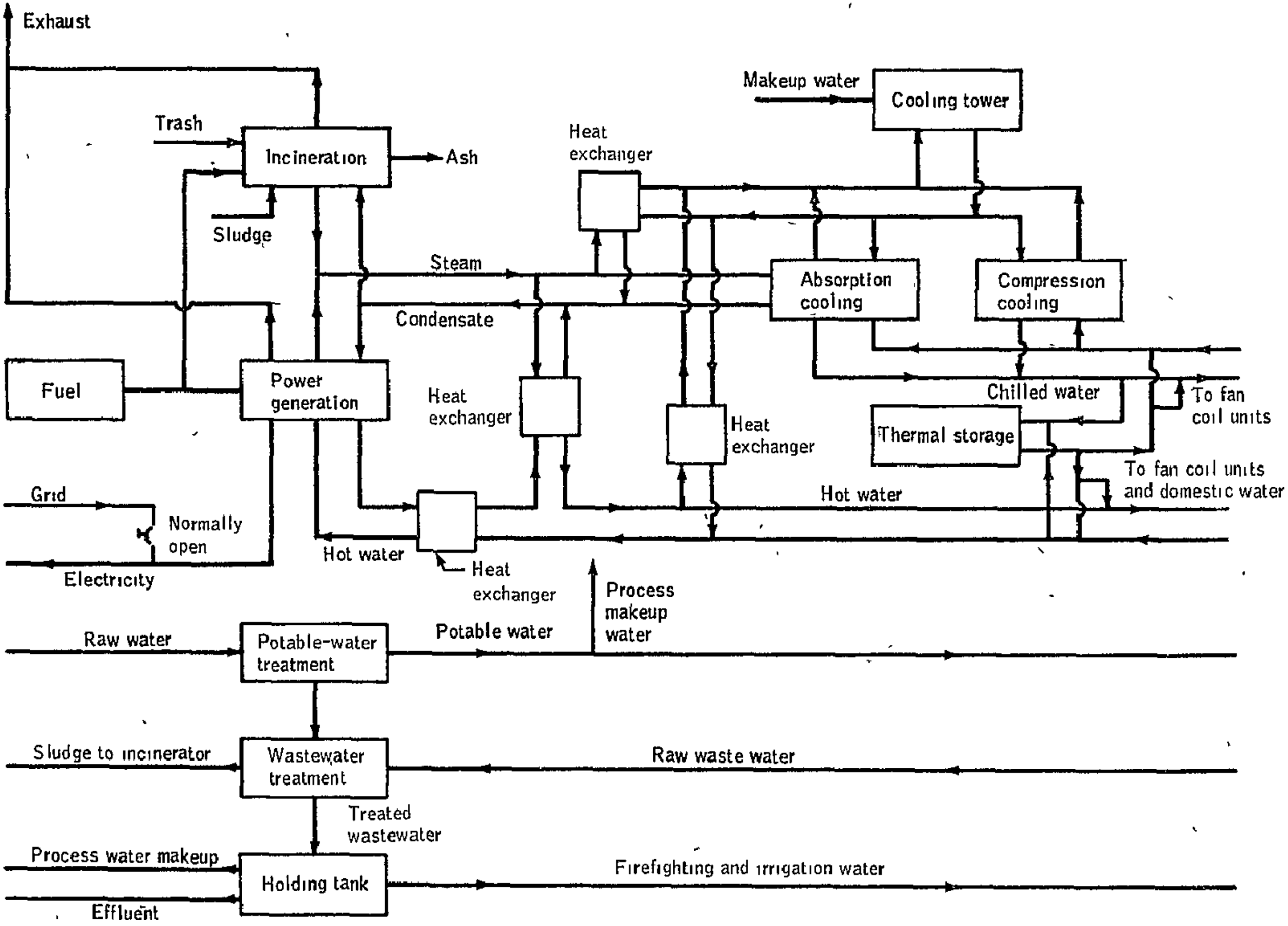


Figure 11.- Baseline MIUS overview.

C-3

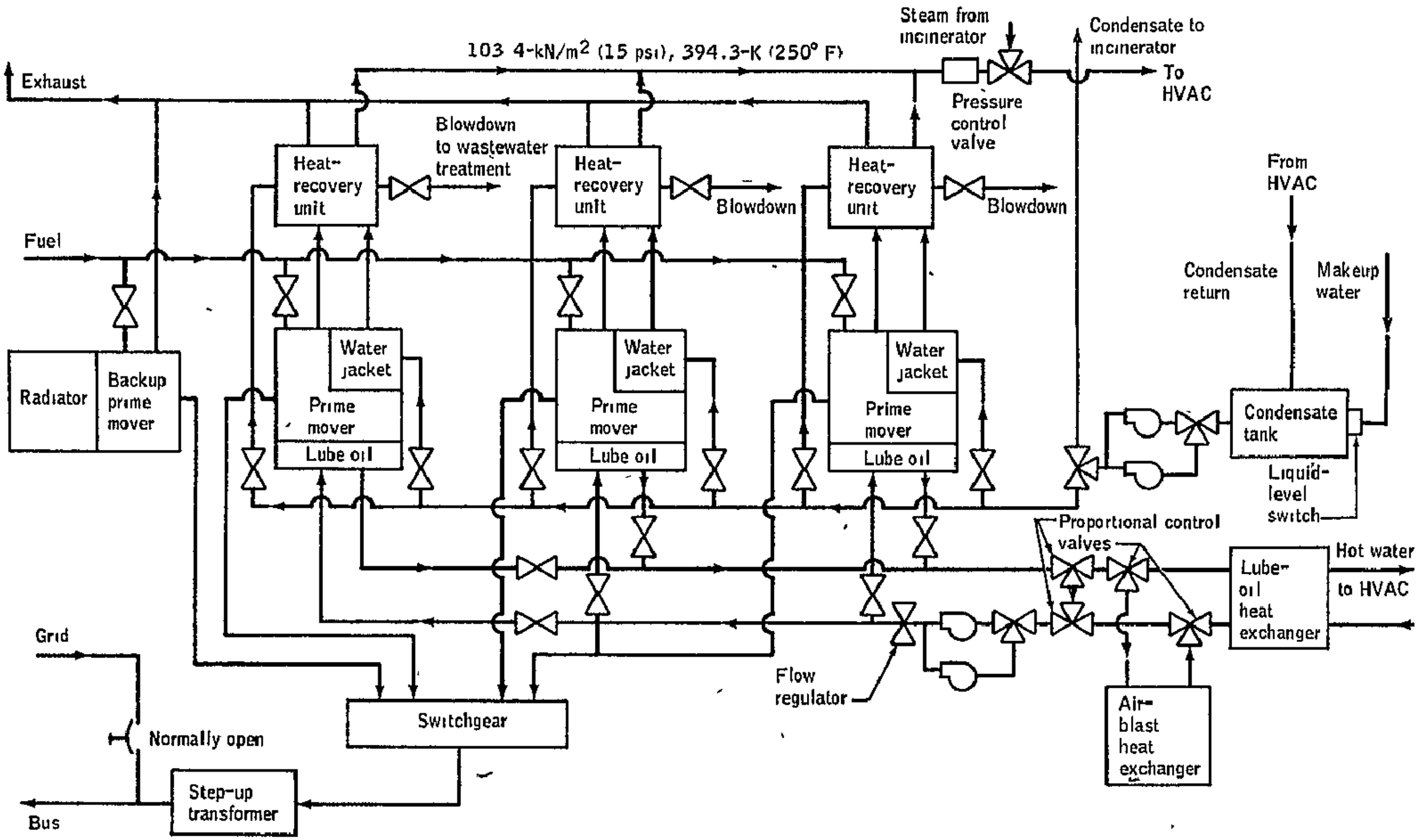


Figure 12.- Electrical power subsystem.

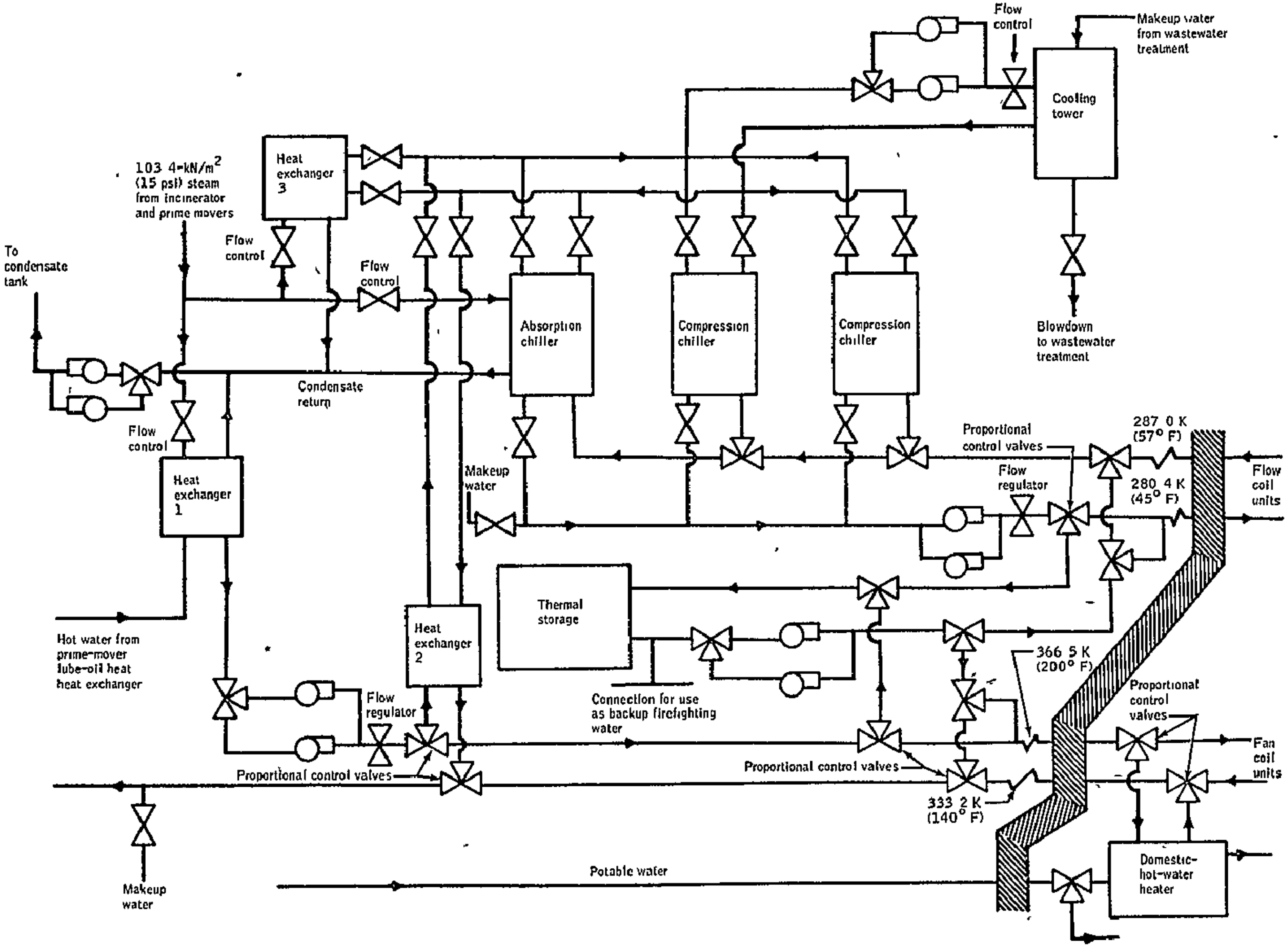


Figure 13.- HVAC subsystem.

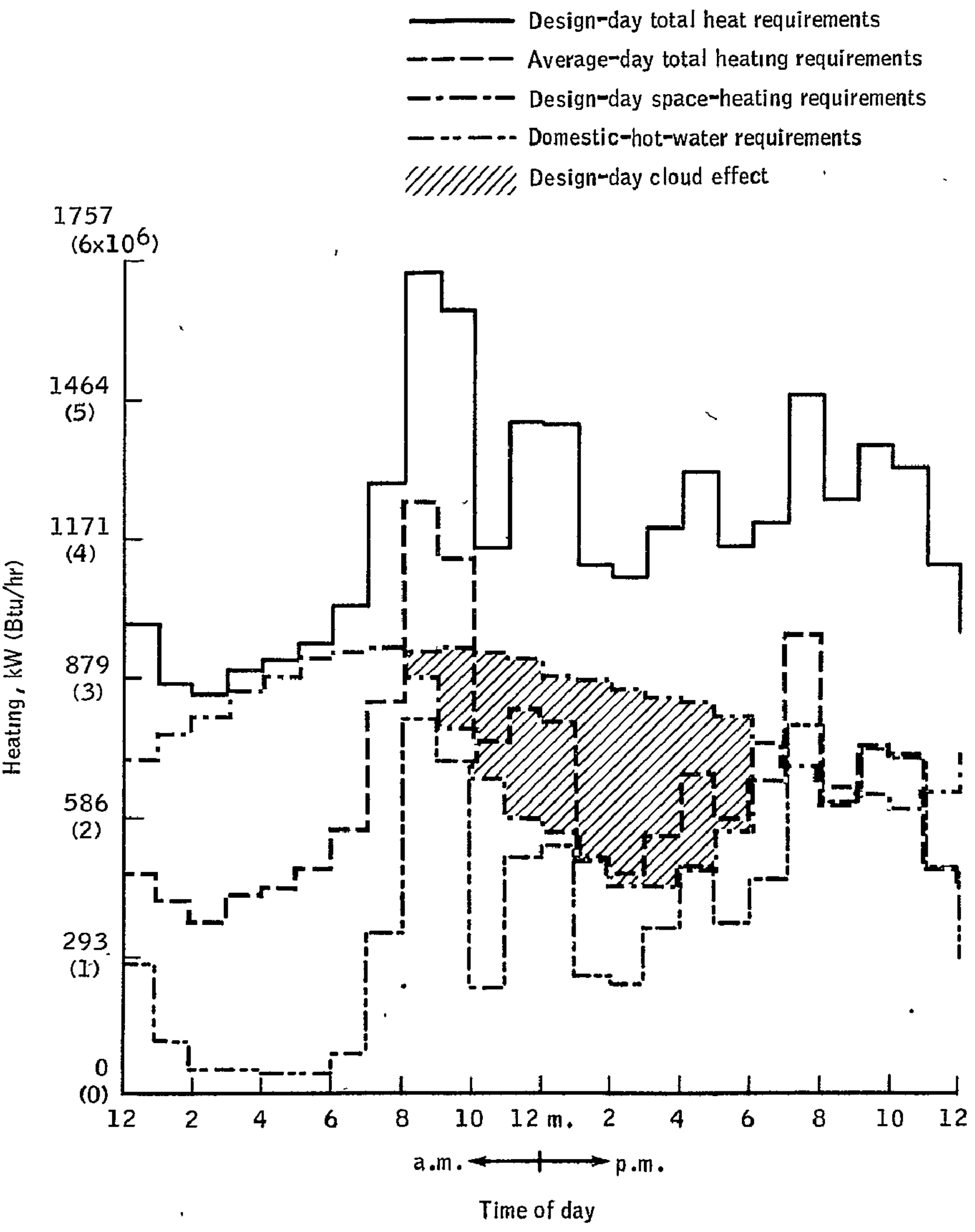


Figure 14.- Winter-heating-requirement components.

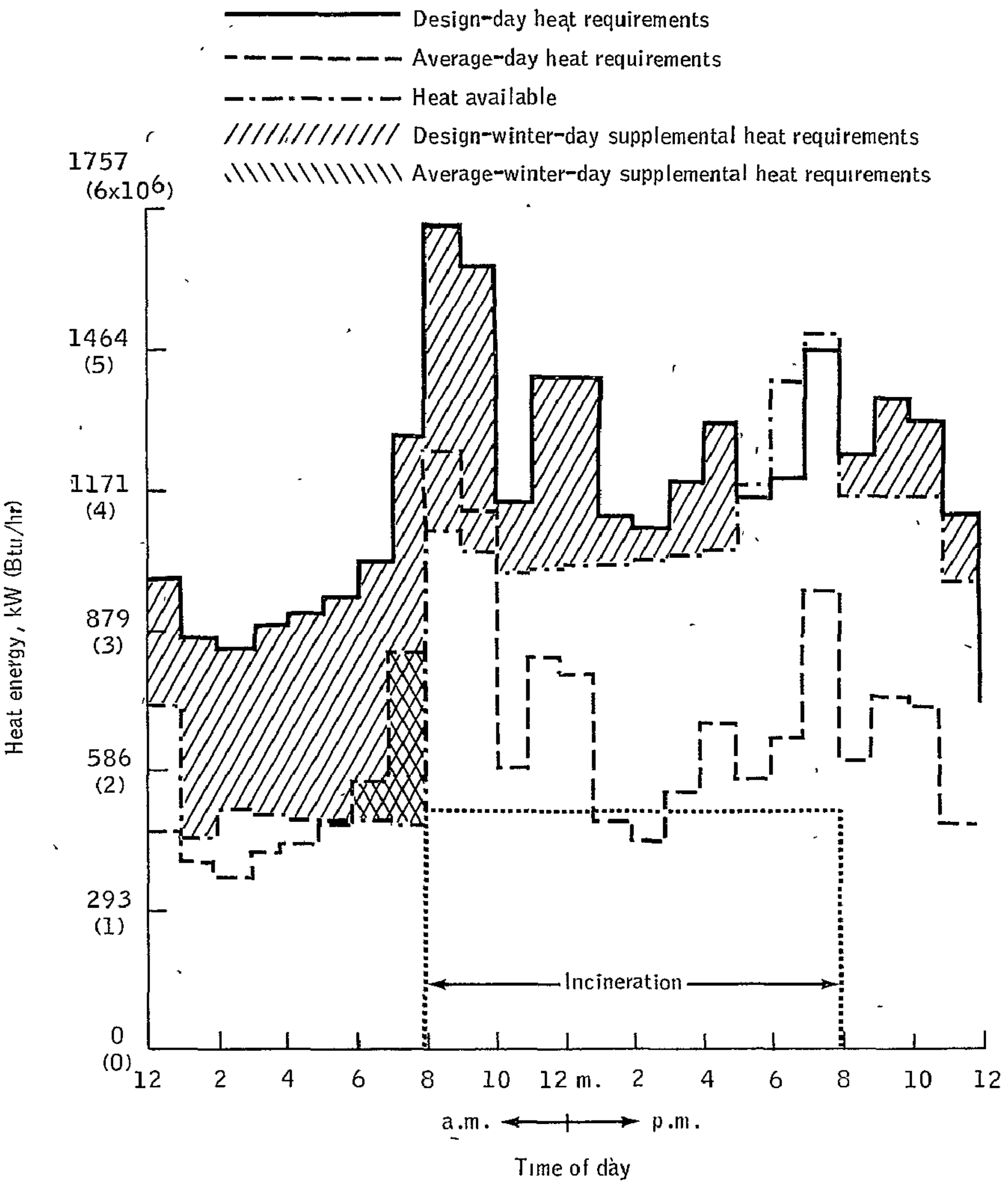


Figure 15.- Winter-heating storage requirements.

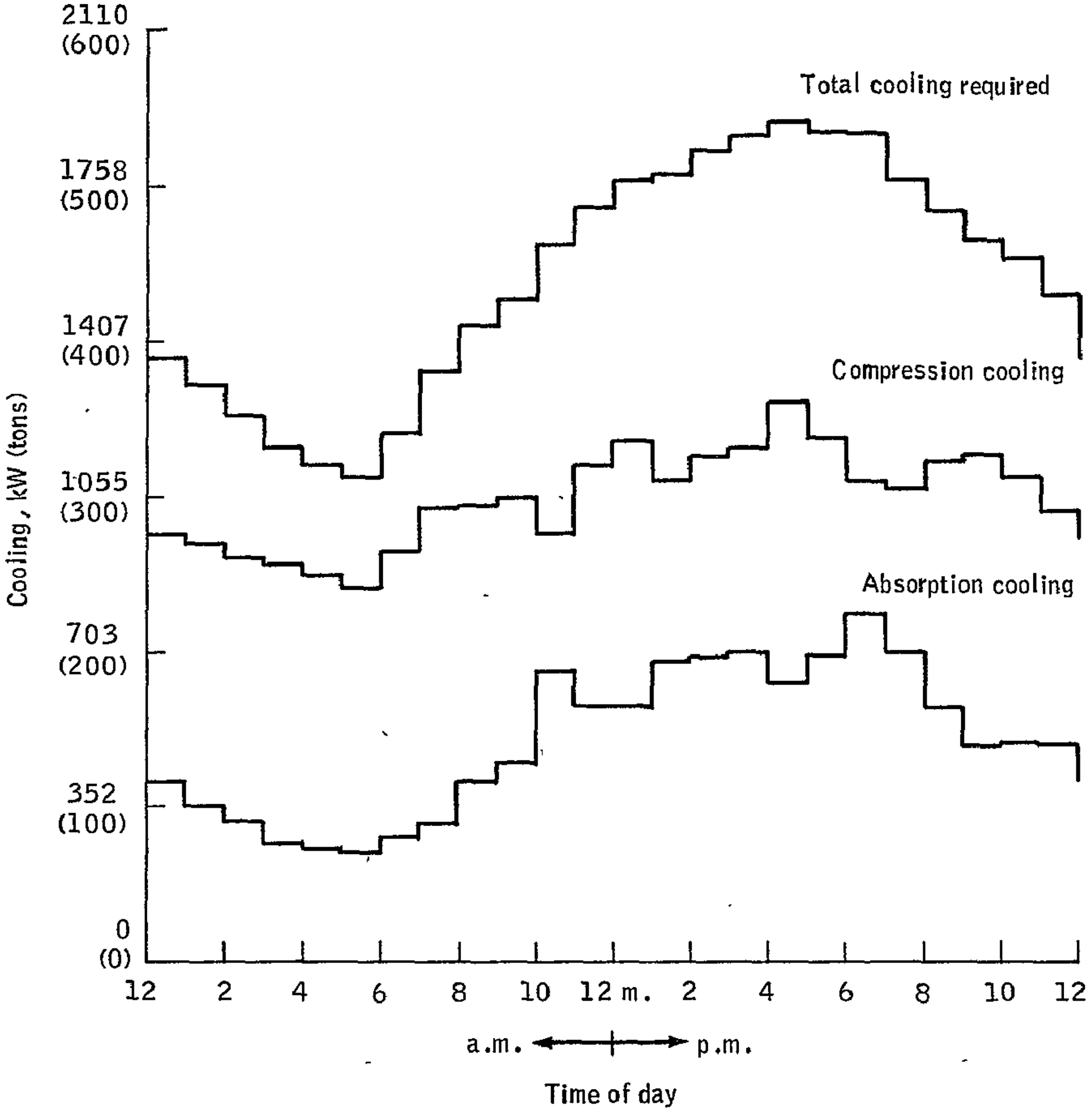


Figure 16.- Design-summer-day total cooling load and absorption/compression splits without storage.

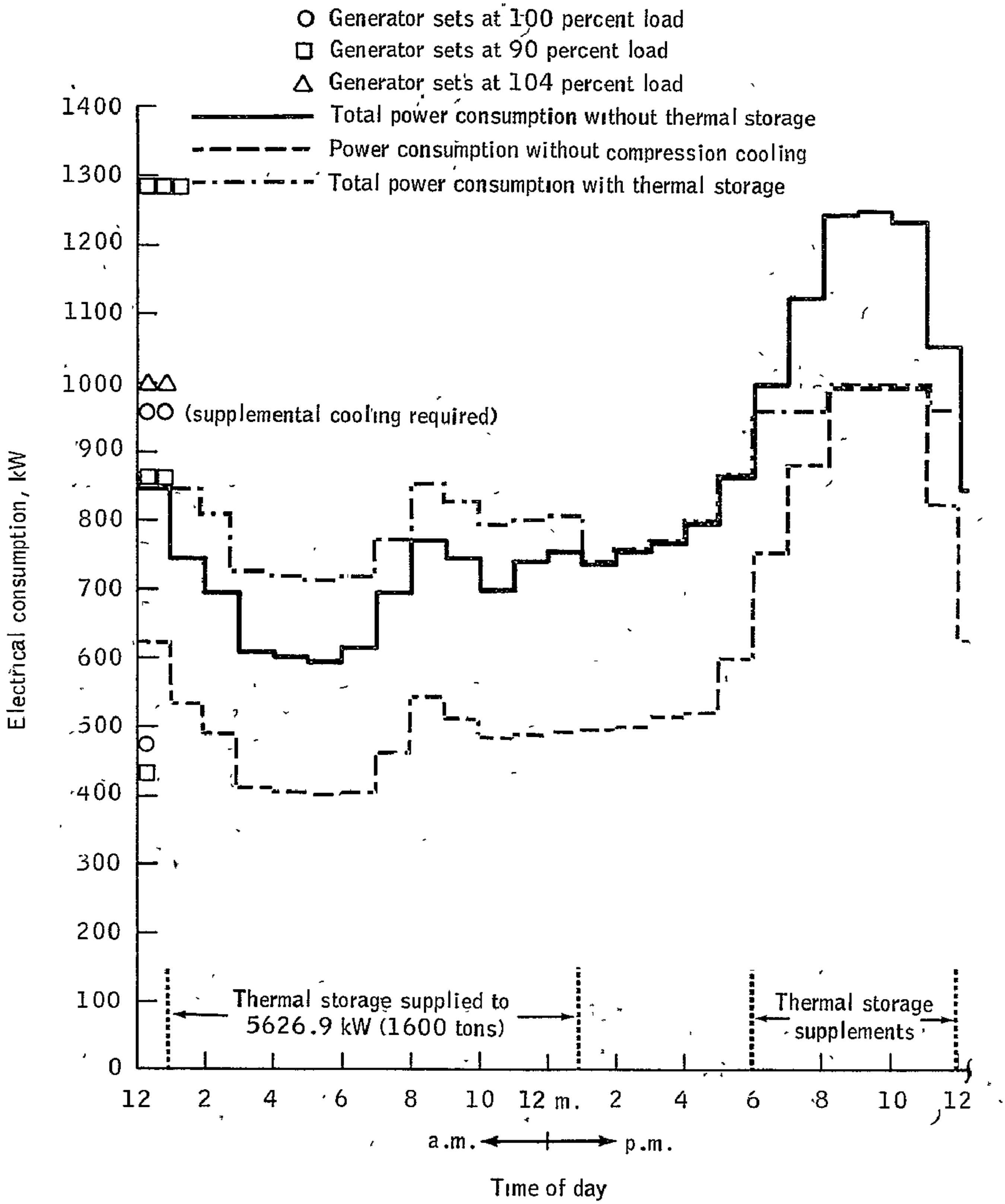


Figure 17.- Design-summer-day electrical consumption.

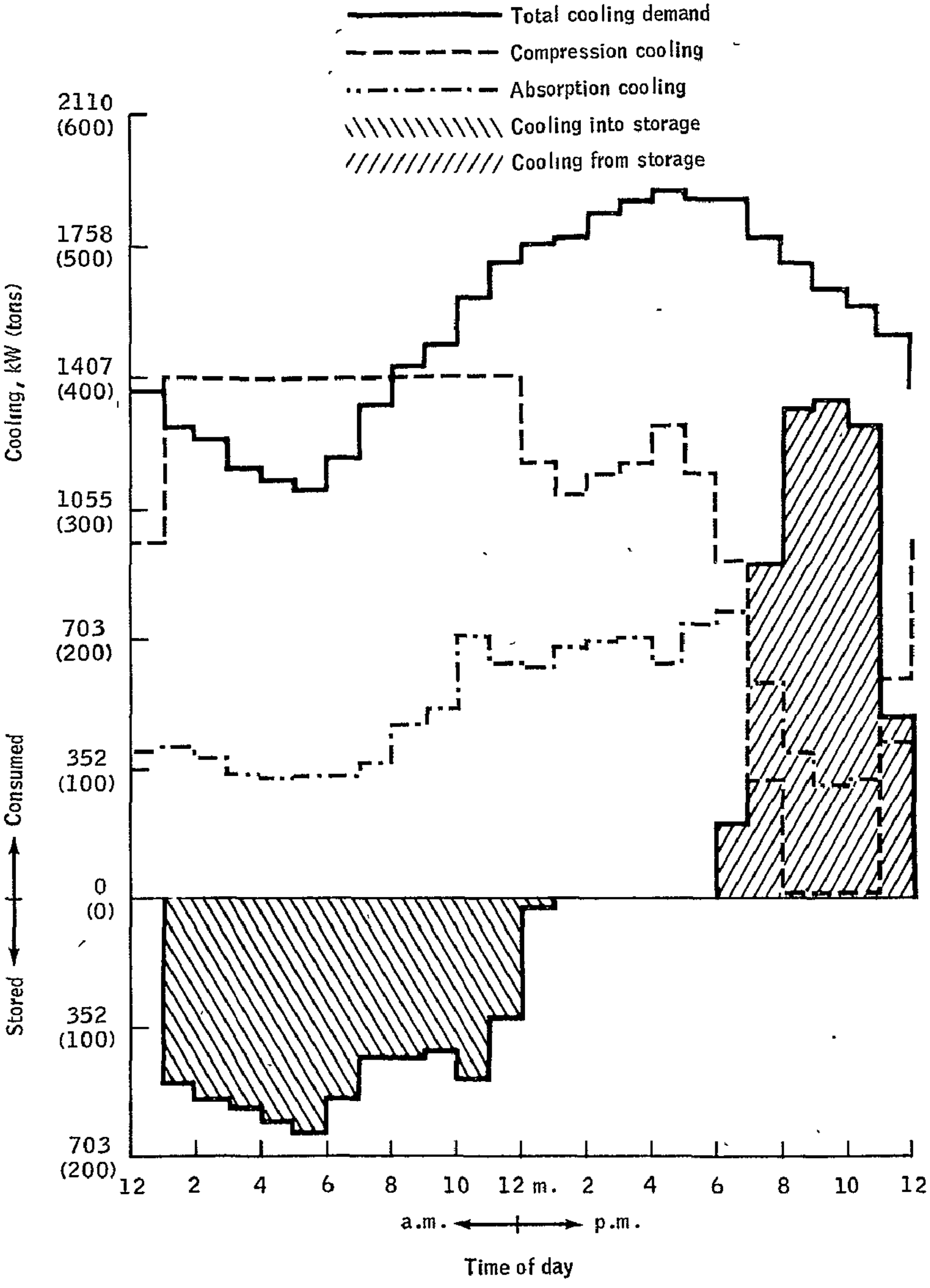


Figure 18.- Cooling-load components.

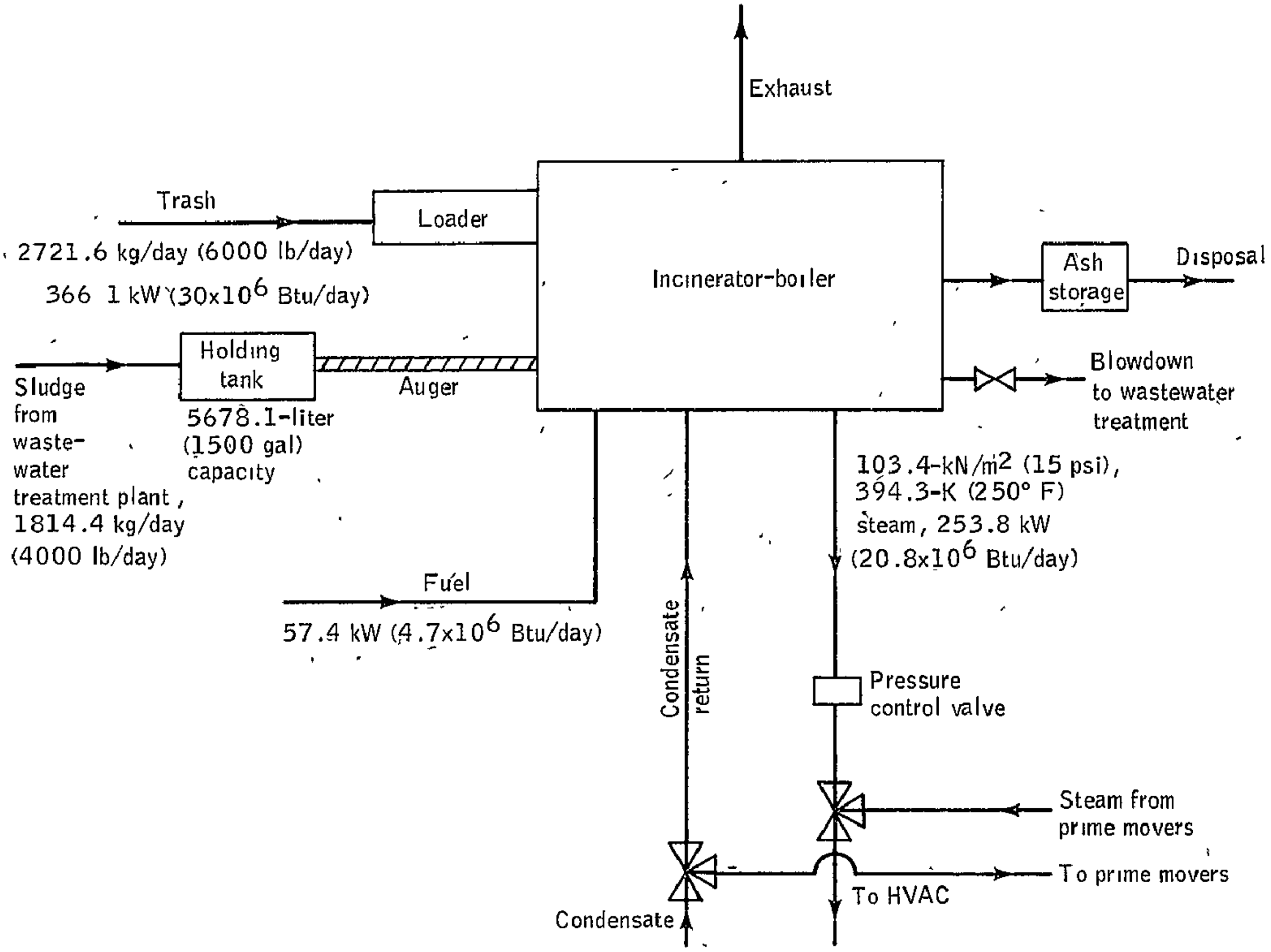


Figure 19.- Solid-waste-disposal subsystem.

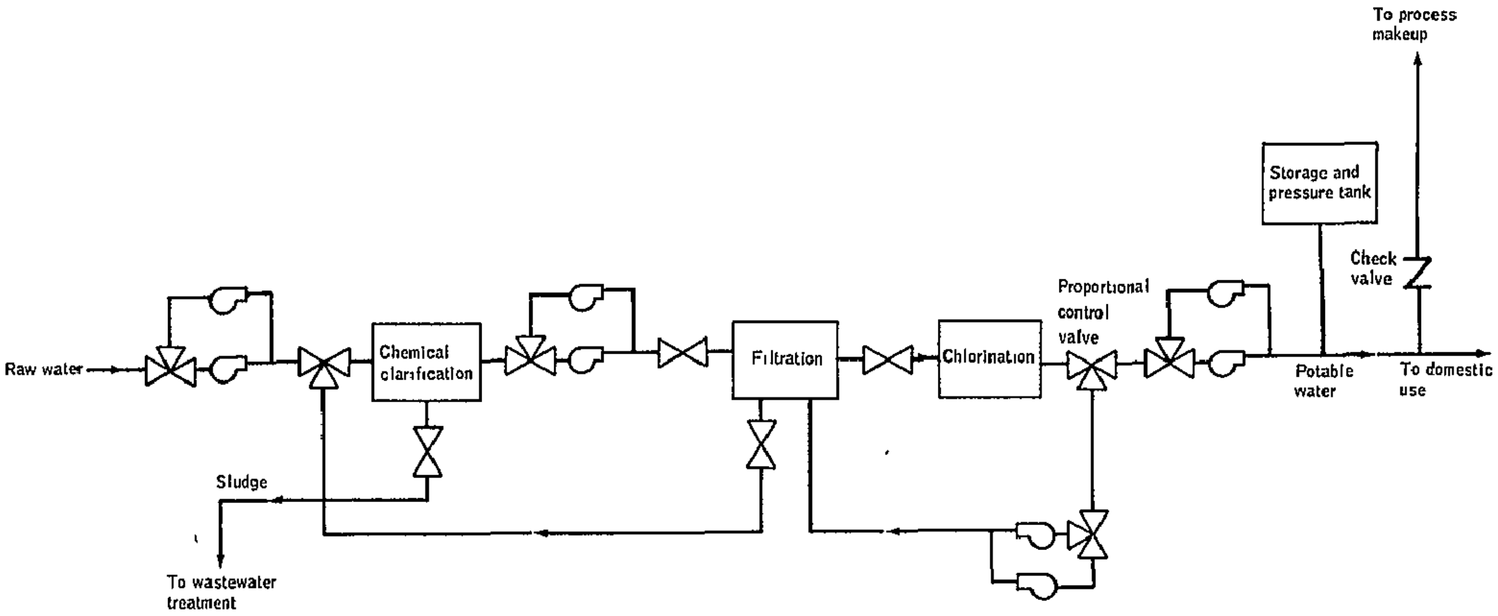


Figure 20.- Potable-water treatment.

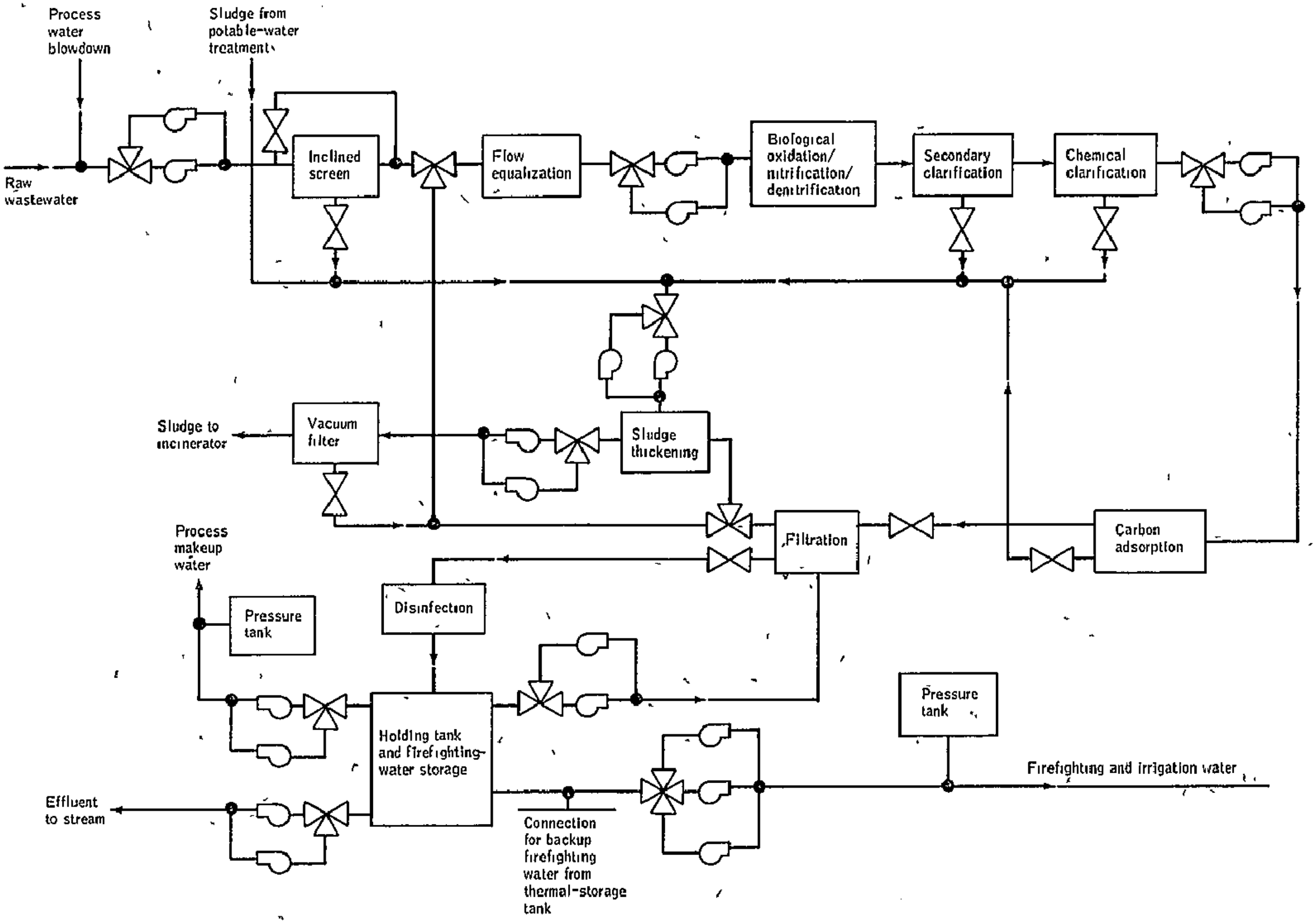


Figure 21.- Wastewater treatment.

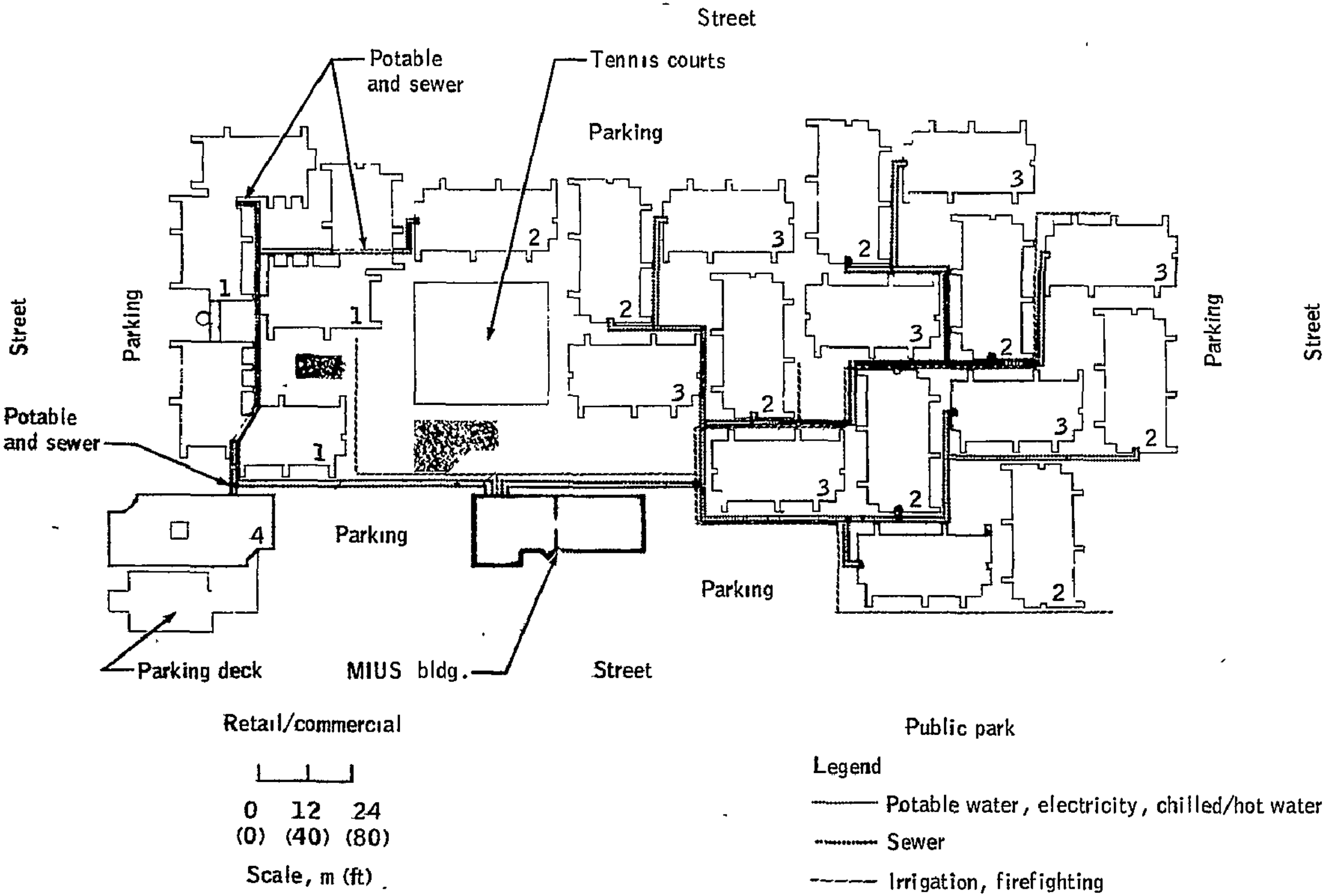


Figure 22.- Utility distribution.

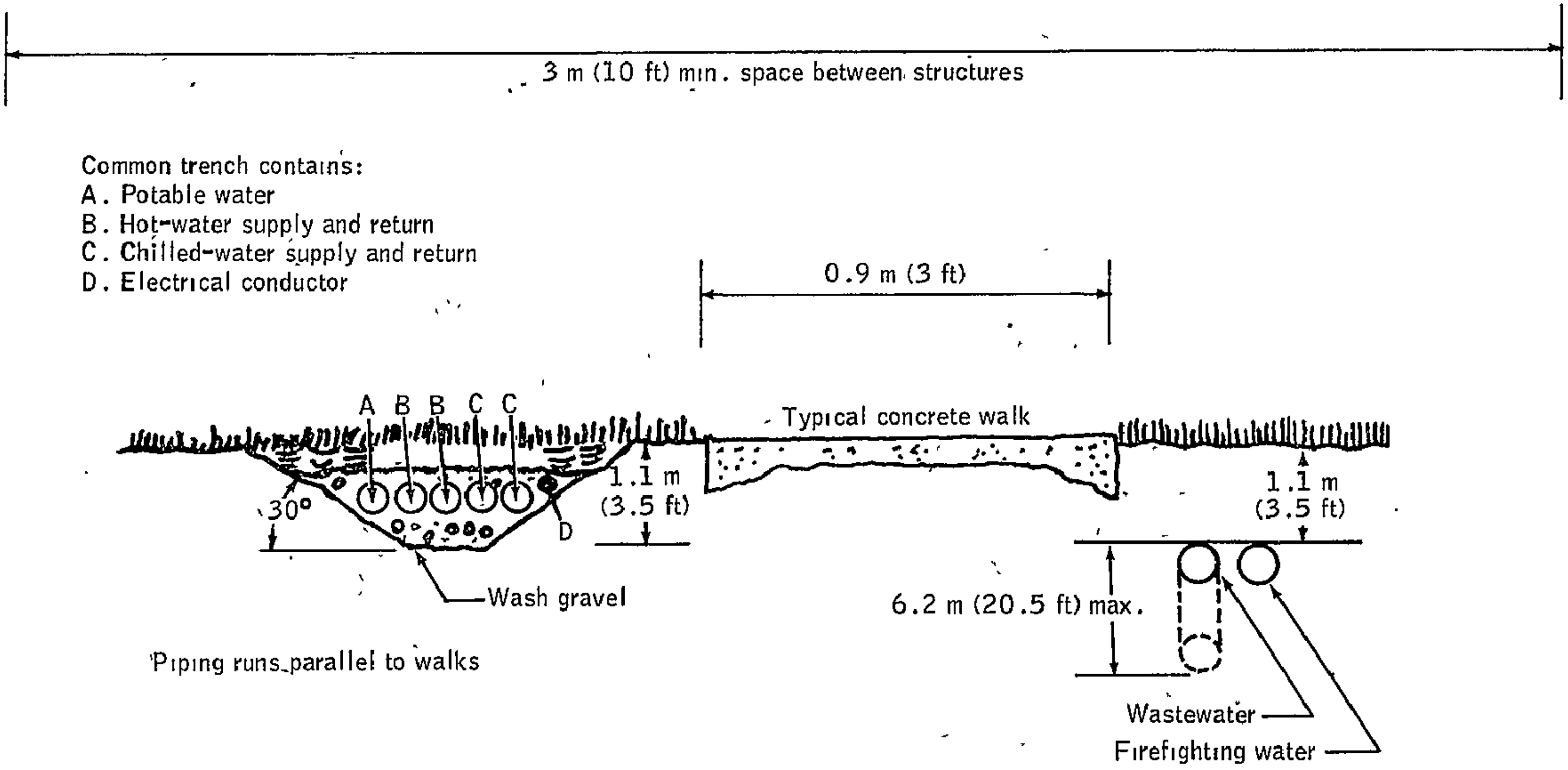


Figure 23.- Typical cross section of trench (not to scale).

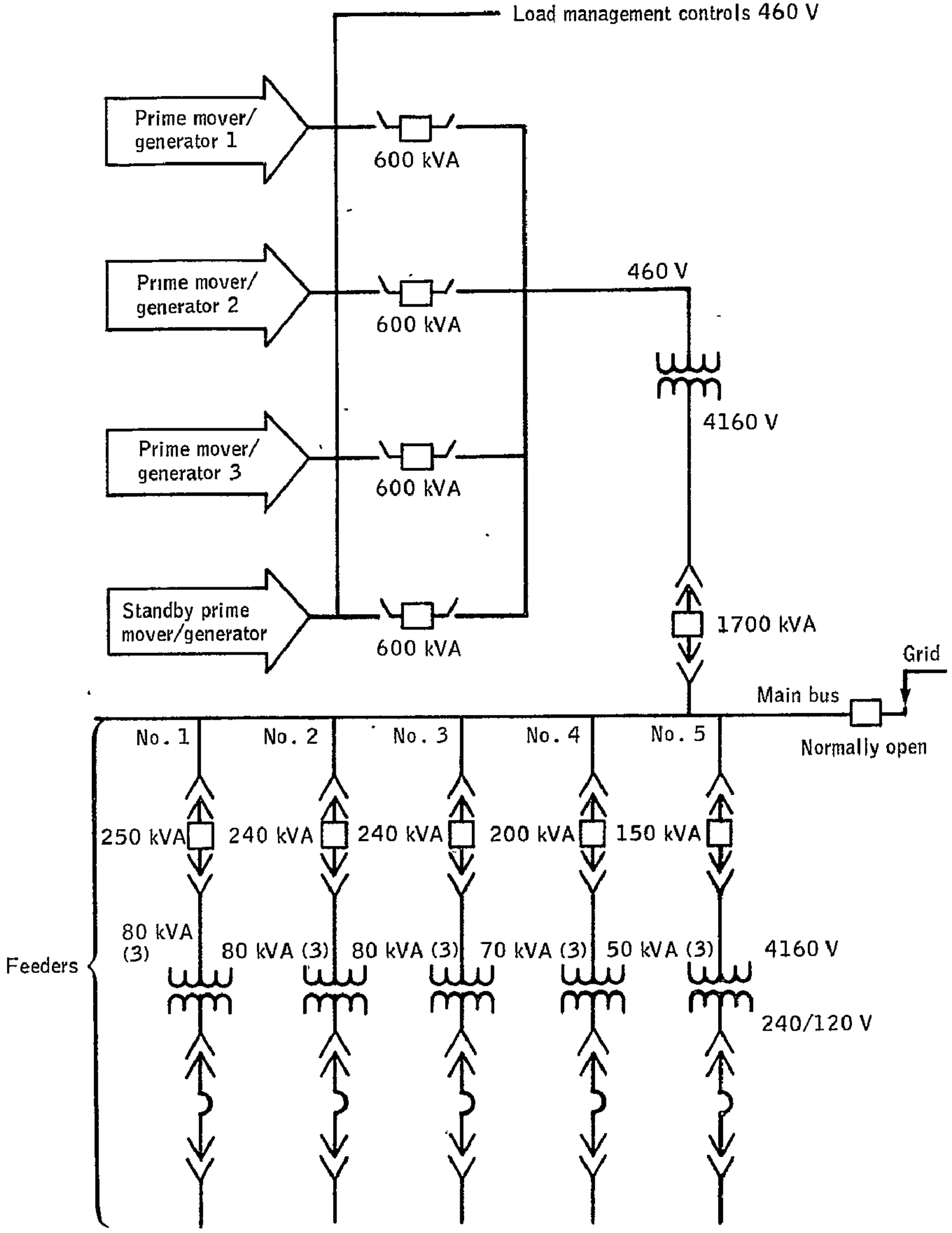
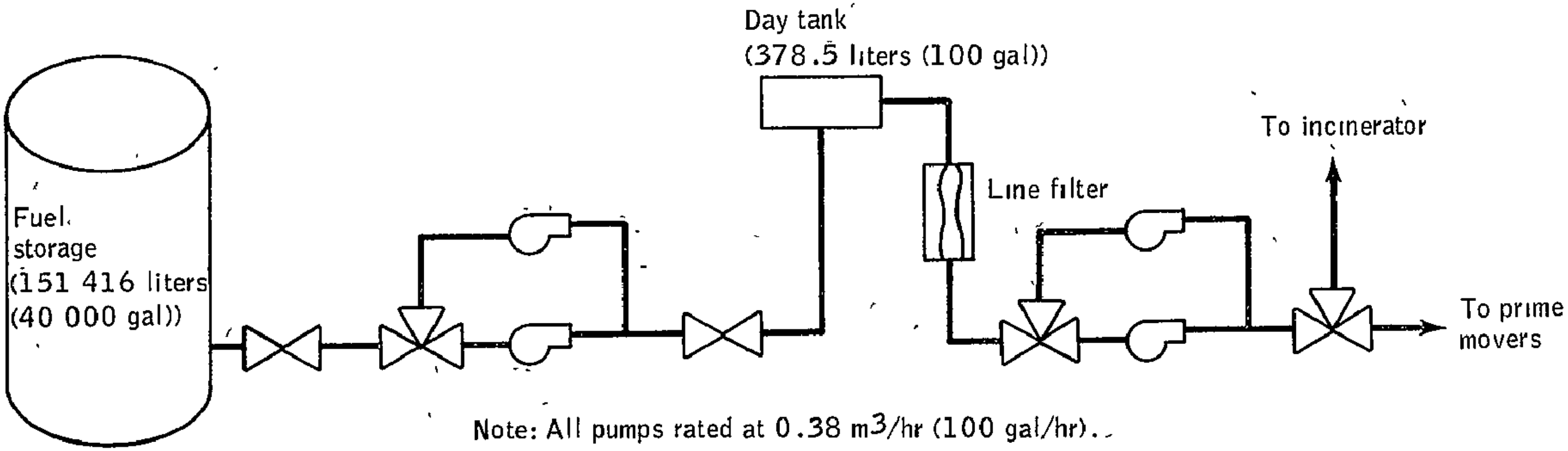


Figure 24.- Electrical power distribution.



Note: All pumps rated at 0.38 m^3/hr (100 gal/hr).

Figure 25.- Fuel supply system.

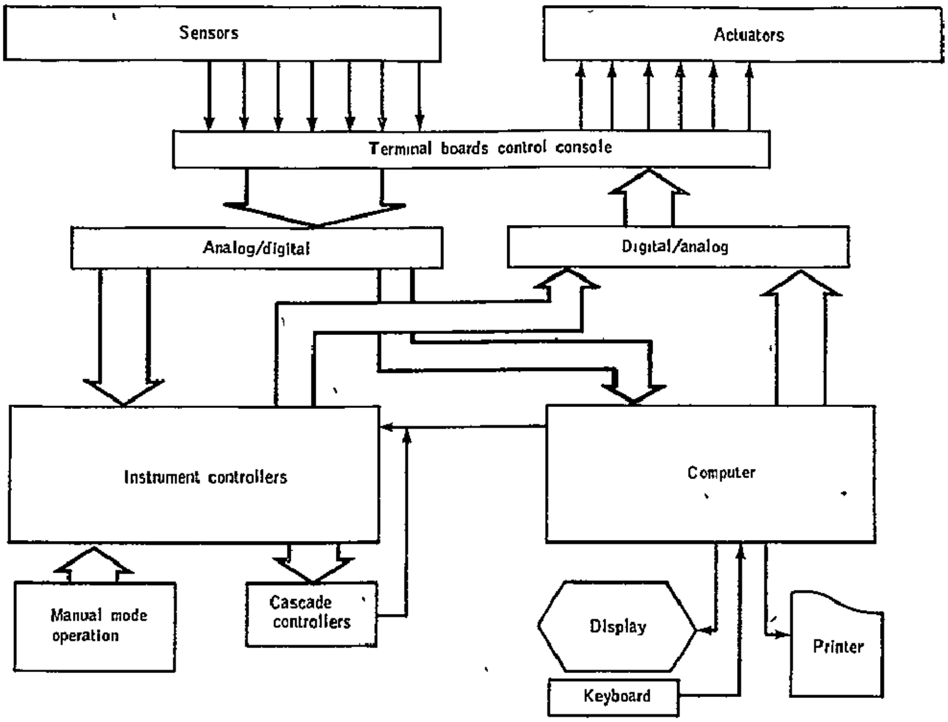


Figure 26.- Functional schematic — control/monitoring.

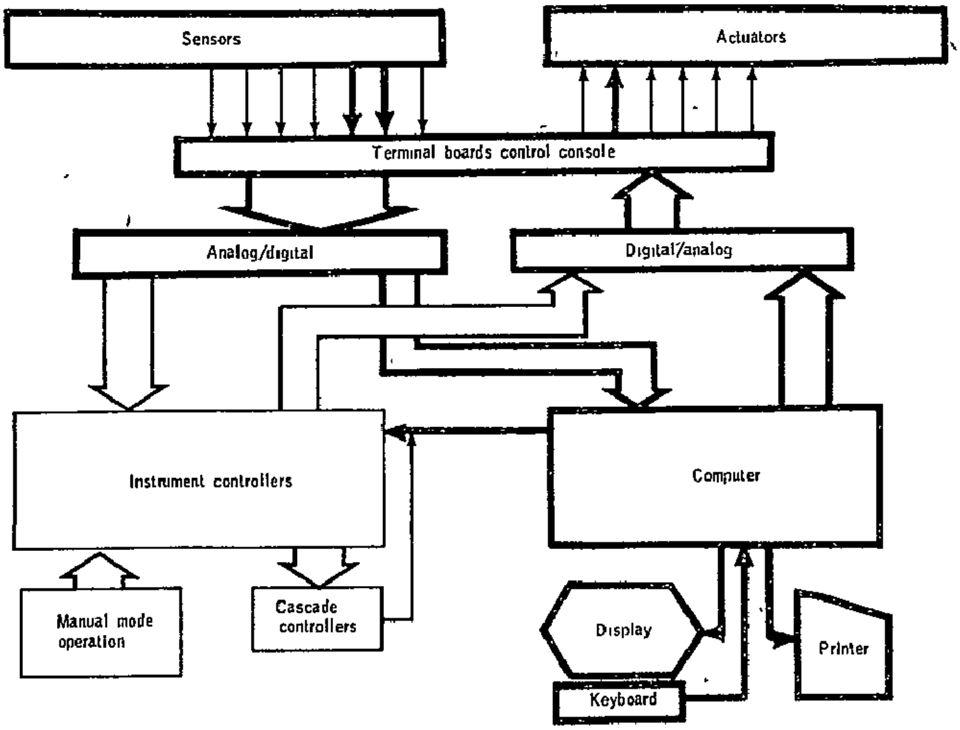


Figure 27.- Computer control — operational mode.

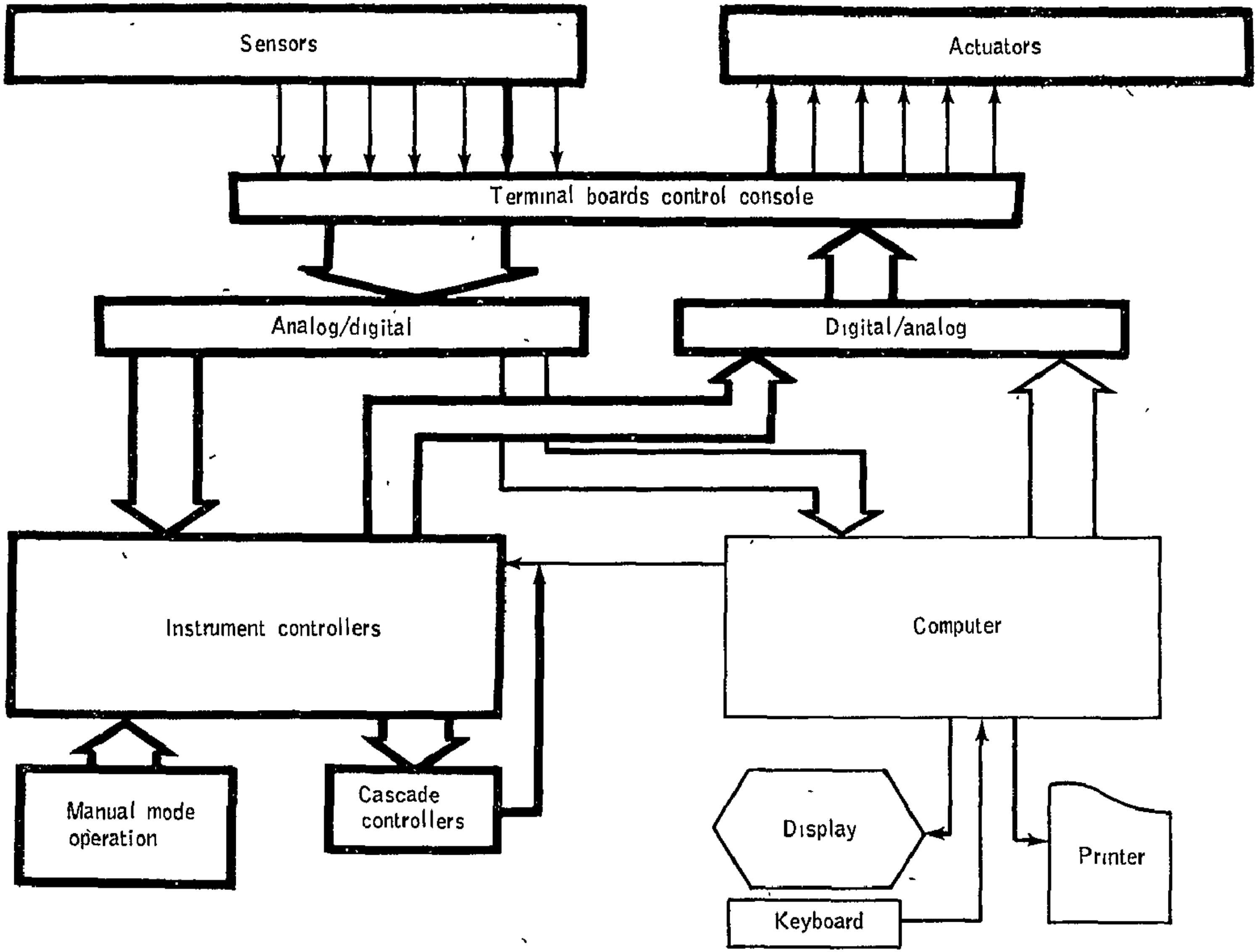


Figure 28.- Instrument controller — operational mode.

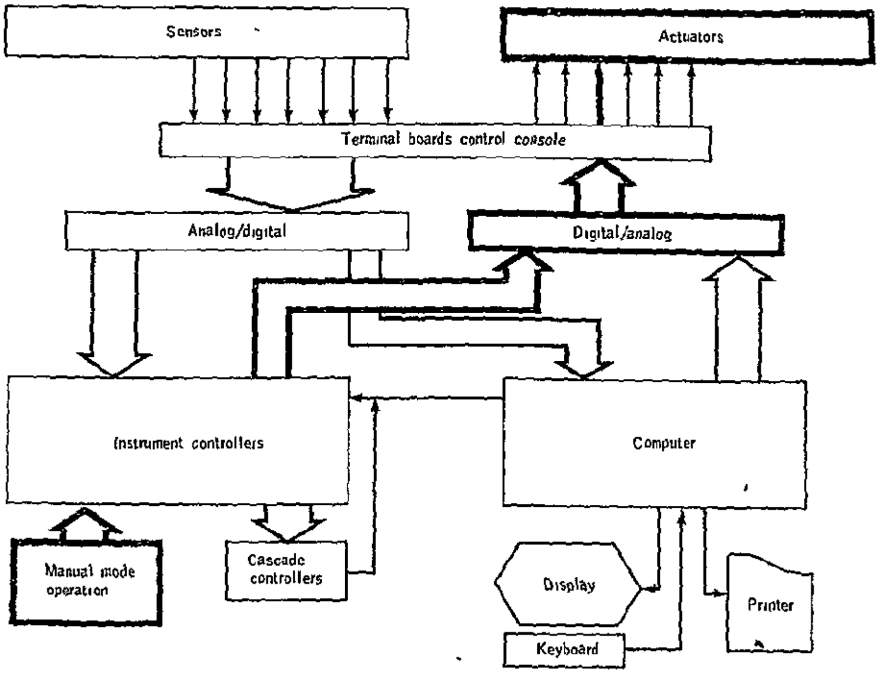


Figure 29.- Manual valve control.

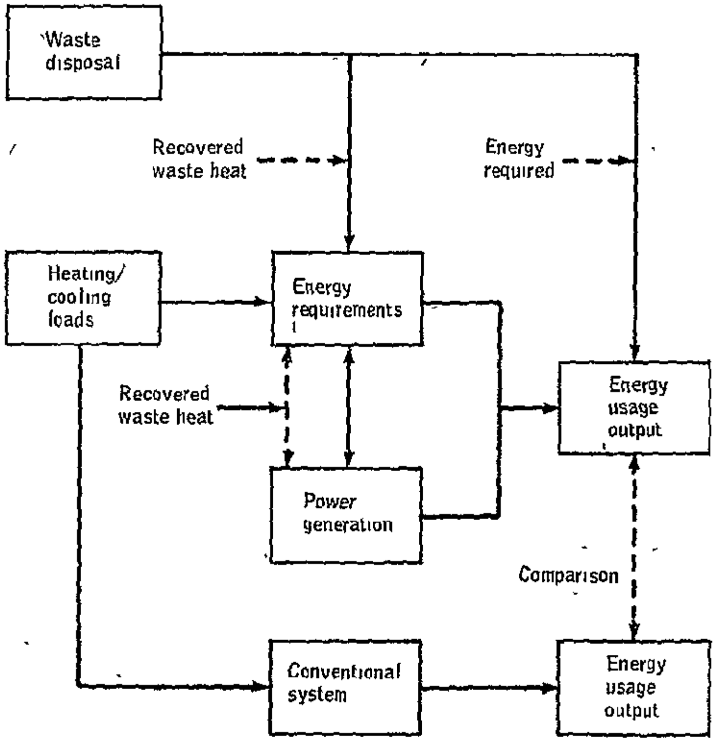
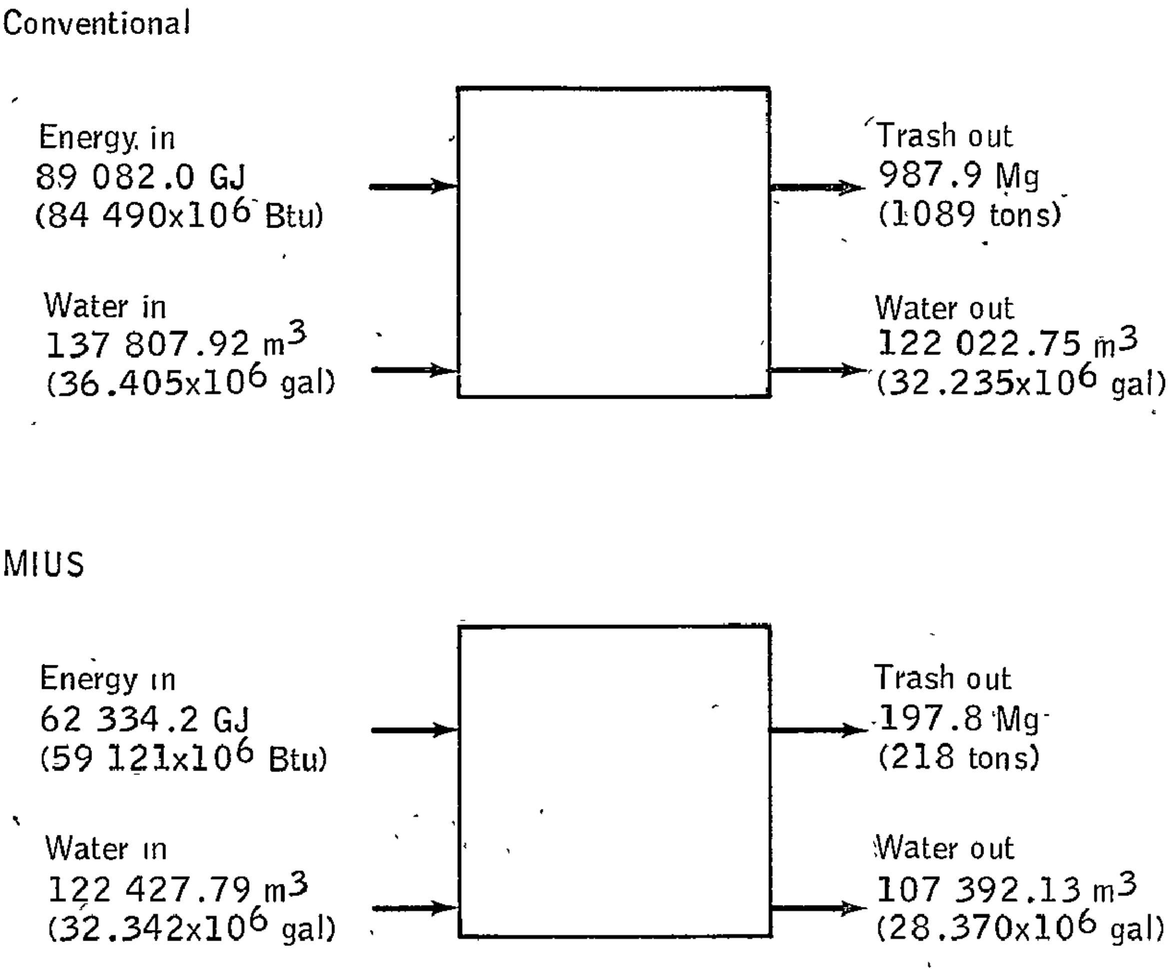


Figure 30.- Generalized ESOP analysis schematic.



Energy savings: 30.0 percent
Water savings: 11.2 percent
Effluent water reduction: 12.0 percent
Trash reduction: 80.0 percent

Figure 31.- Annual summary: Washington 500-unit complex, comparison of the baseline MIUS and the conventional system.

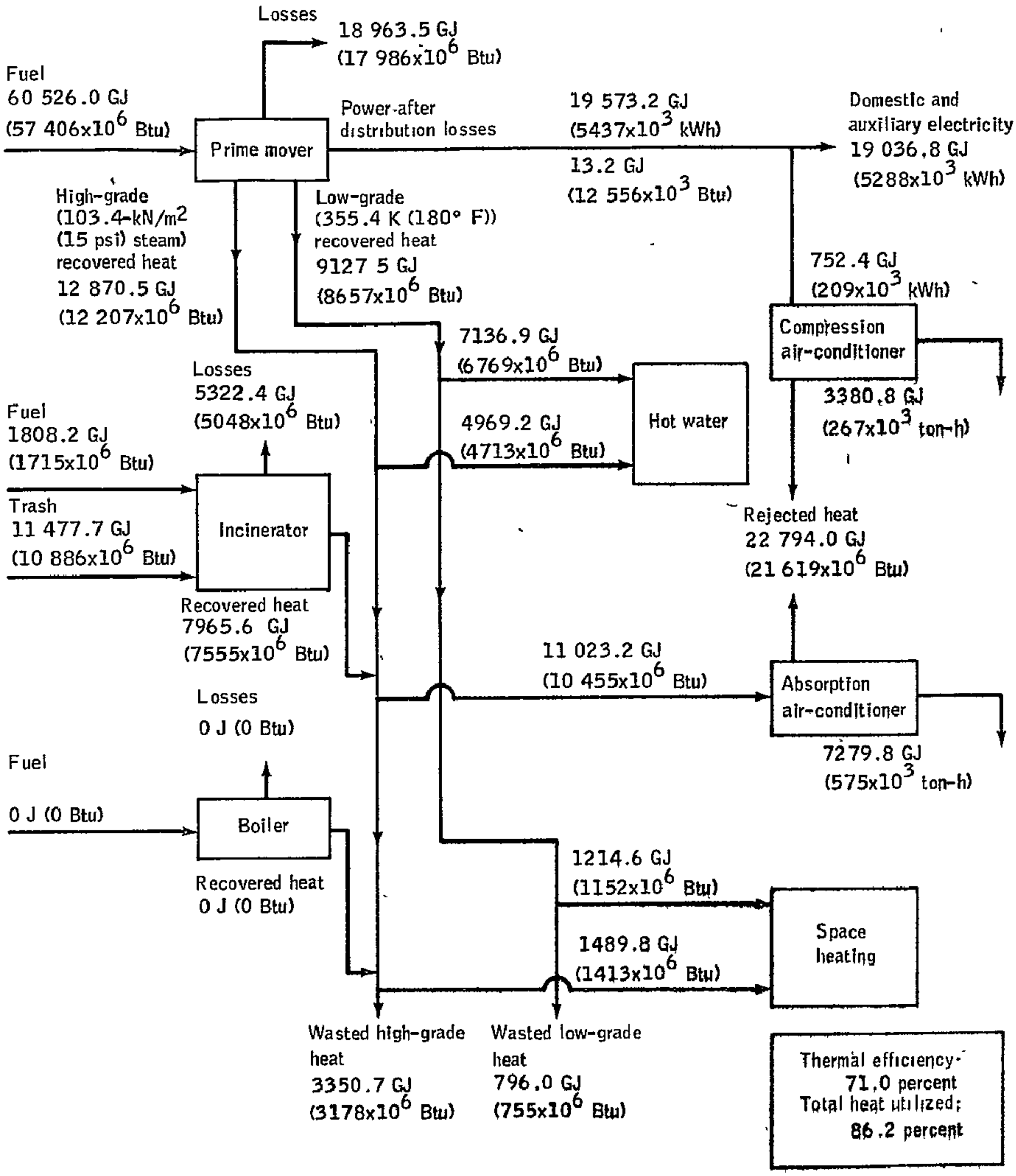
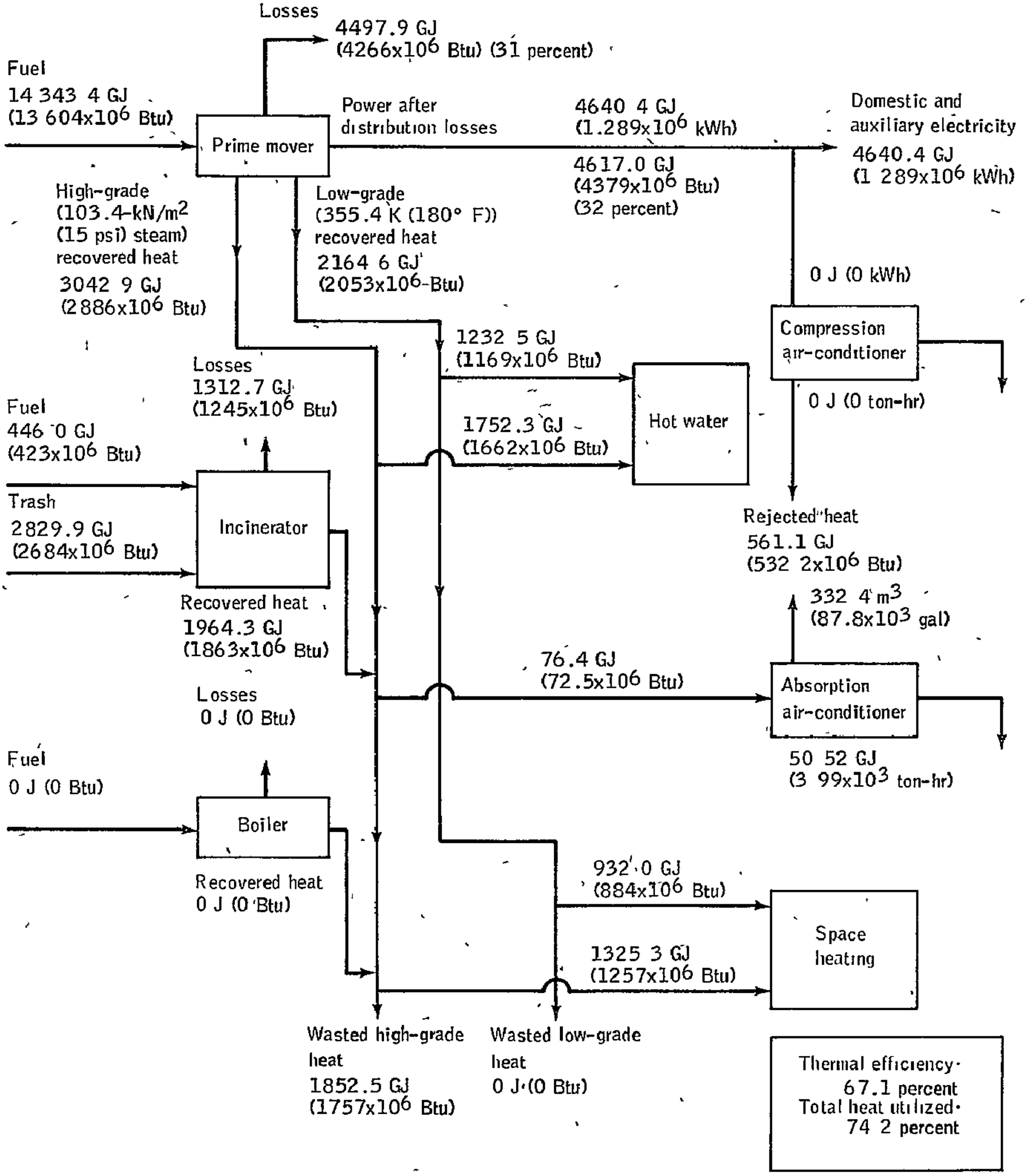


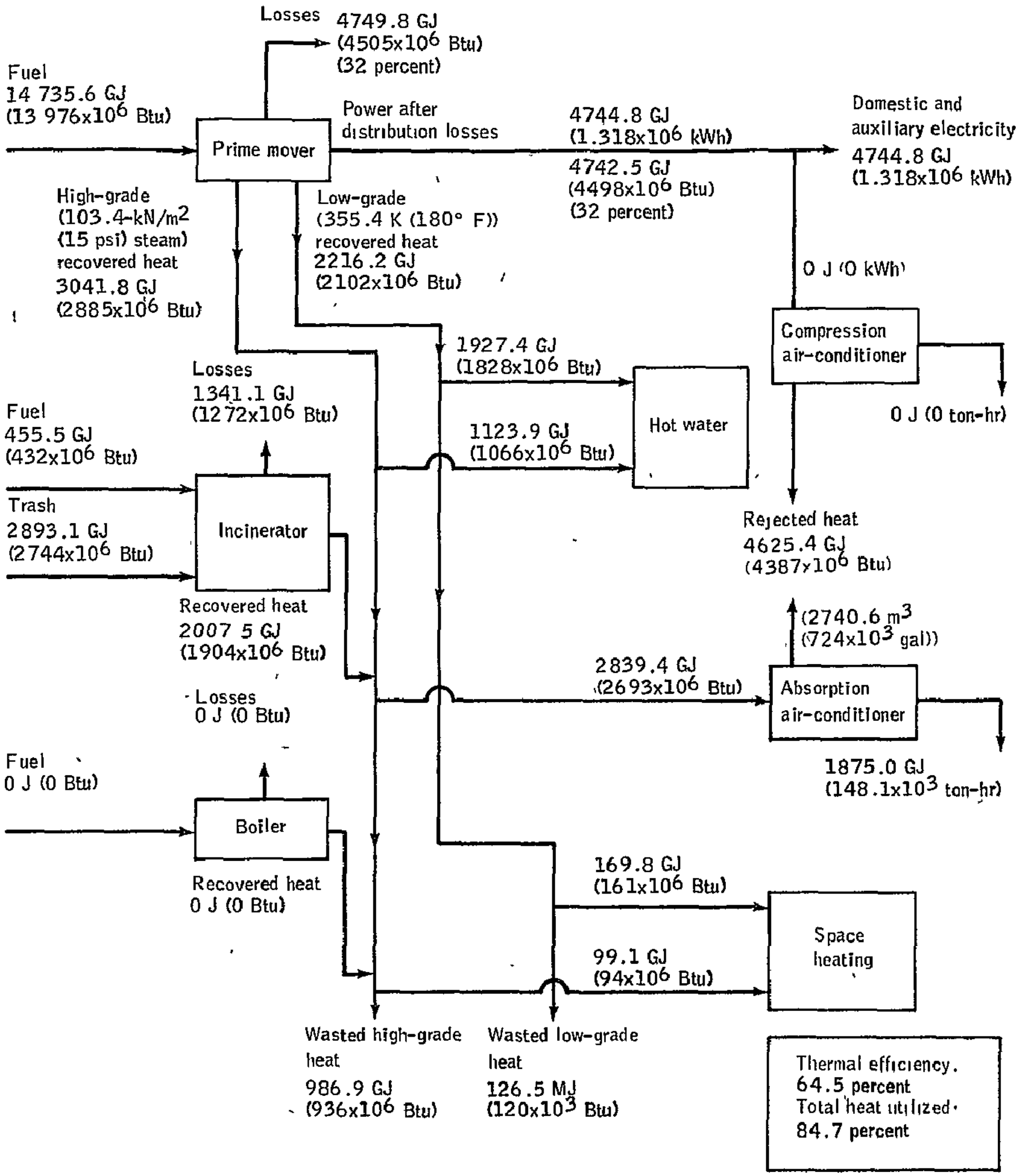
Figure 32.- Washington 500-unit MIUS.

(a) Annual.



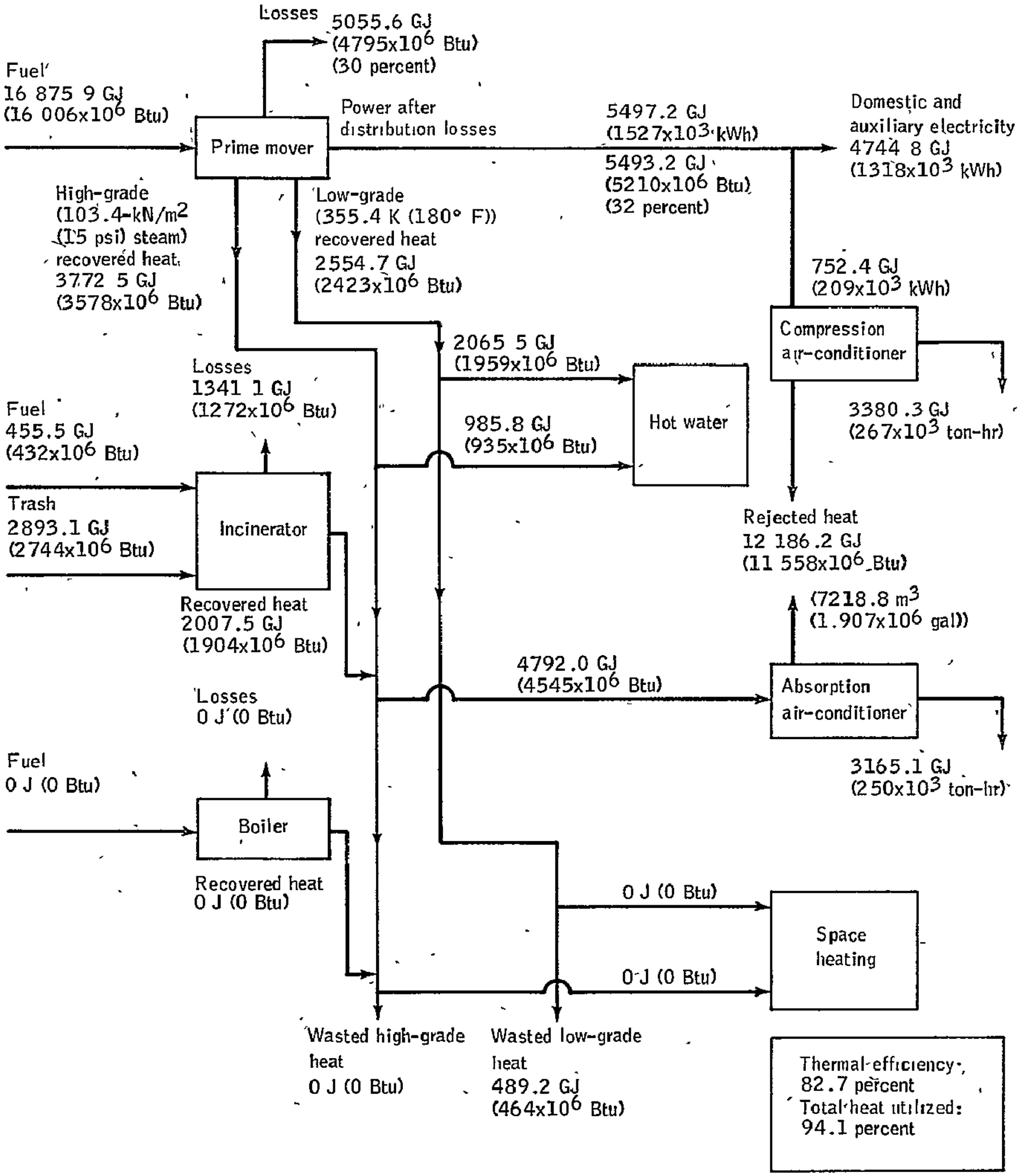
(b) Winter.

Figure 32.- Continued.



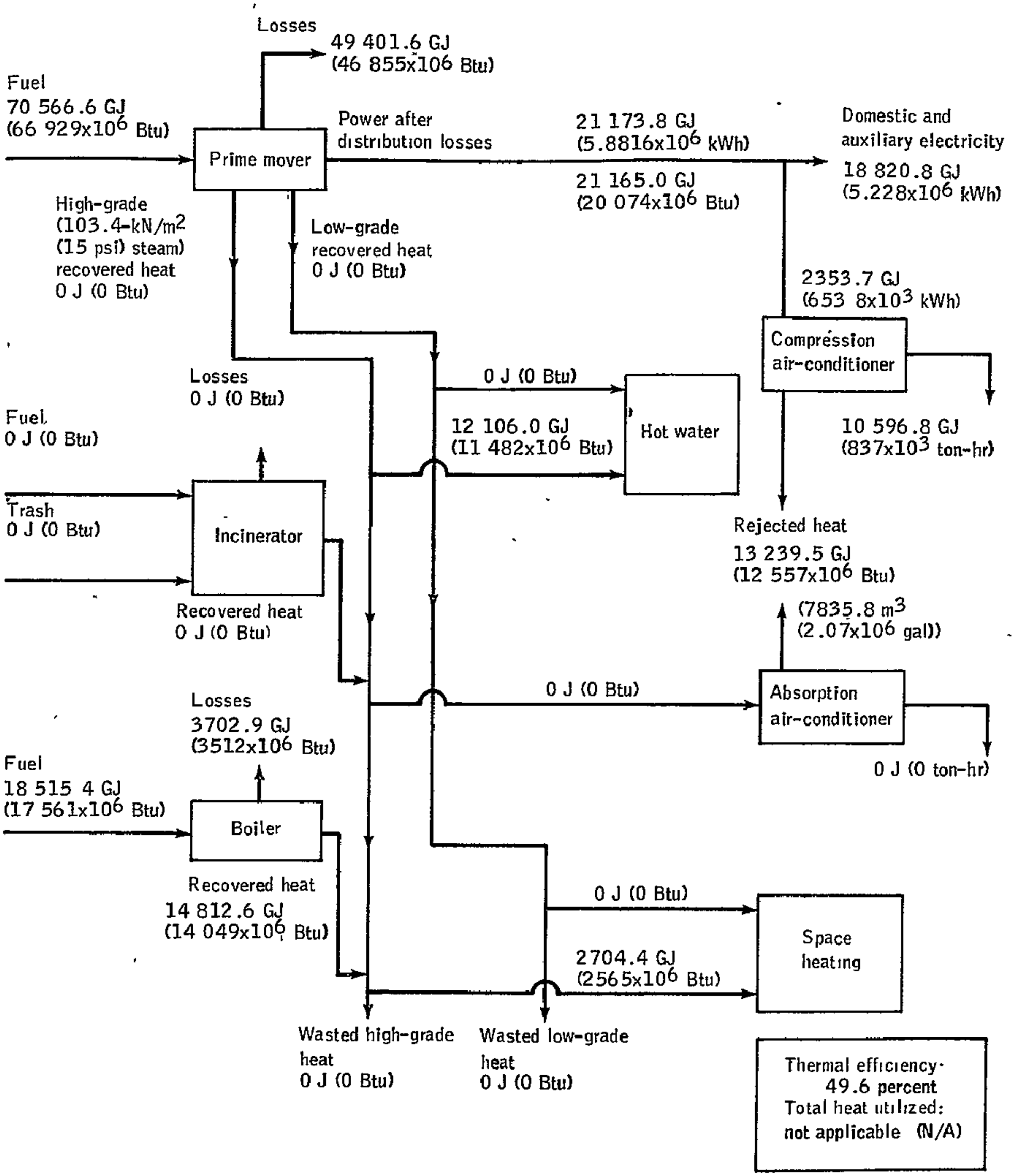
(c) Spring.

Figure 32.- Continued.



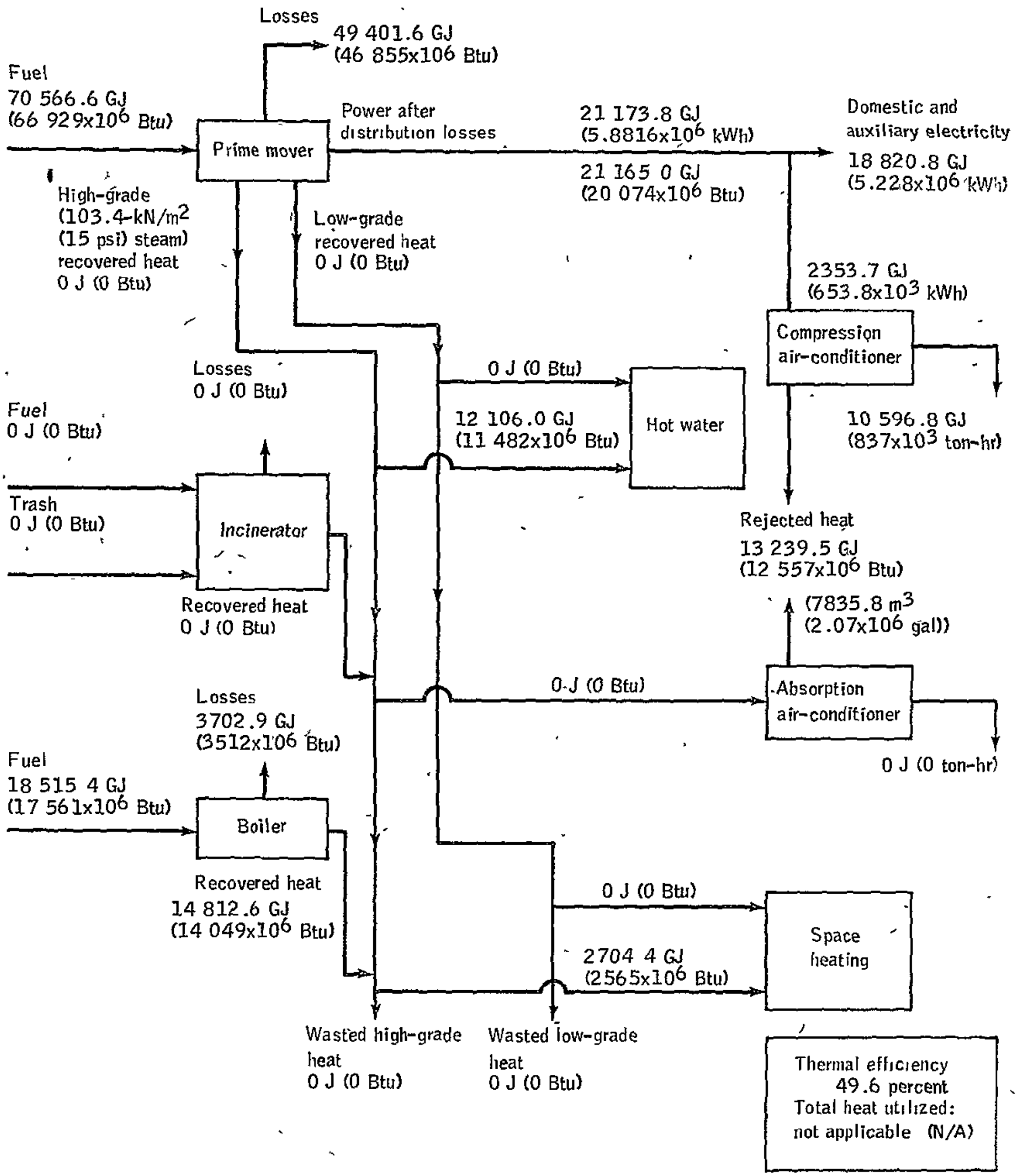
(d) Summer.

Figure 32.- Continued.



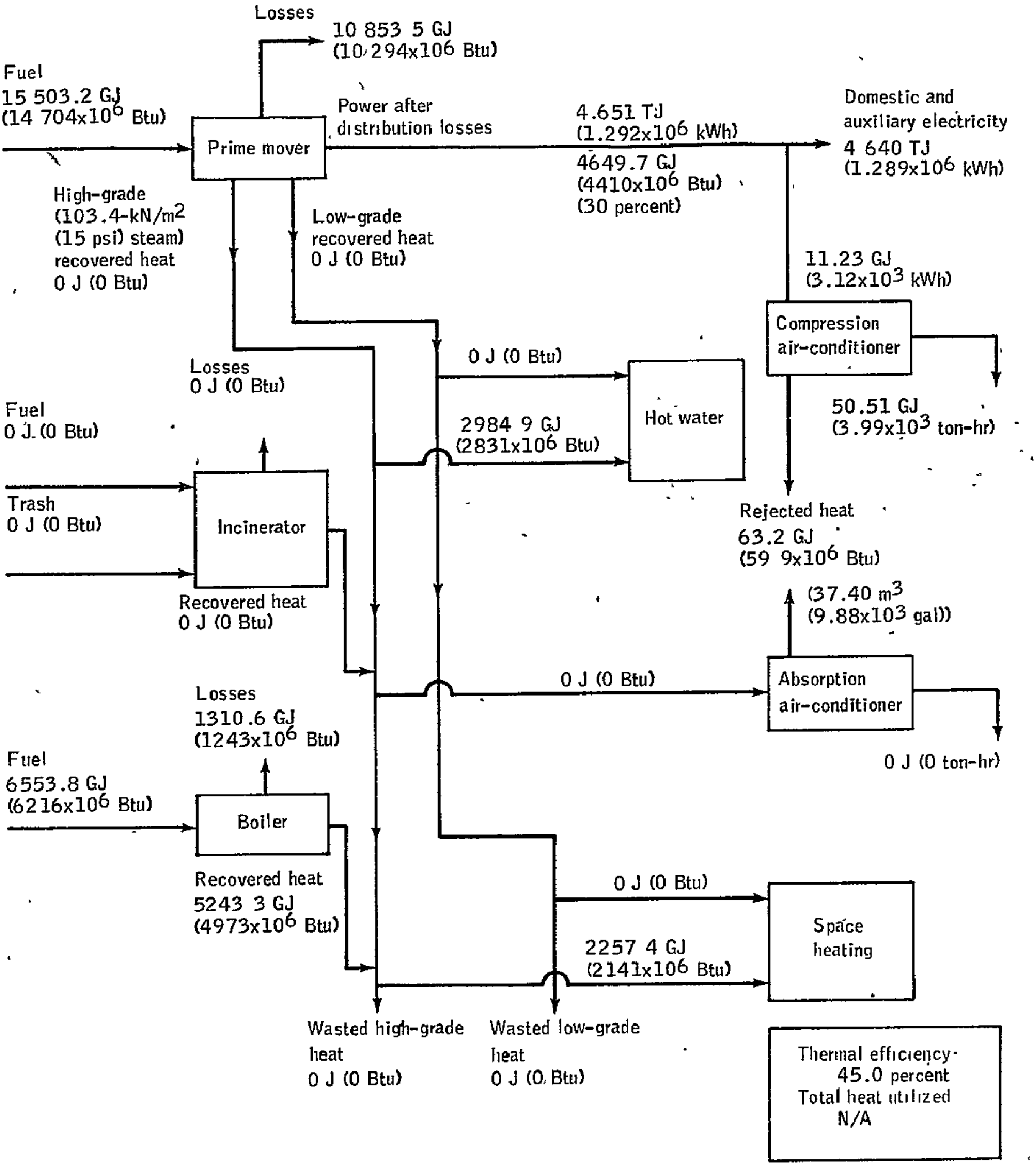
(e) Fall.

Figure 32.- Concluded.



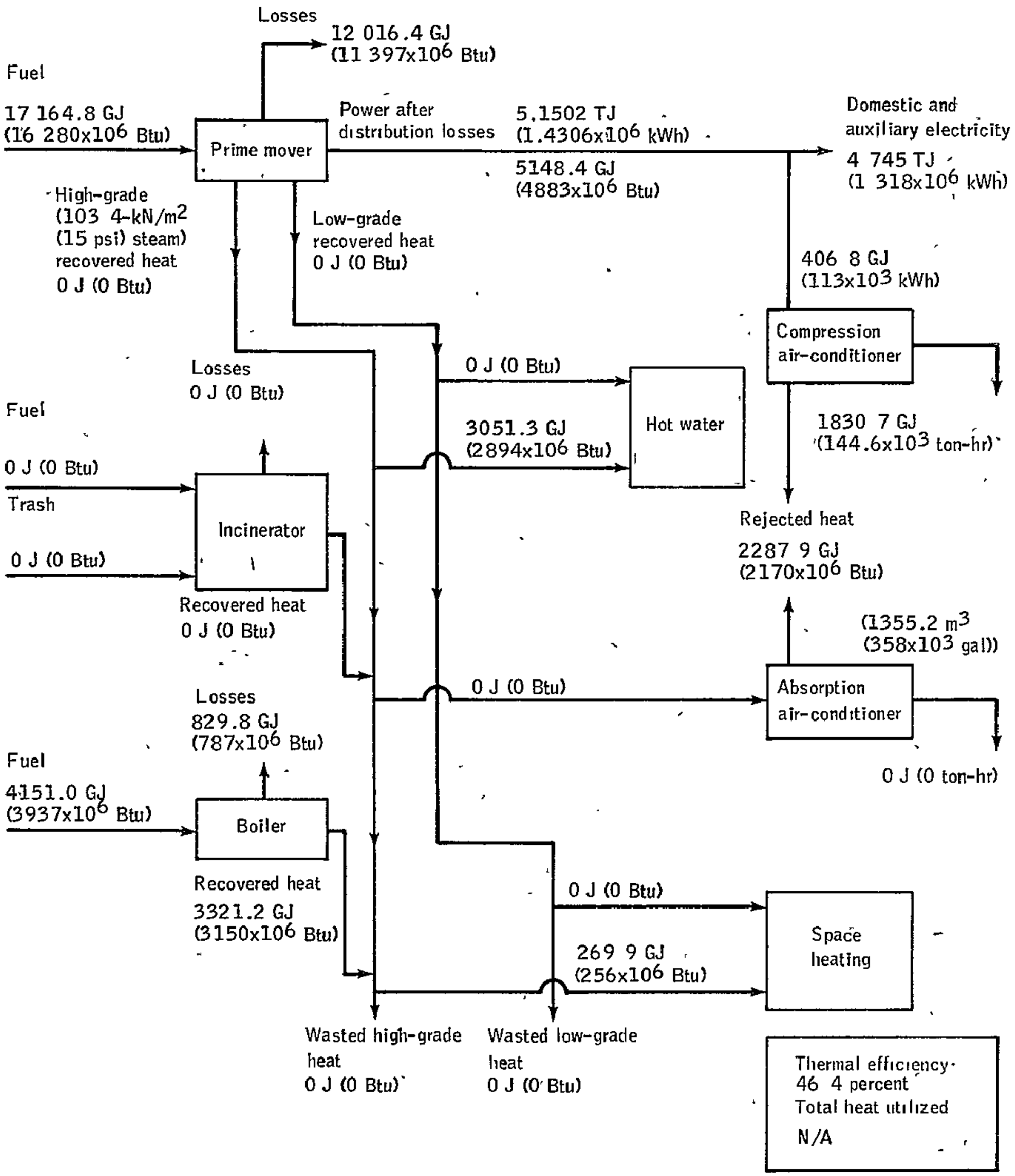
(a) Annual.

Figure 33.- Washington 500-unit conventional system.



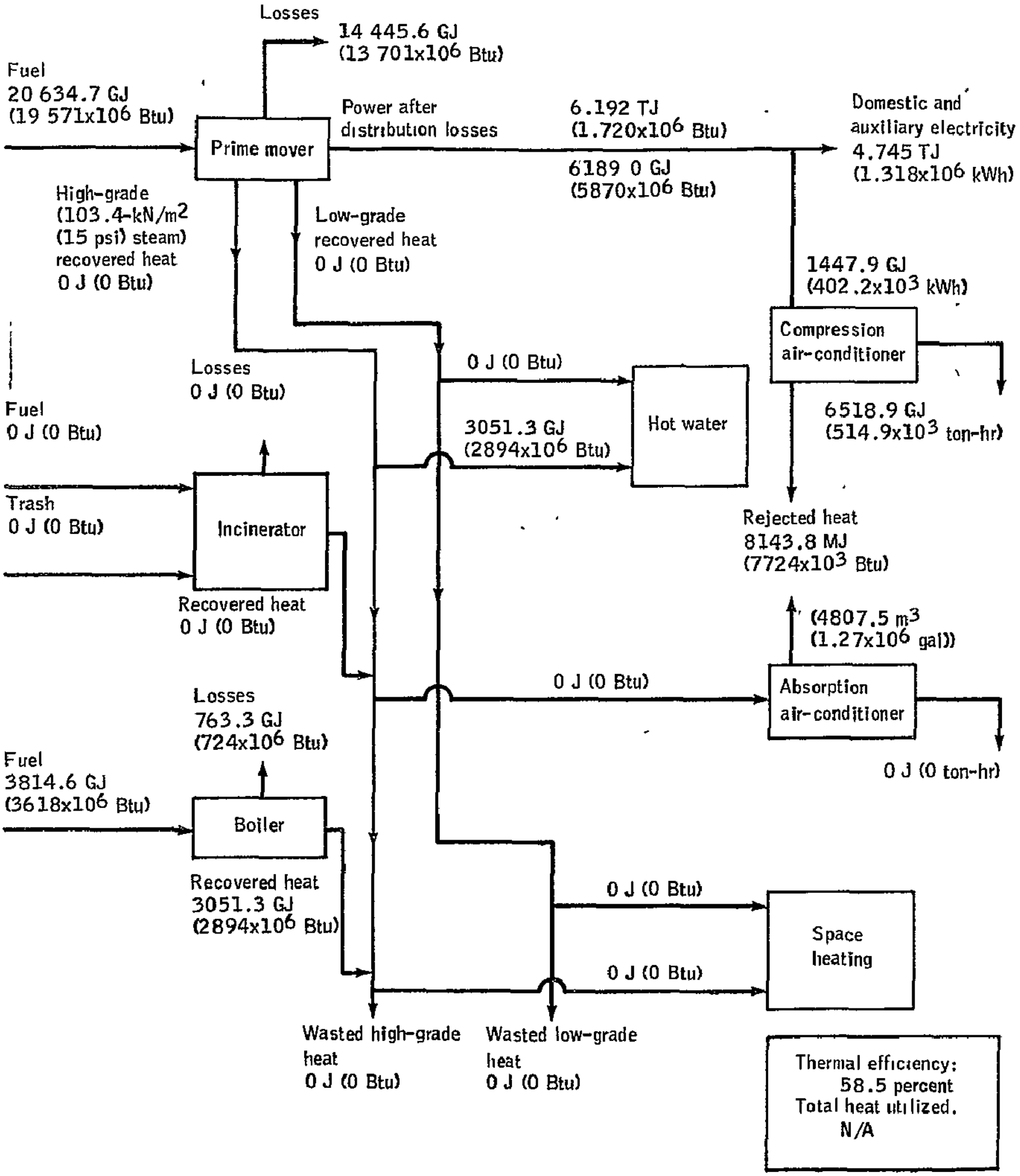
(b) Winter.

Figure 33.- Continued.



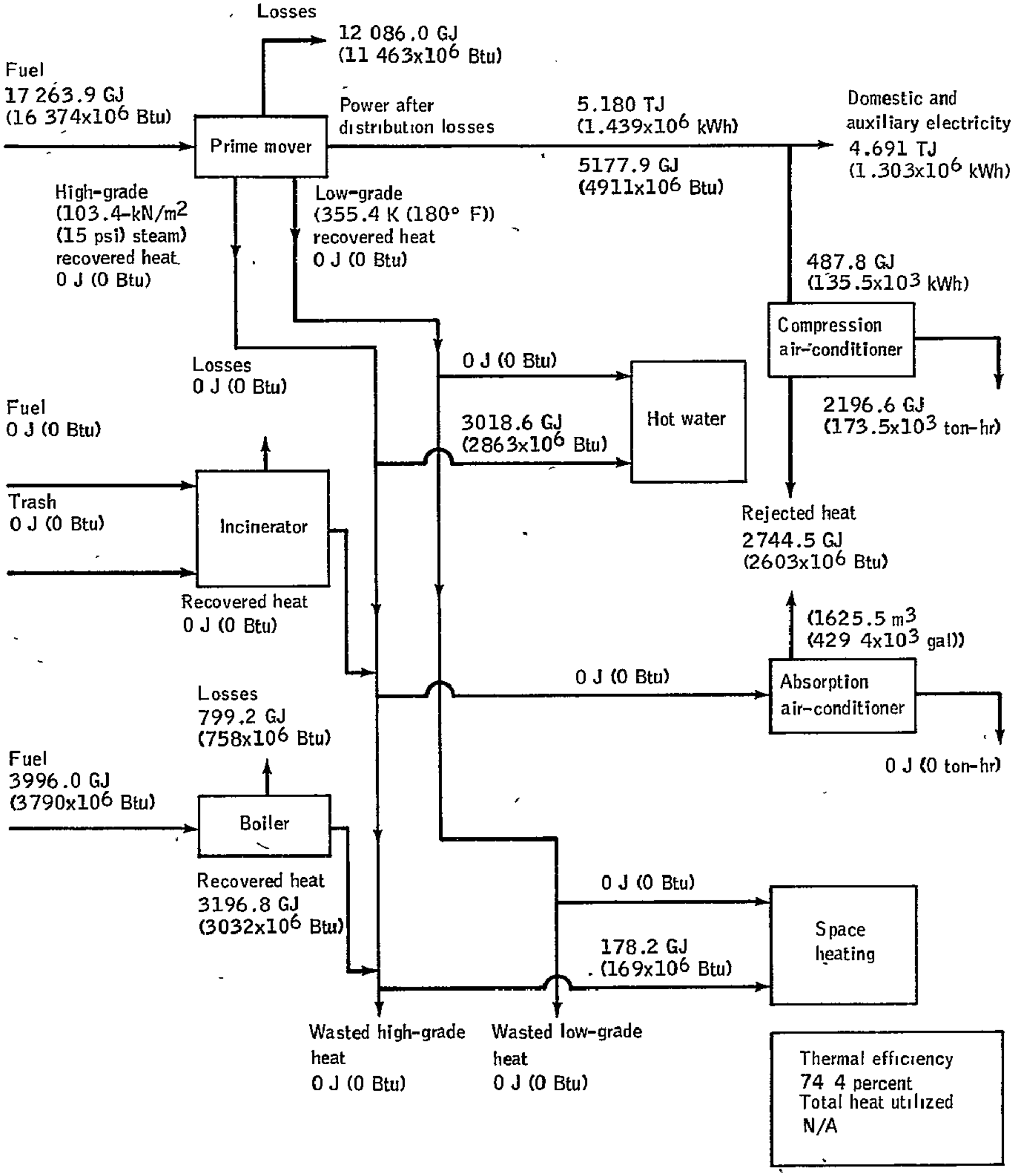
(c) Spring.

Figure 33.- Continued.



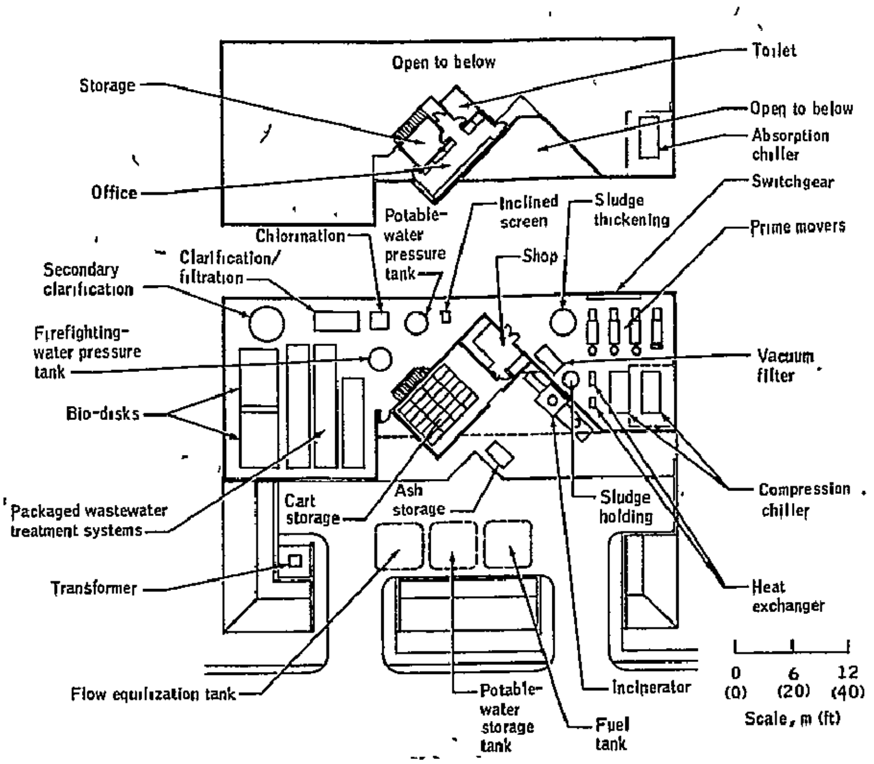
(d) Summer.

Figure 33.- Continued.

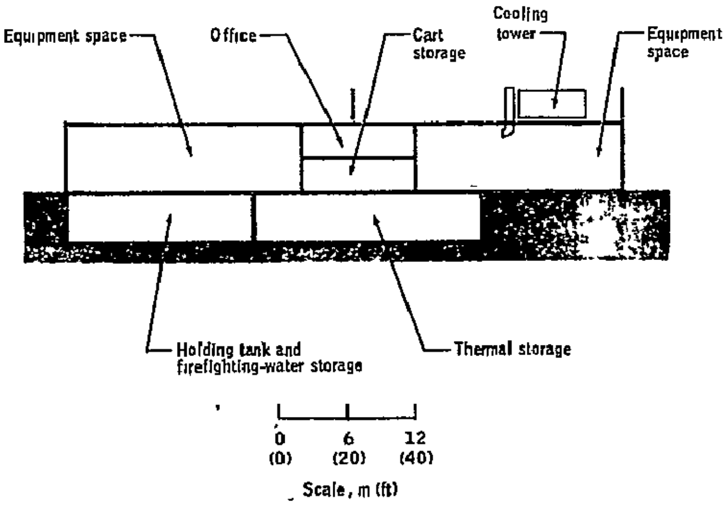


(e) Fall.

Figure 33.- Concluded.

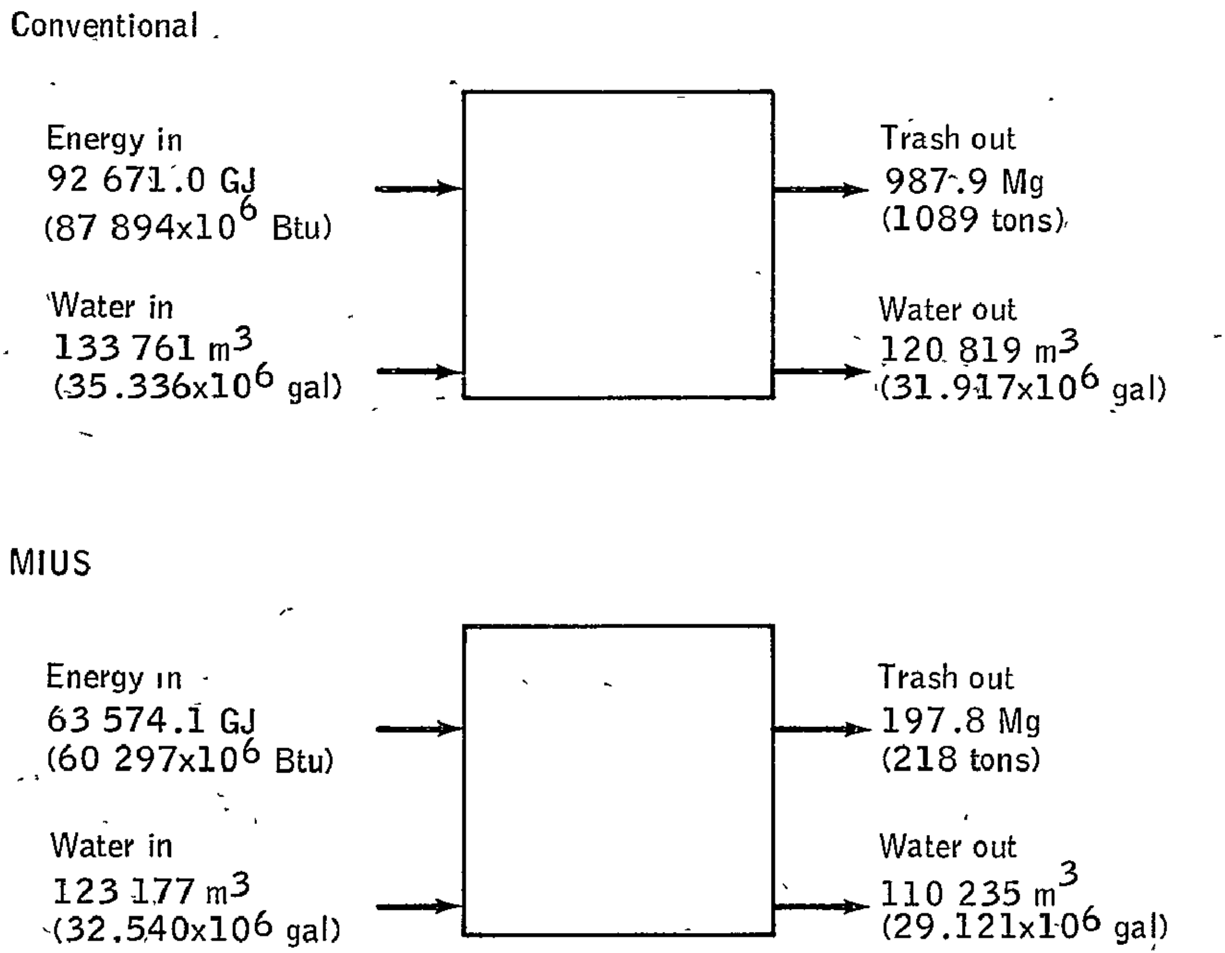


(a) First floor.



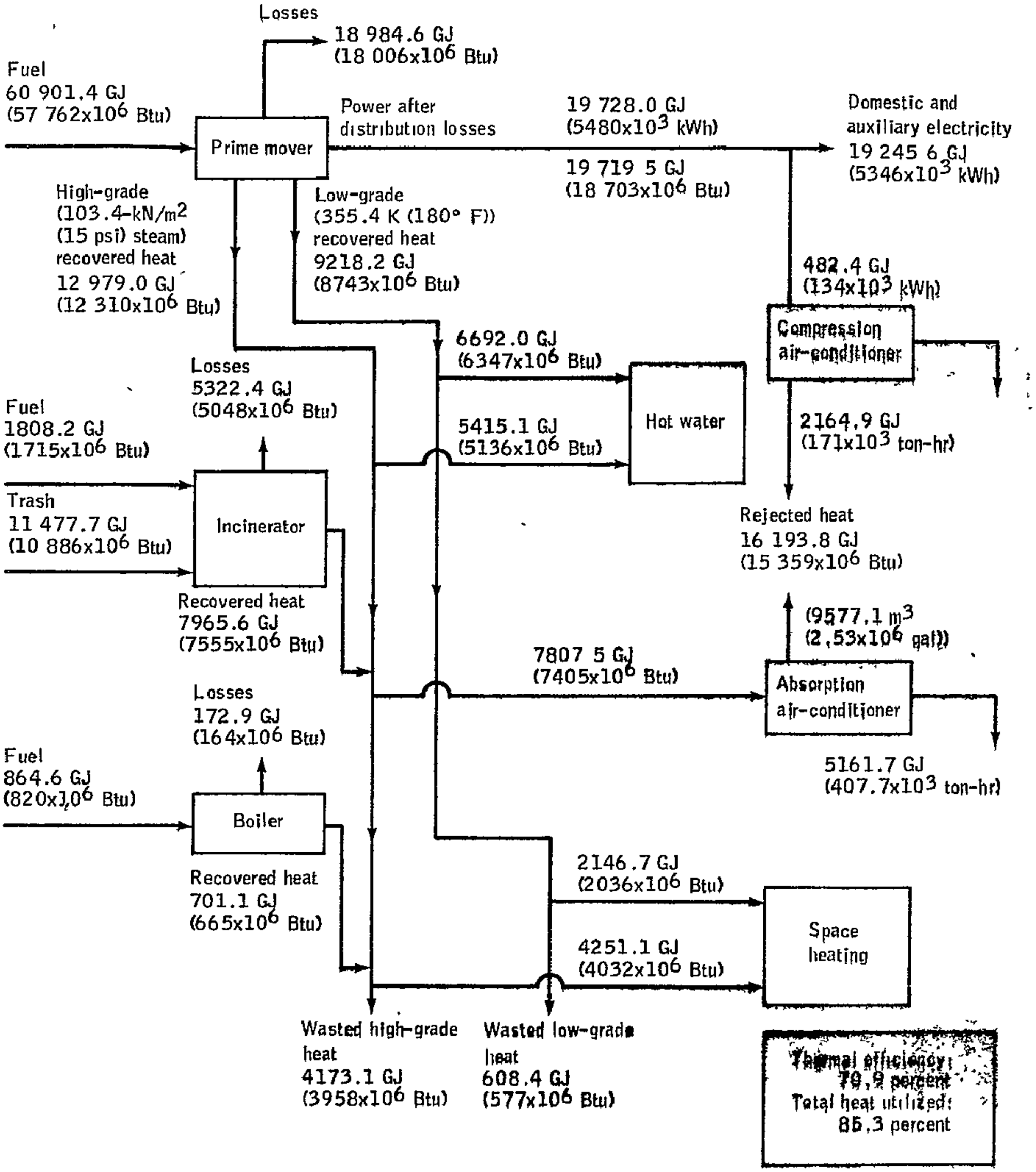
(b) Cross section.

Figure 34.- The MIUS building.



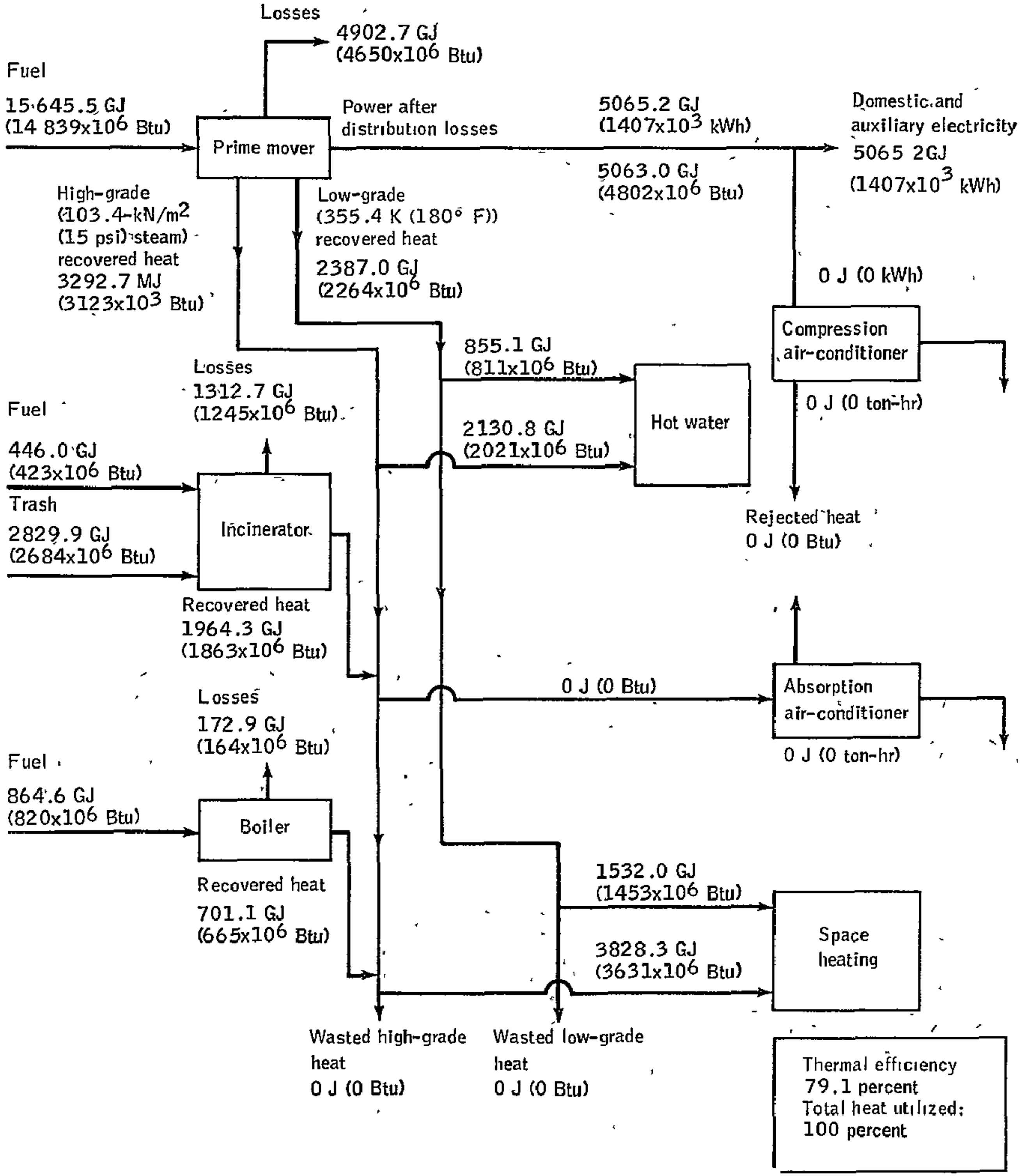
Energy savings:	31.4 percent
Water savings:	7.9 percent
Effluent water reduction:	8.8 percent
Trash reduction:	80.0 percent

Figure 35.- Annual summary: Minneapolis 500-unit complex, comparison of the MIUS and the conventional system.



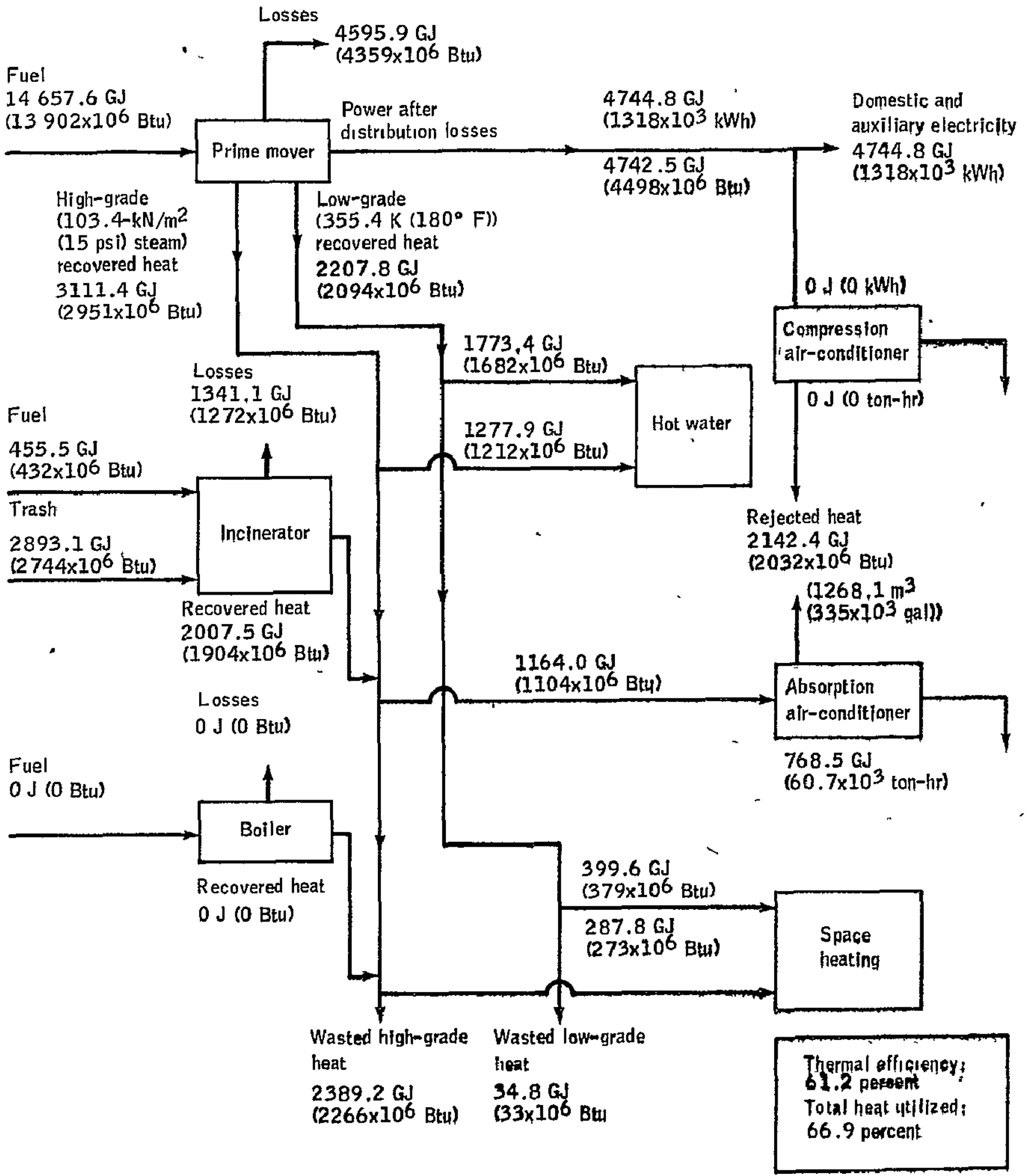
(a) Annual.

Figure 36.- Minneapolis 500-unit MIUS.



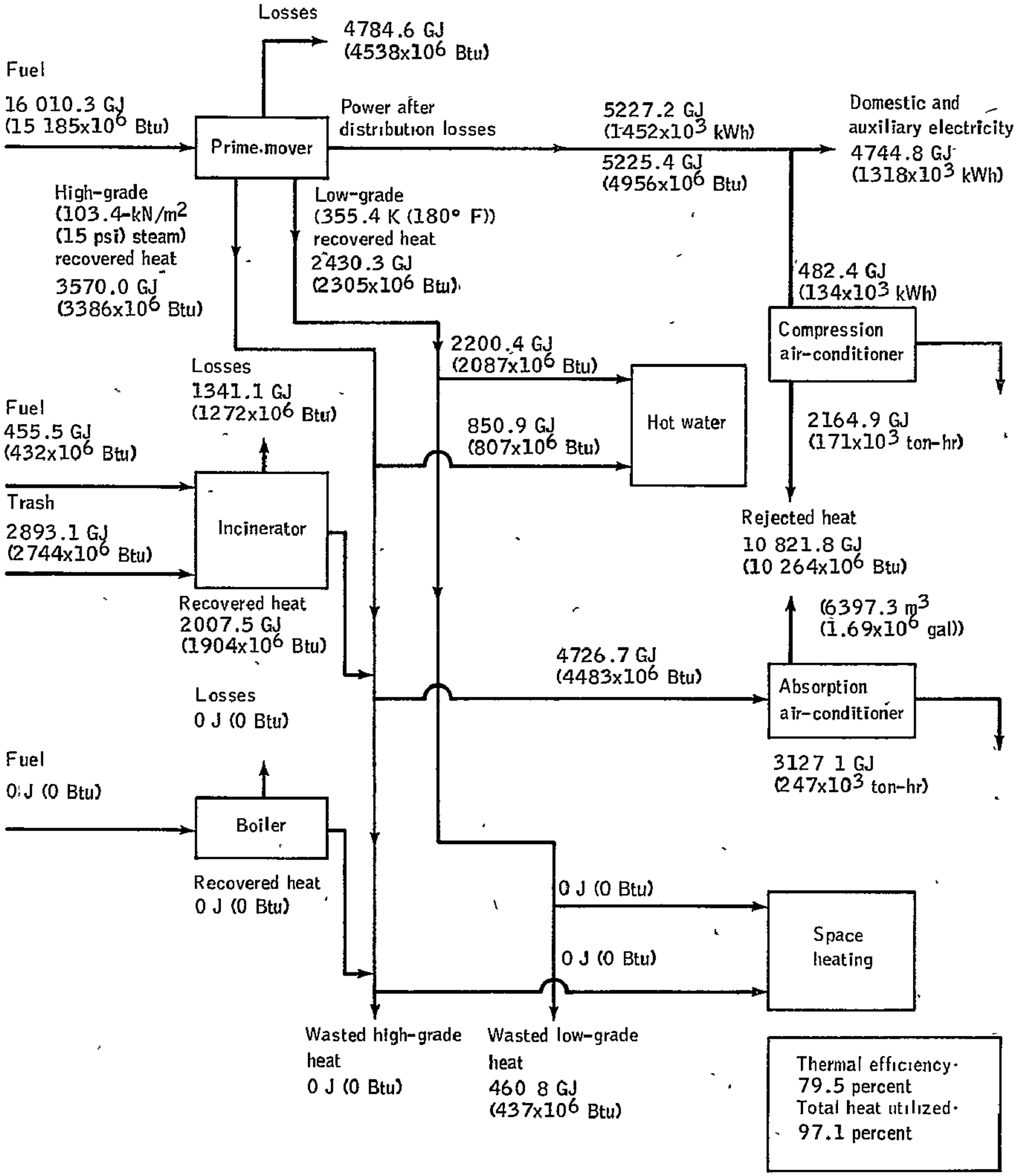
(b) Winter.

Figure 36.- Continued.



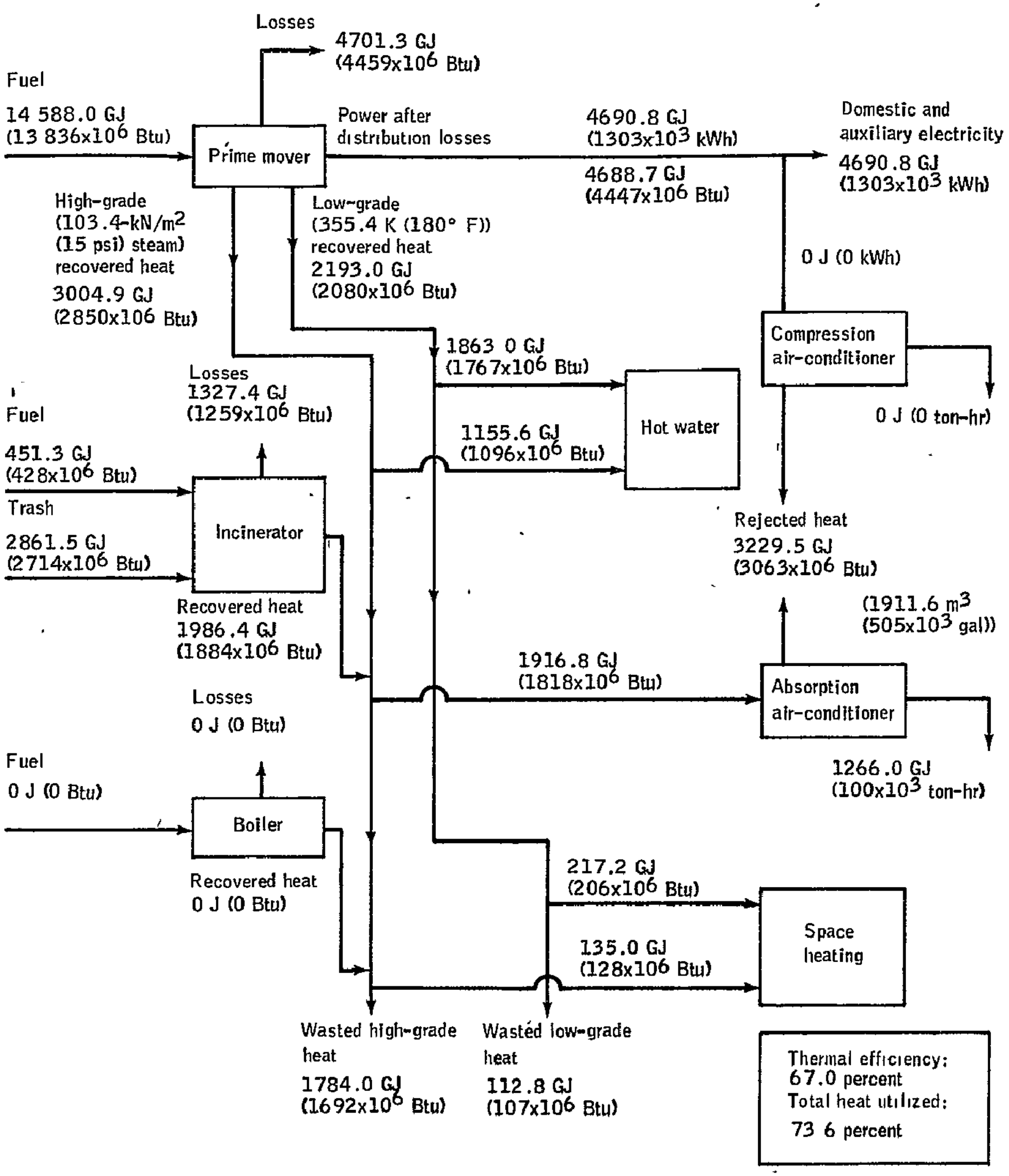
(c) Spring.

Figure 36.- Continued.



(d) Summer.

Figure 36.- Continued.



(e) Fall.

Figure 36.- Concluded.

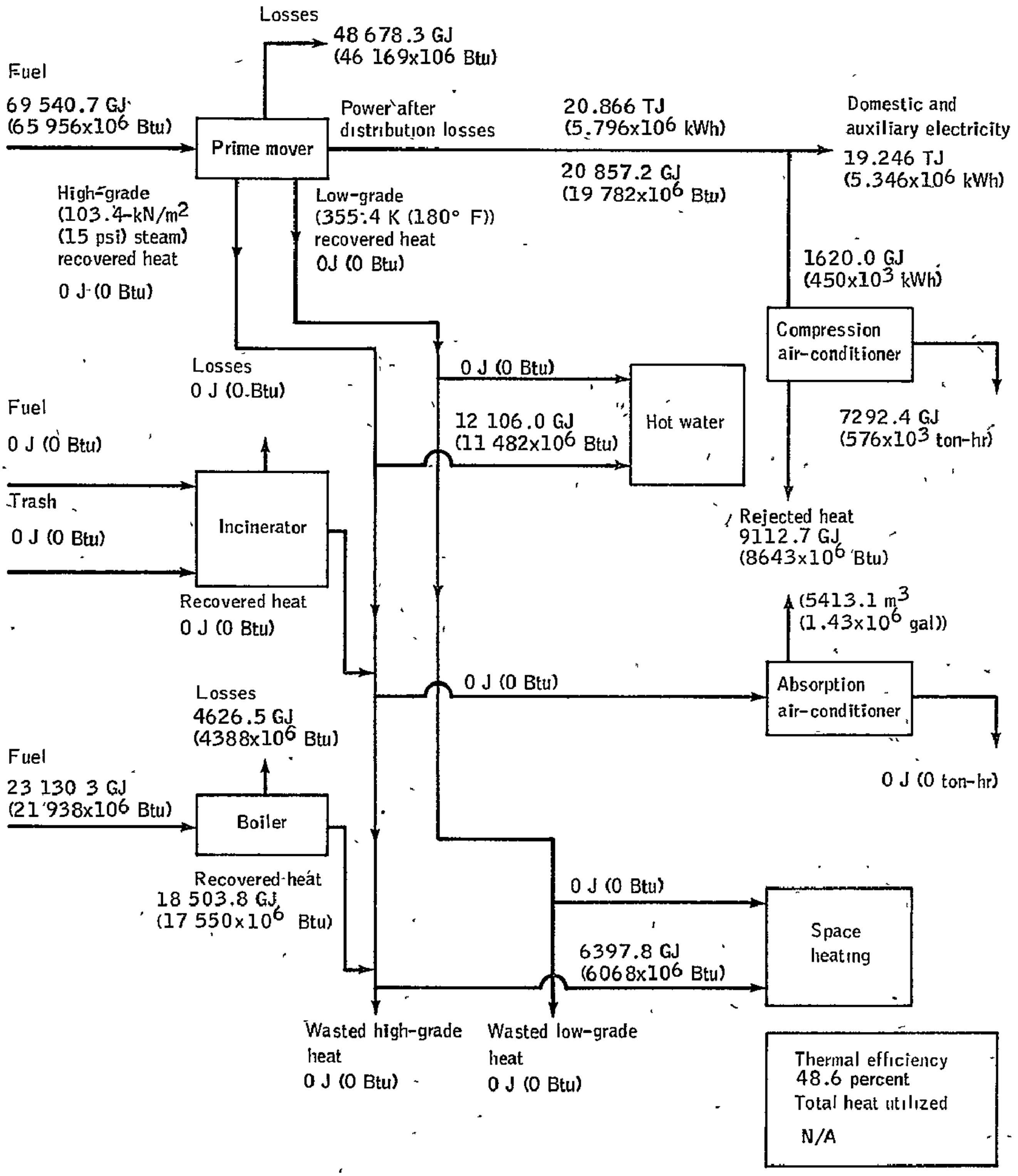
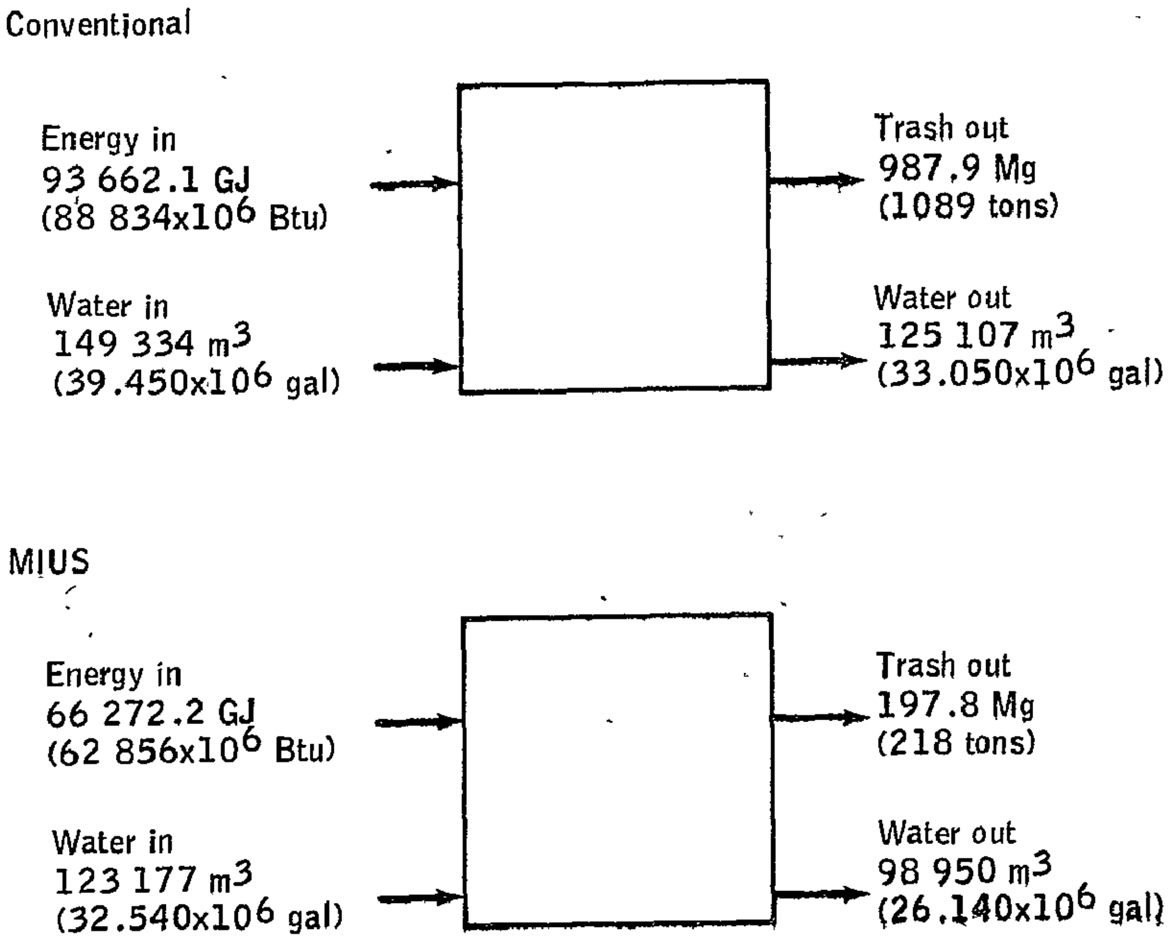
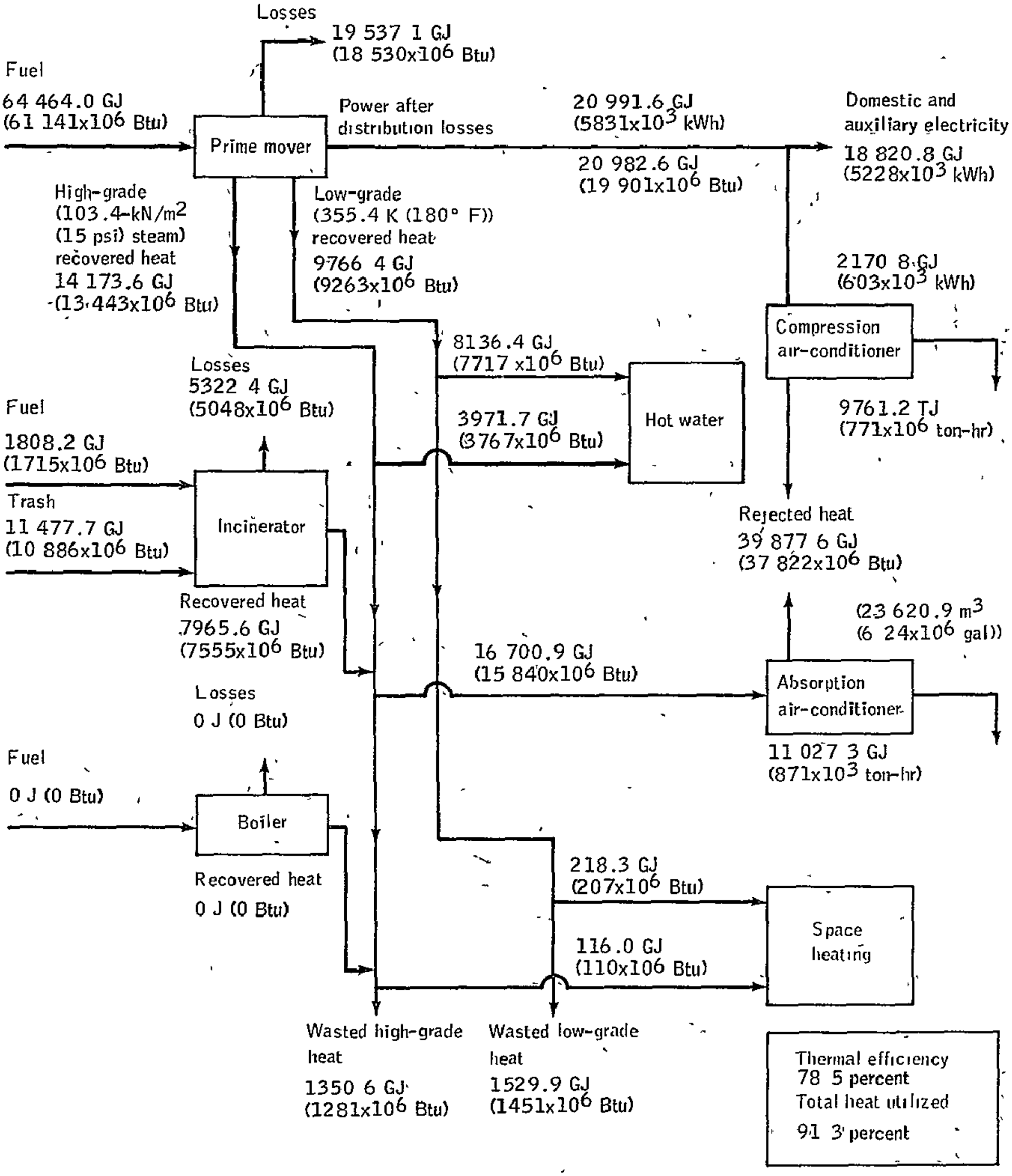


Figure 37.- Minneapolis 500-unit conventional system: annual.



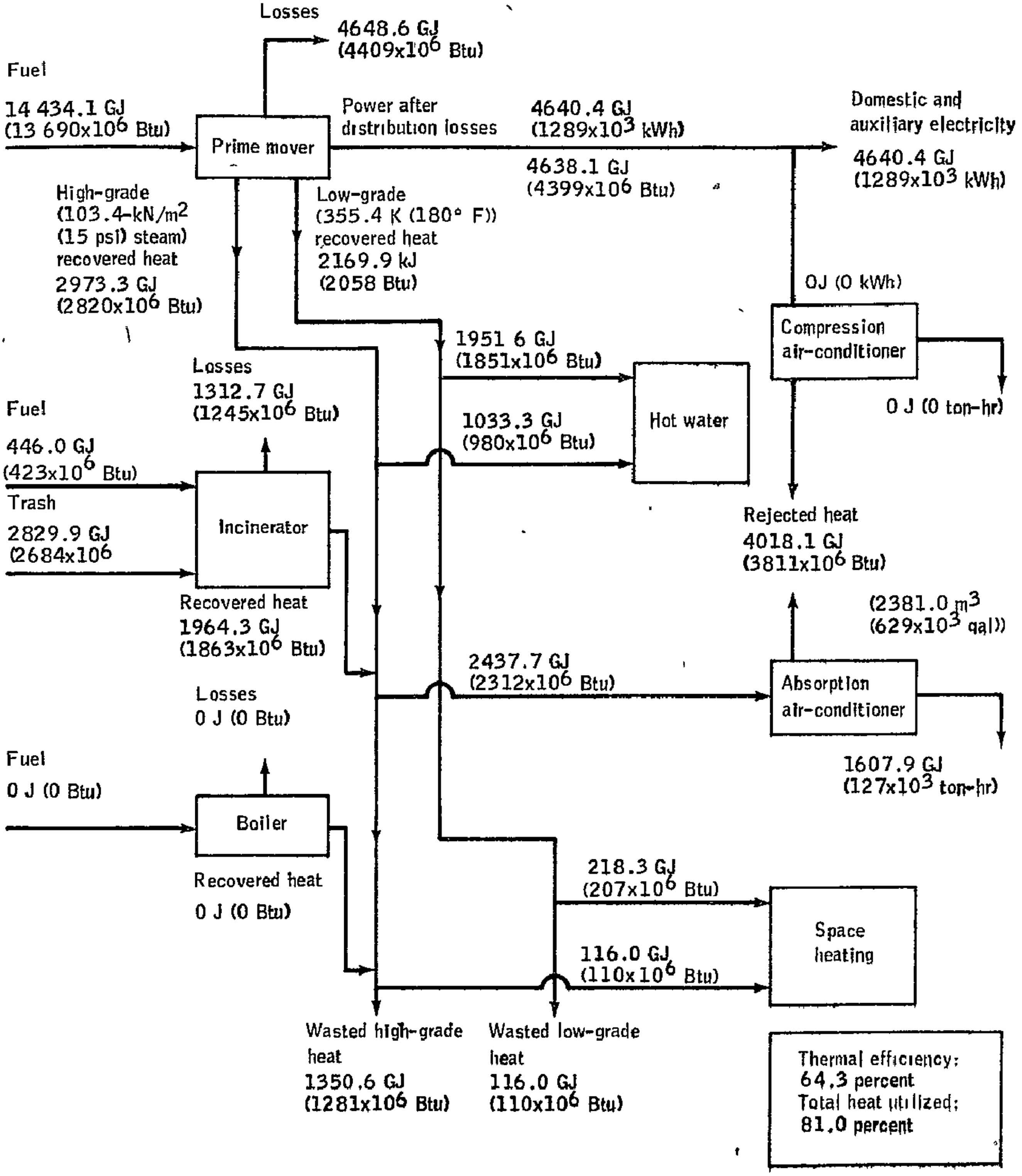
Energy savings:	29.2 percent
Water savings:	17.5 percent
Effluent water reduction:	20.9 percent
Trash reduction:	80.0 percent

Figure 38.- Annual summary: Houston 500-unit complex, comparison of the MIUS and the conventional system.



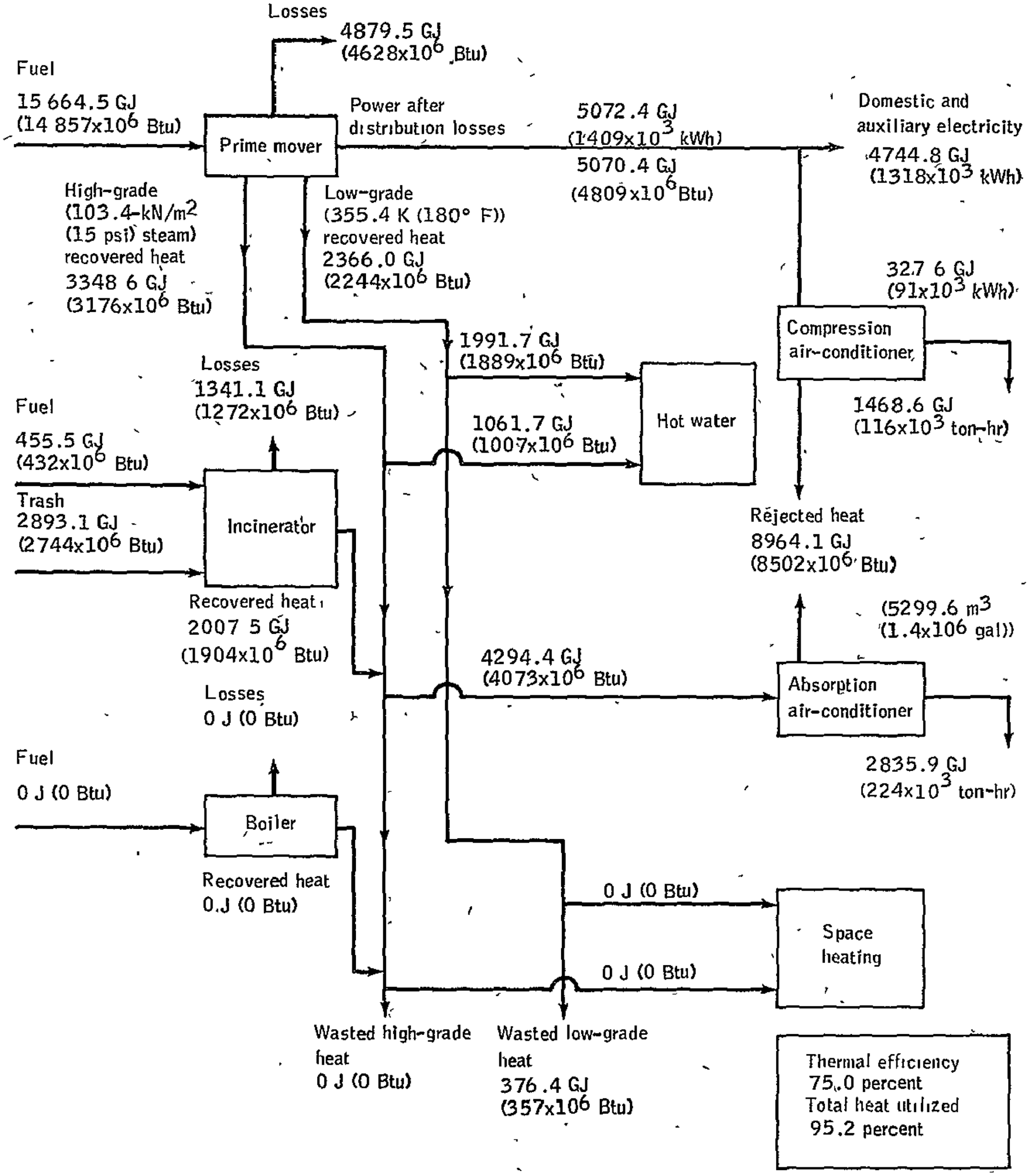
(a) Annual.

Figure 39.- Houston 500-unit MIUS.



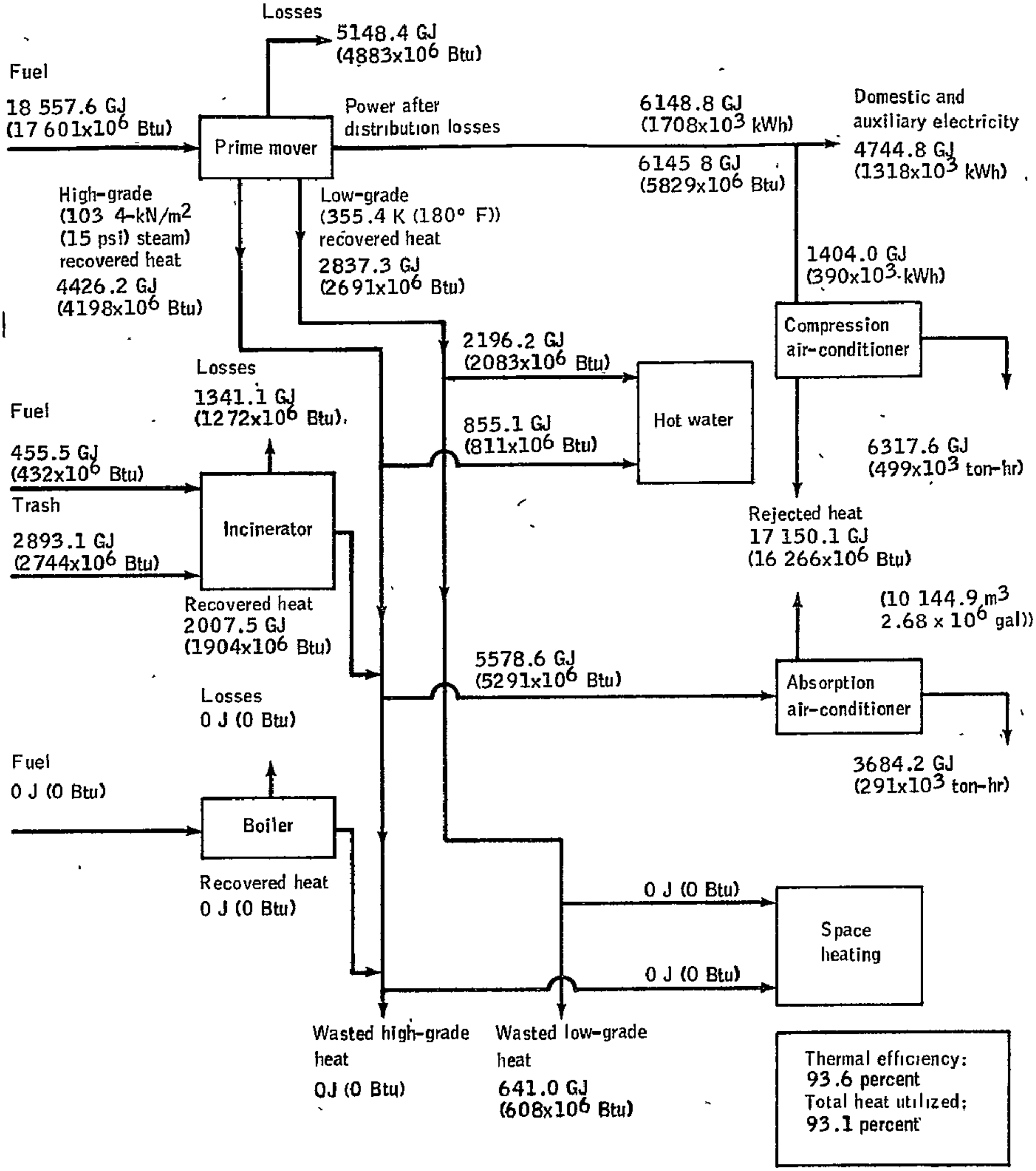
(b) Winter.

Figure 39.- Continued.



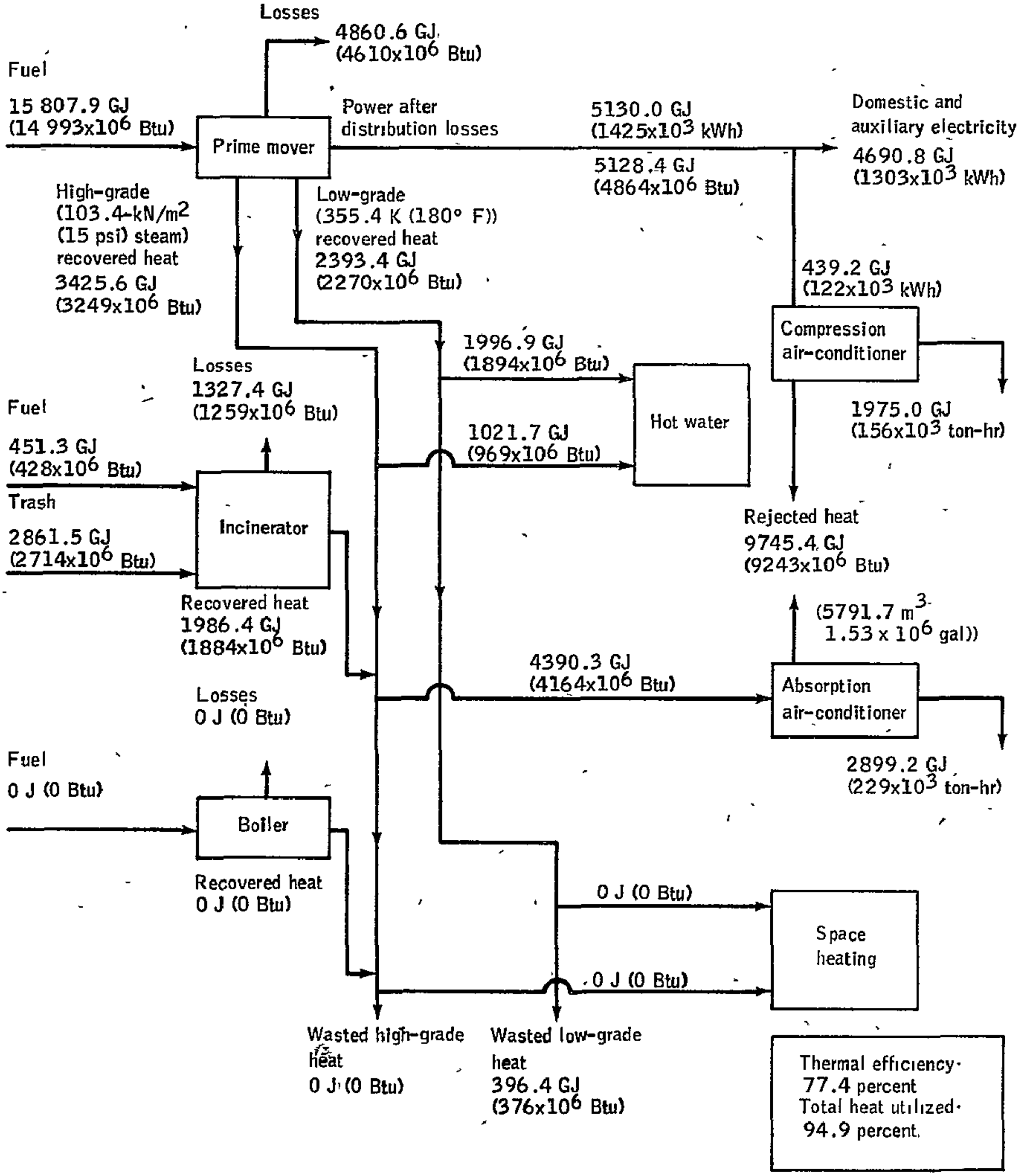
(c) Spring.

Figure 39.- Continued.



(d) Summer.

Figure 39.- Continued.



(e) Fall.

Figure 39.- Concluded.

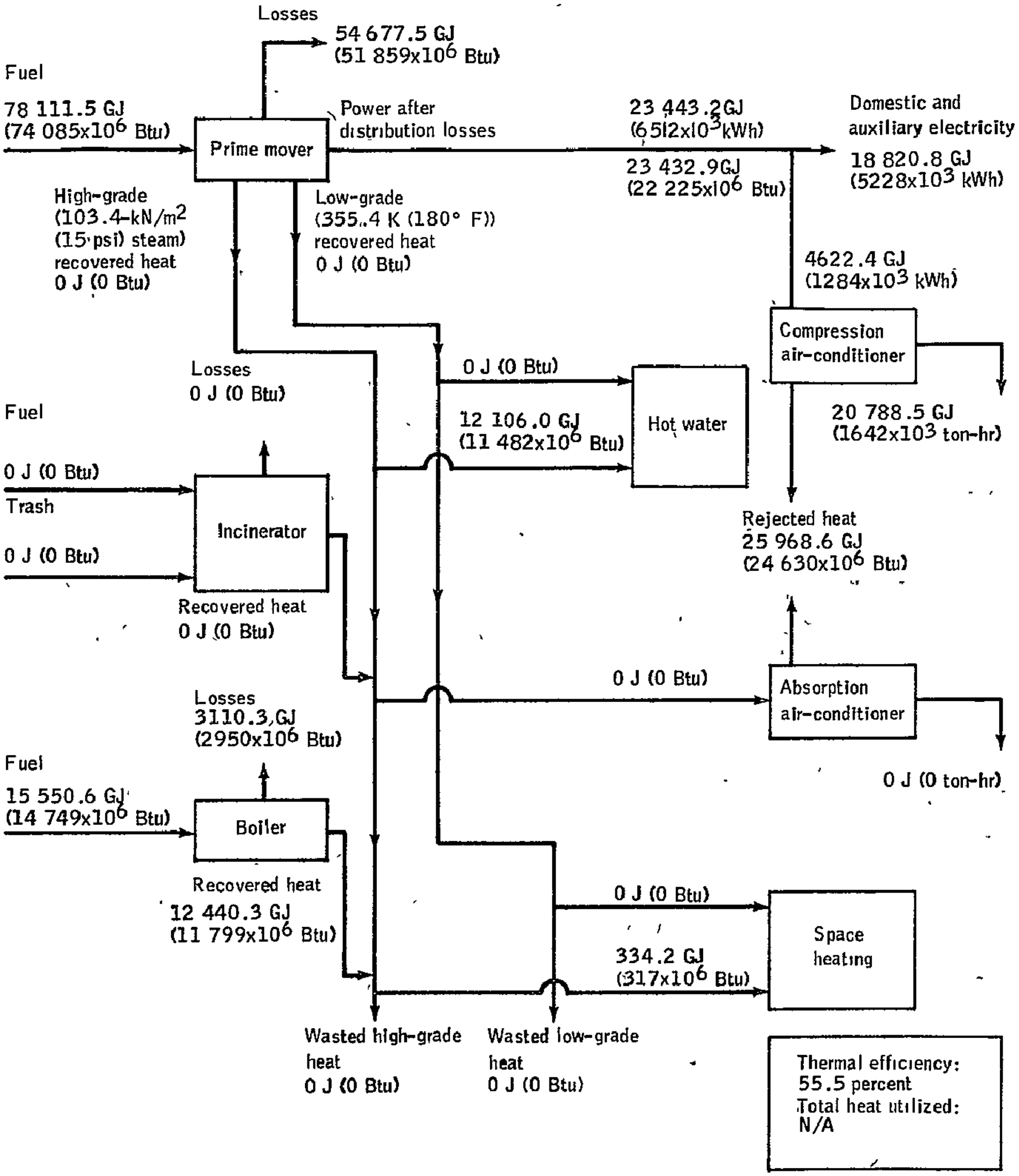
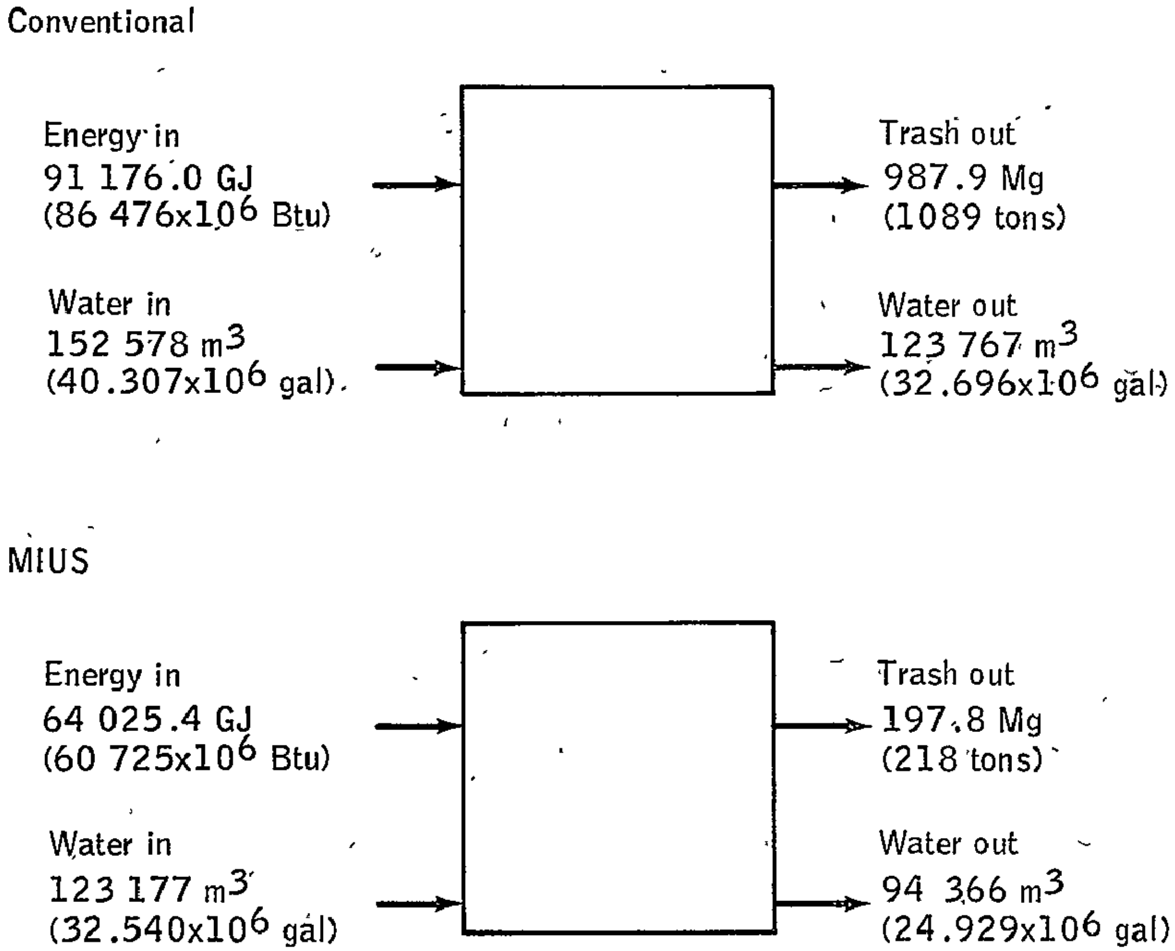
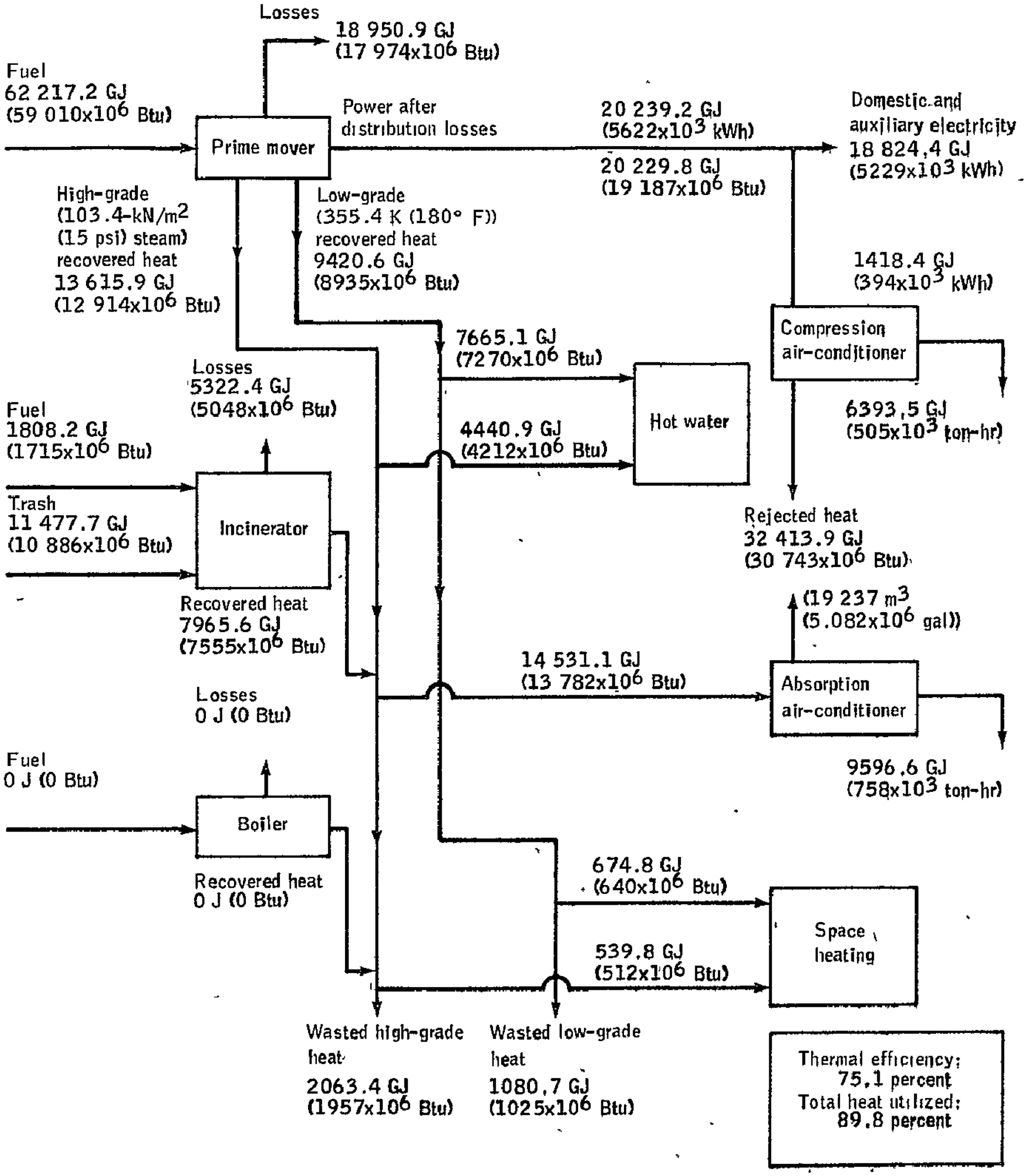


Figure 40.- Houston 500-unit conventional system: annual.



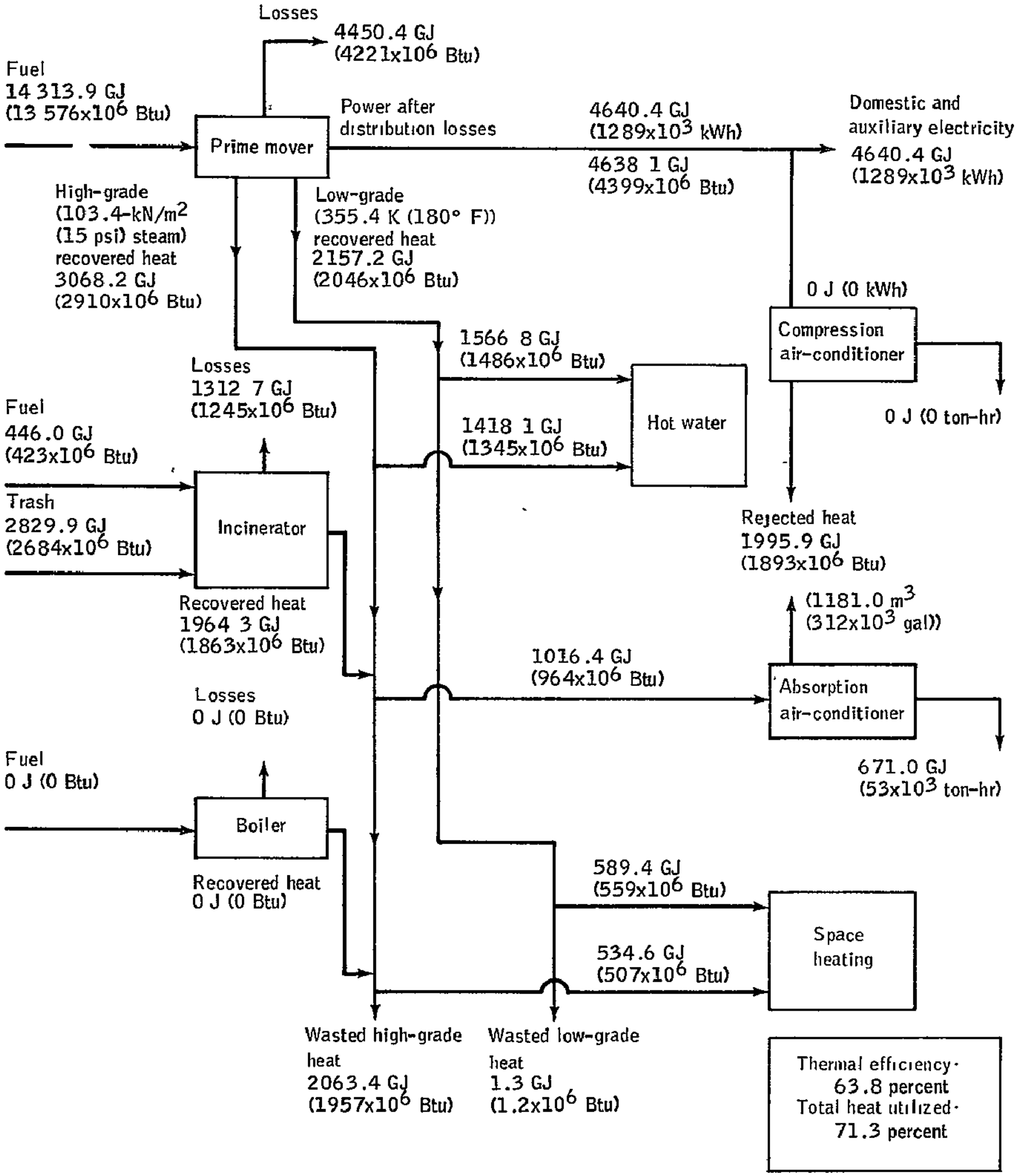
Energy savings:	29.8 percent
Water savings:	19.3 percent
Effluent water reduction:	23.8 percent
Trash reduction:	80.0 percent

Figure 41.- Annual summary: Las Vegas 500-unit complex, comparison of the MIUS and the conventional system.



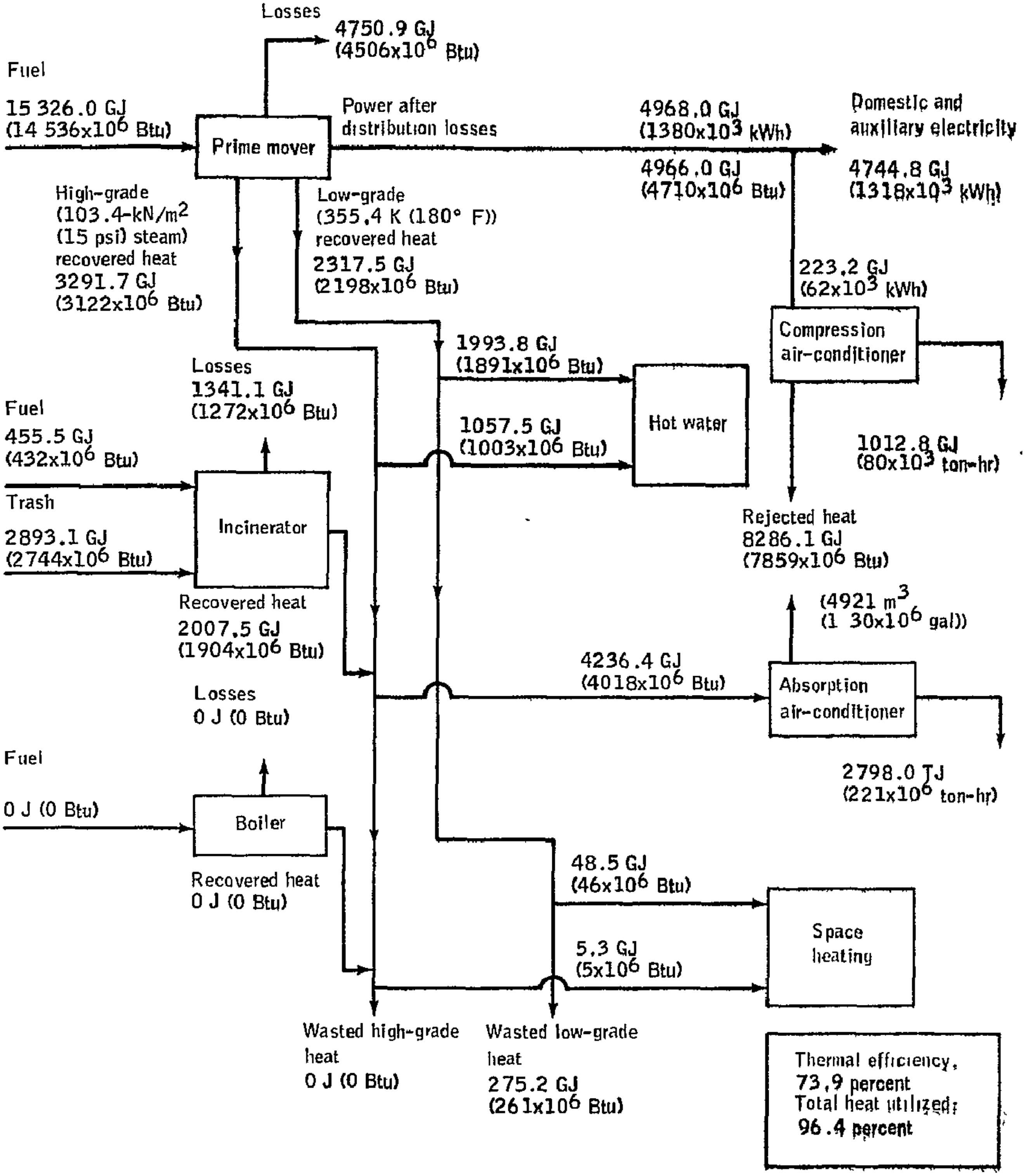
(a) Annual.

Figure 42.- Las Vegas 500-unit MIUS.



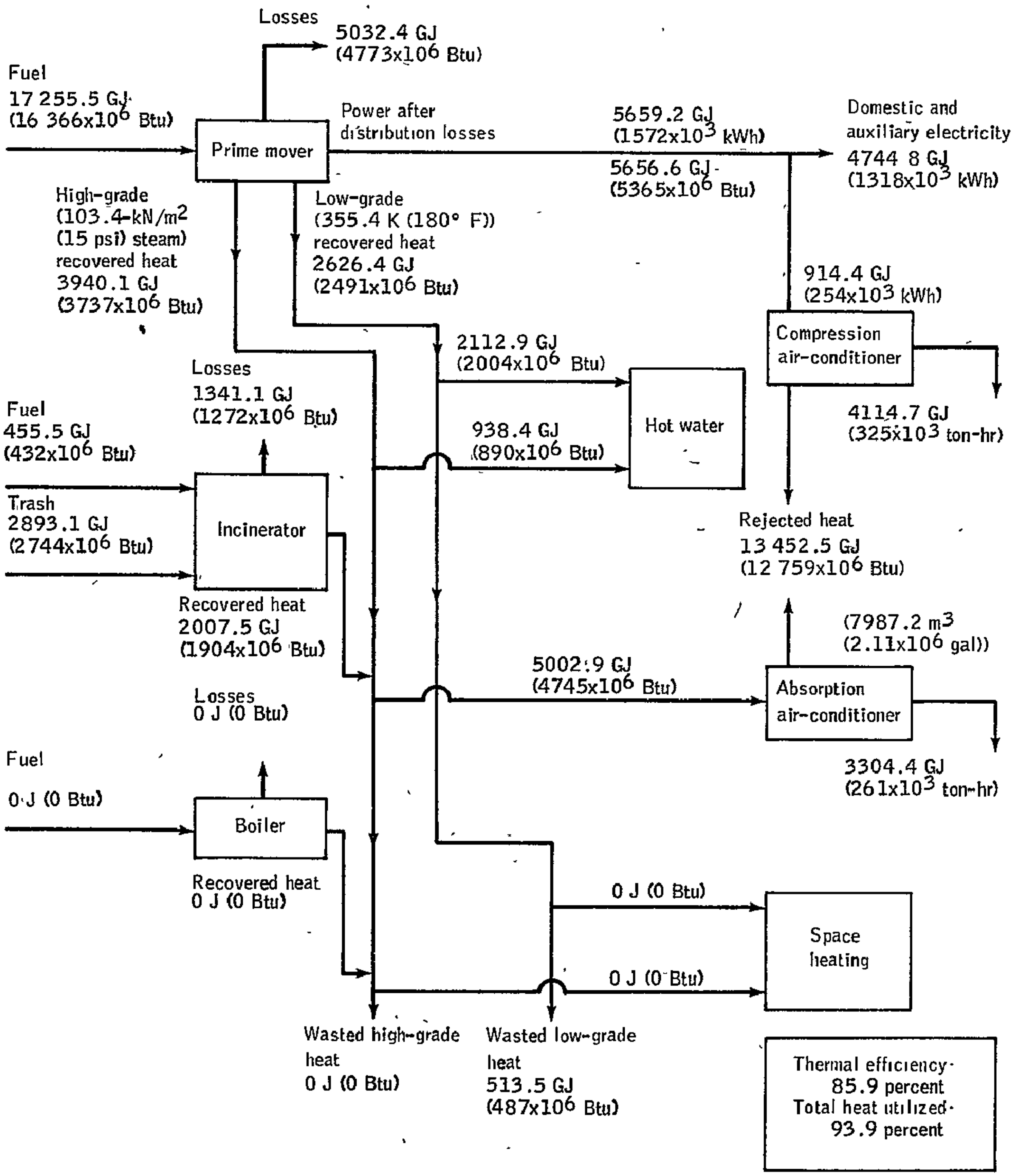
(b) Winter.

Figure 42.- Continued.



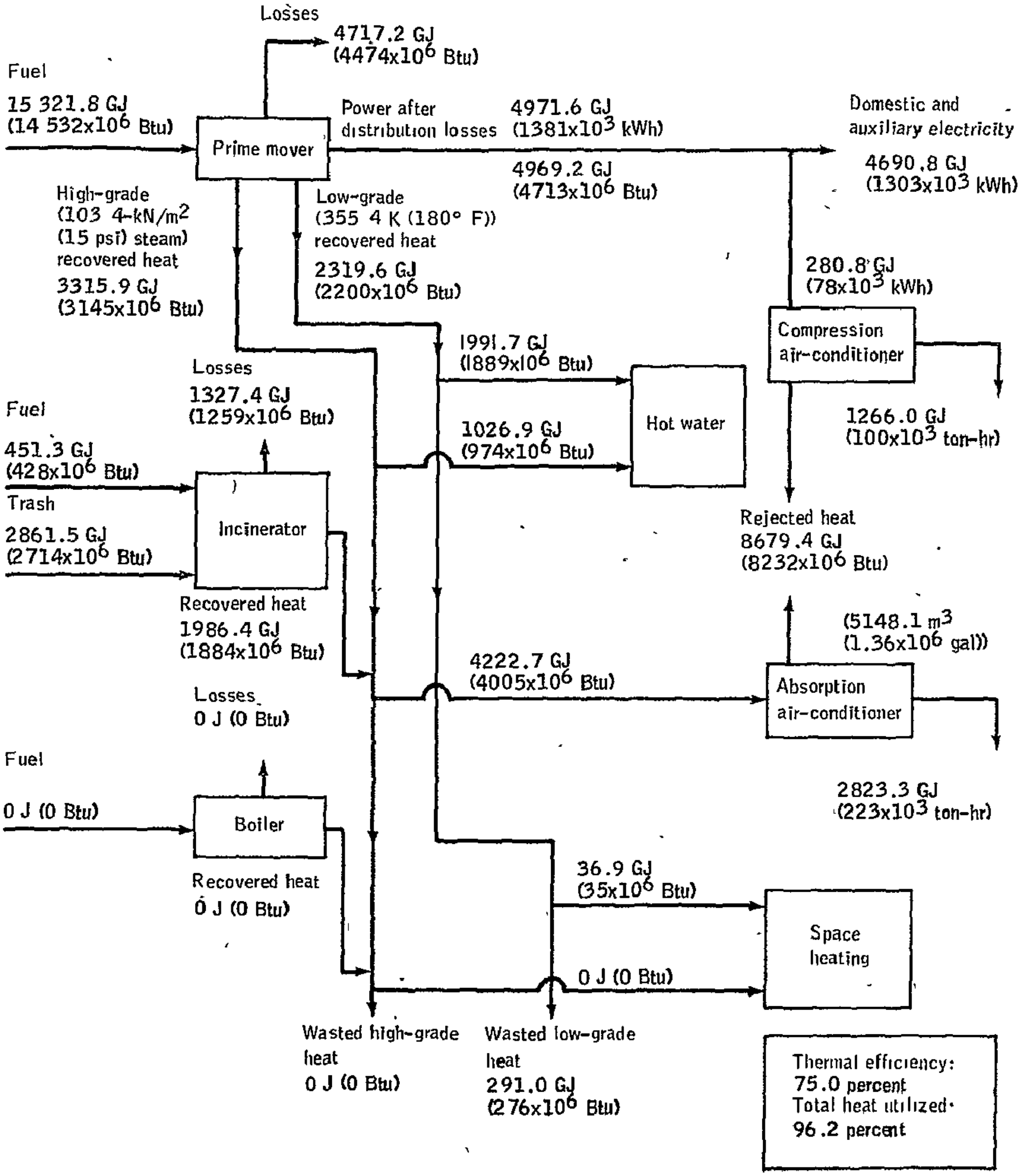
(c) Spring.

Figure 42.- Continued.



(d) Summer.

Figure 42.- Continued.



(e) Fall.

Figure 42.- Concluded.

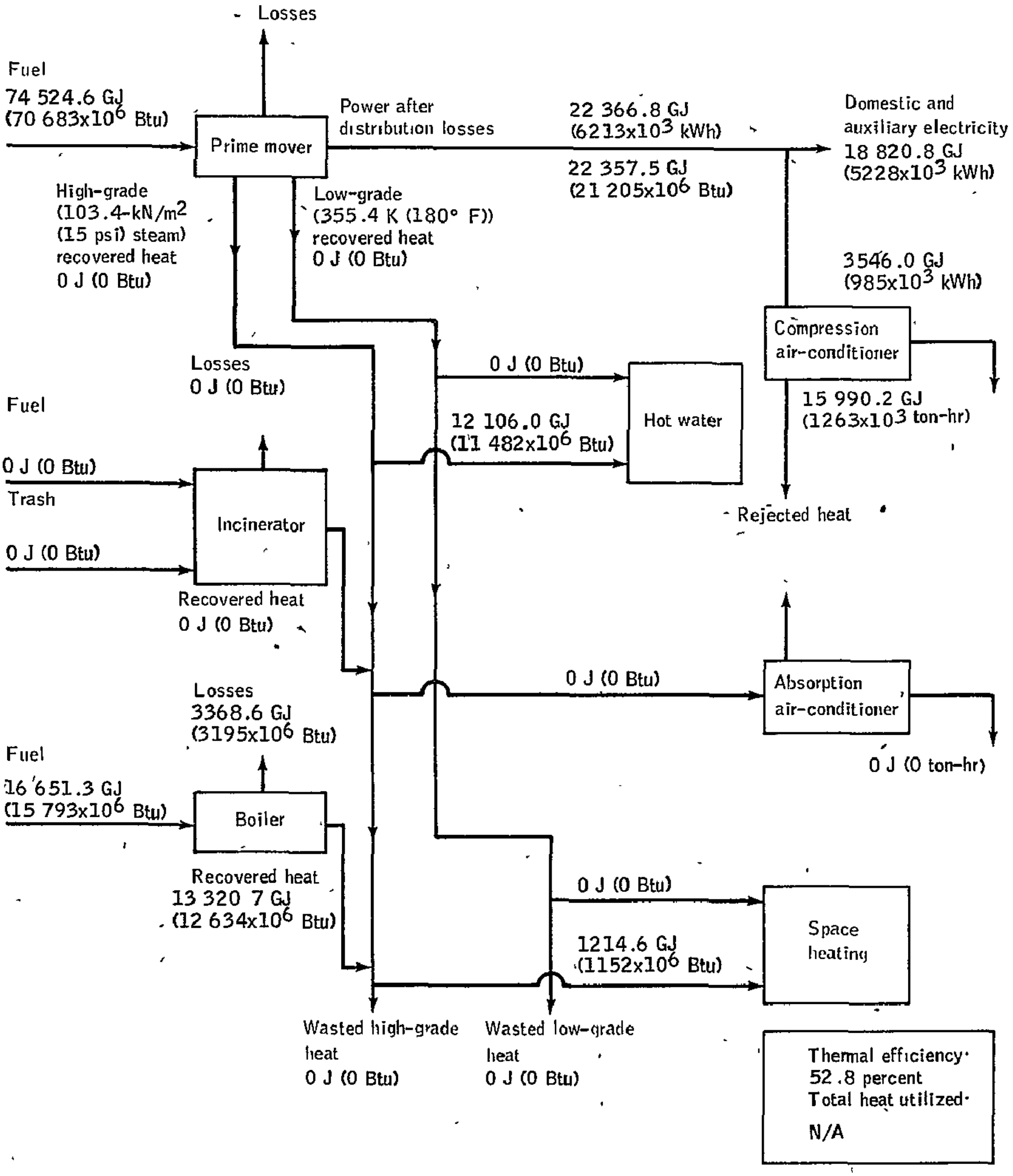
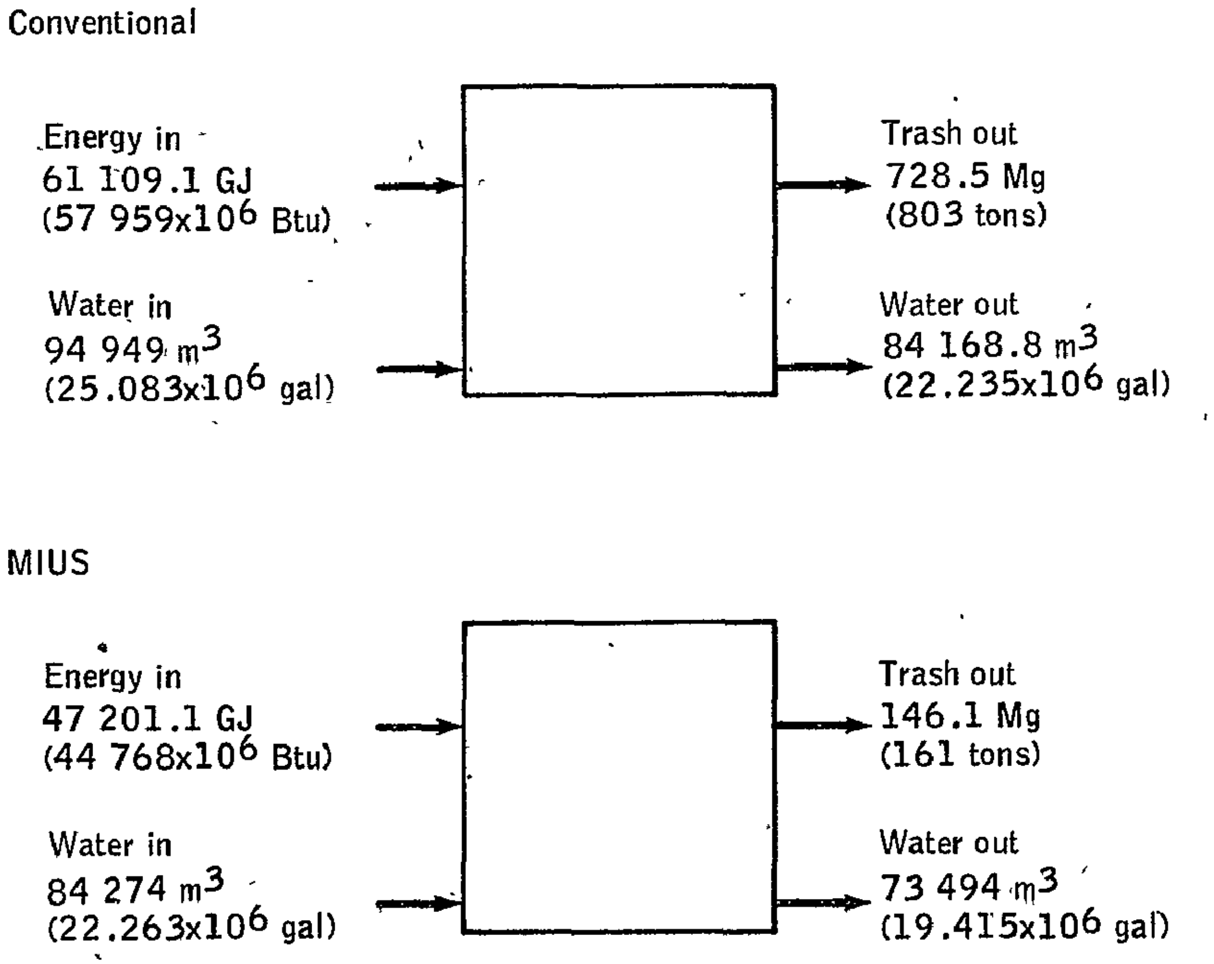
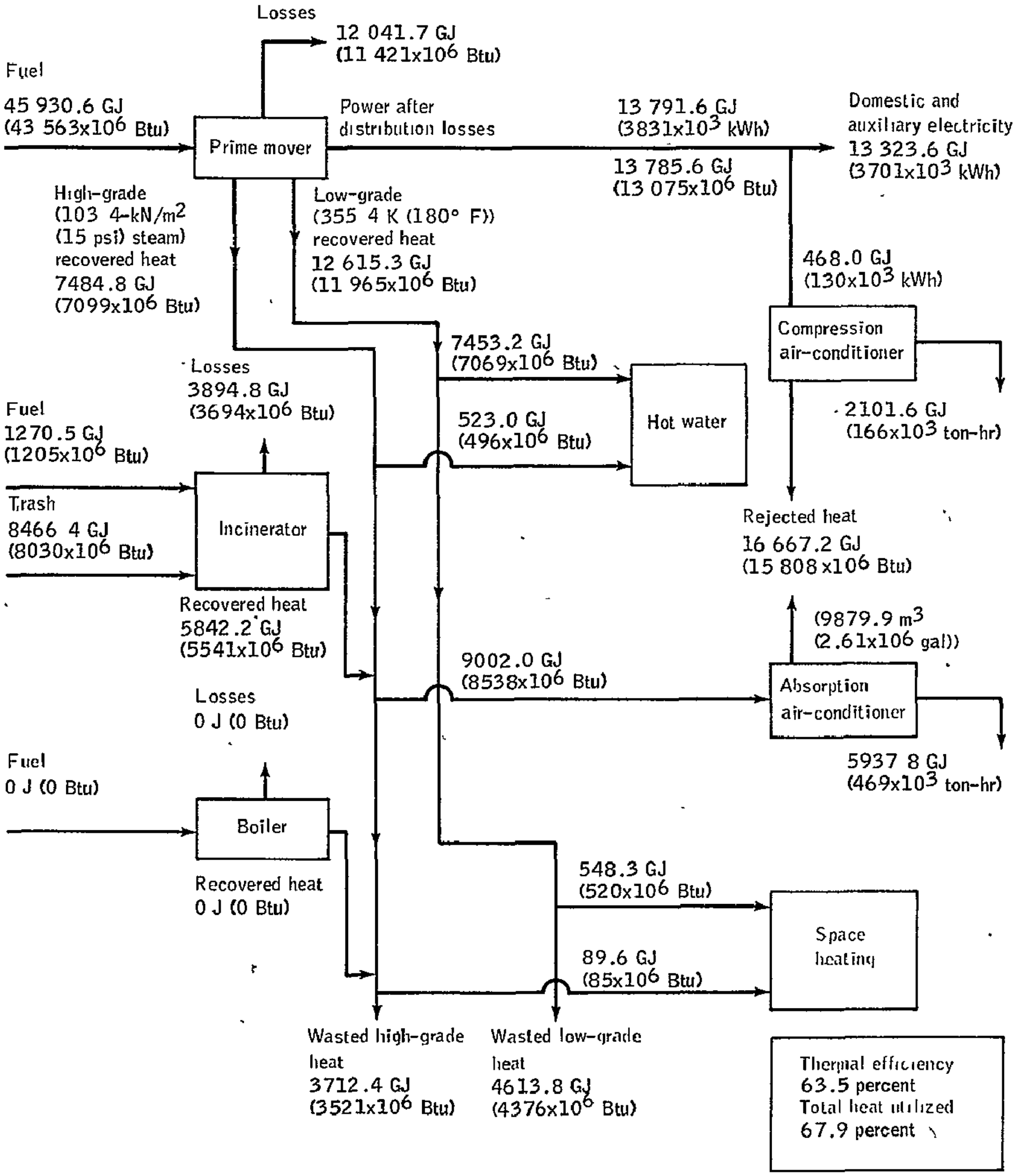


Figure 43.- Las Vegas 500-unit conventional system: annual.



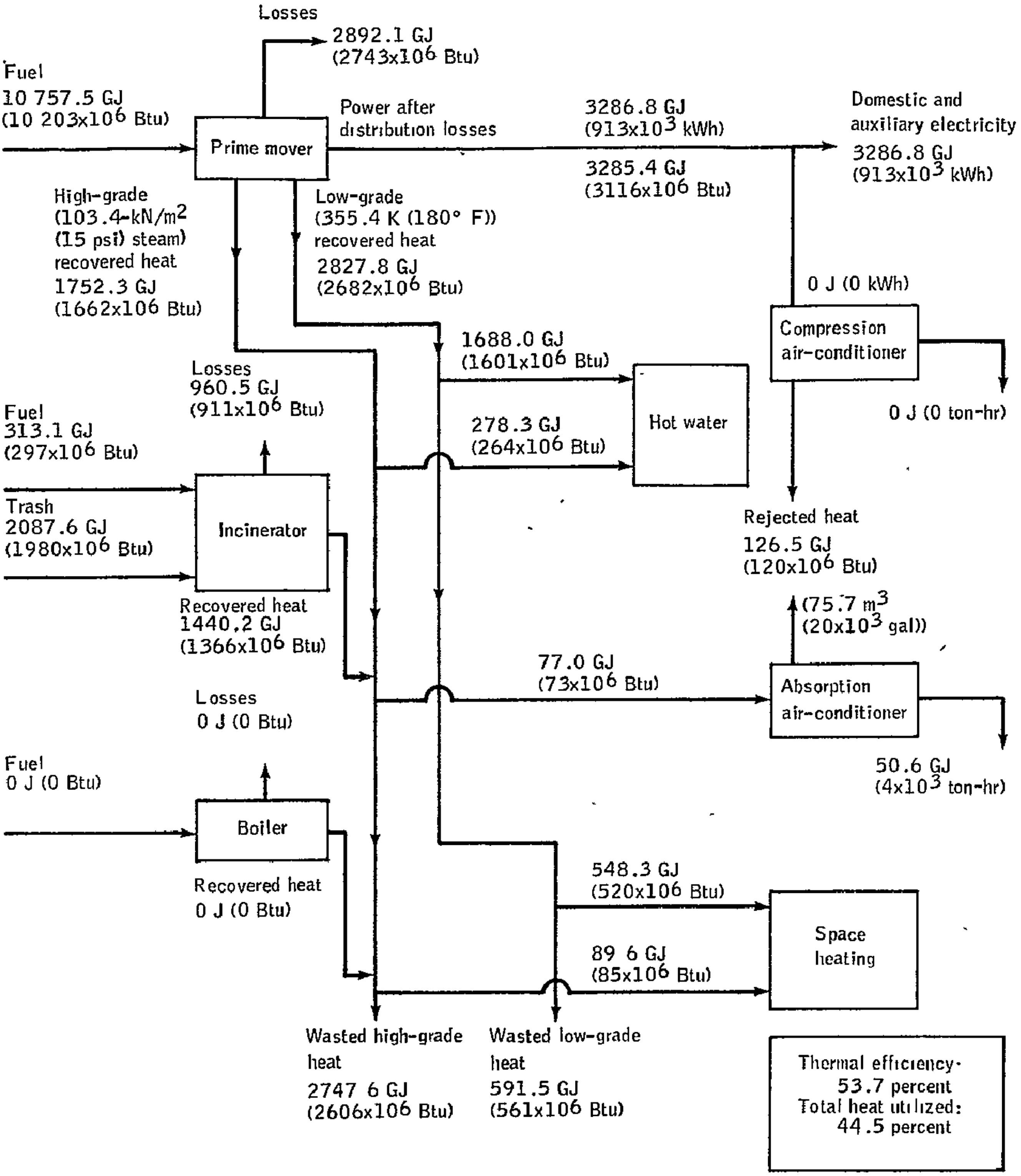
Energy savings:	22.8 percent
Water savings:	11.2 percent
Effluent water reduction:	12.7 percent
Trash reduction:	80.0 percent

Figure 44.- Annual summary: Washington 300-unit complex, comparison of the MIUS and the conventional system.



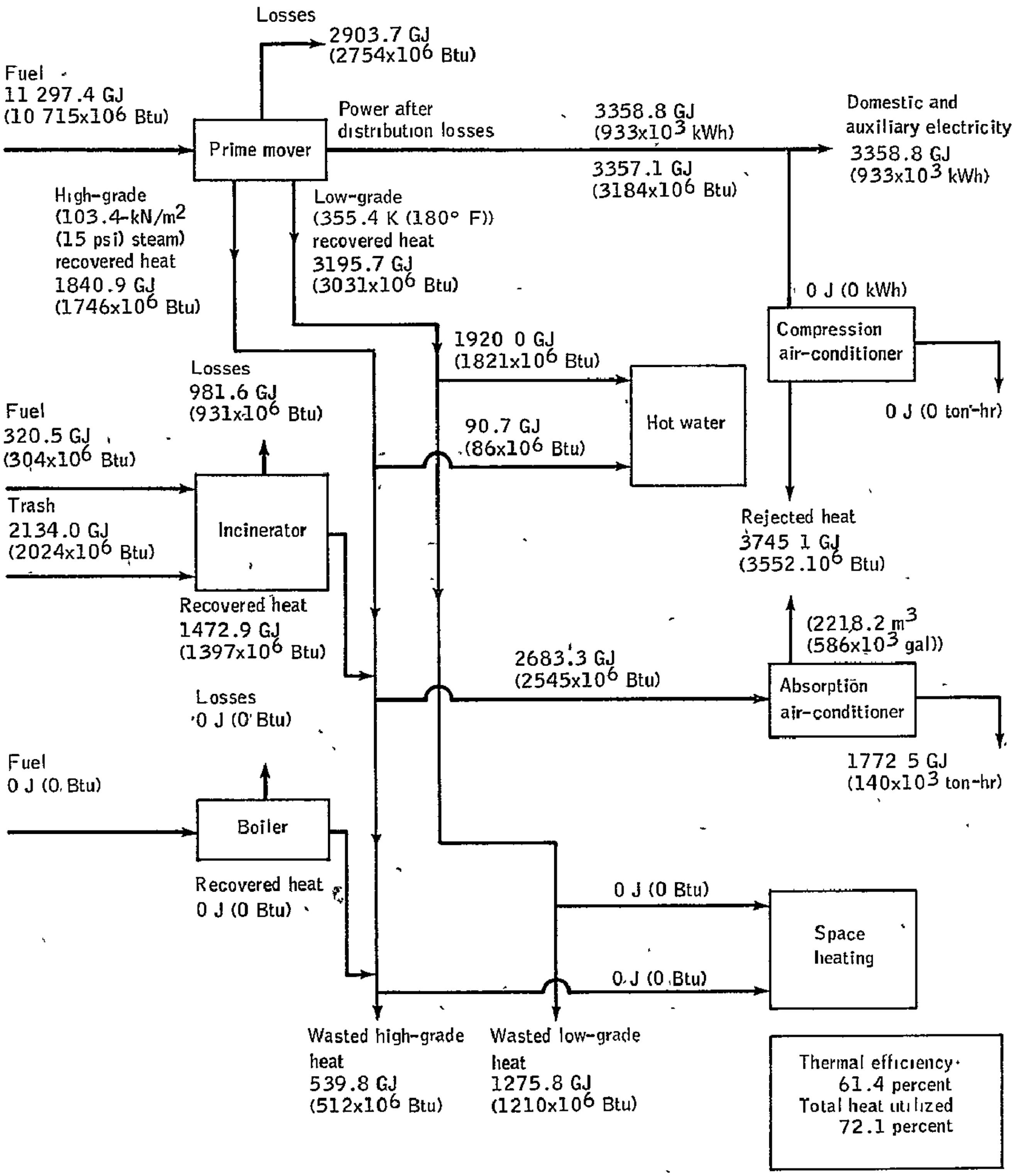
(a) Annual.

Figure 45.- Washington 300-unit MIUS.



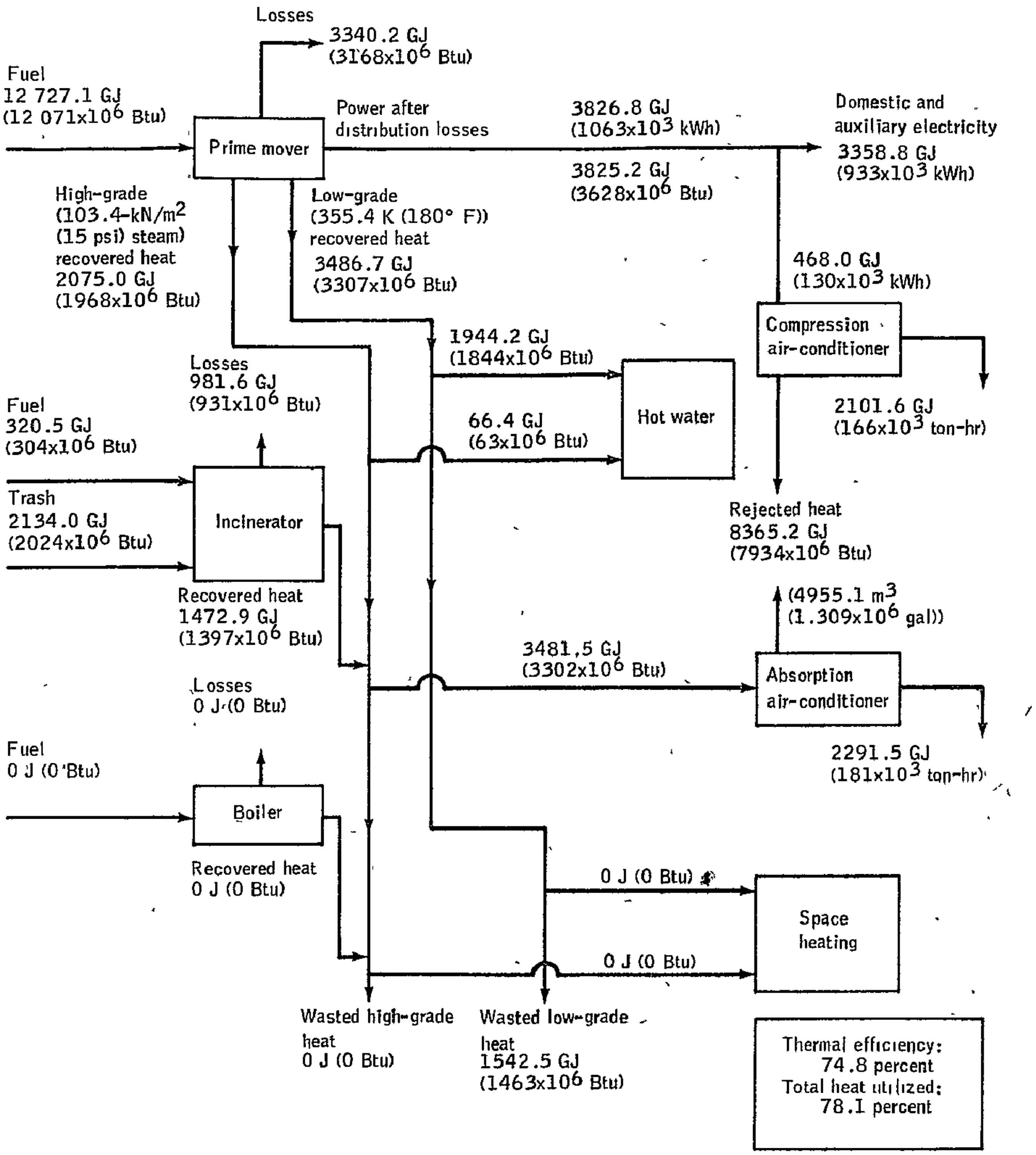
(b) Winter.

Figure 45.- Continued.



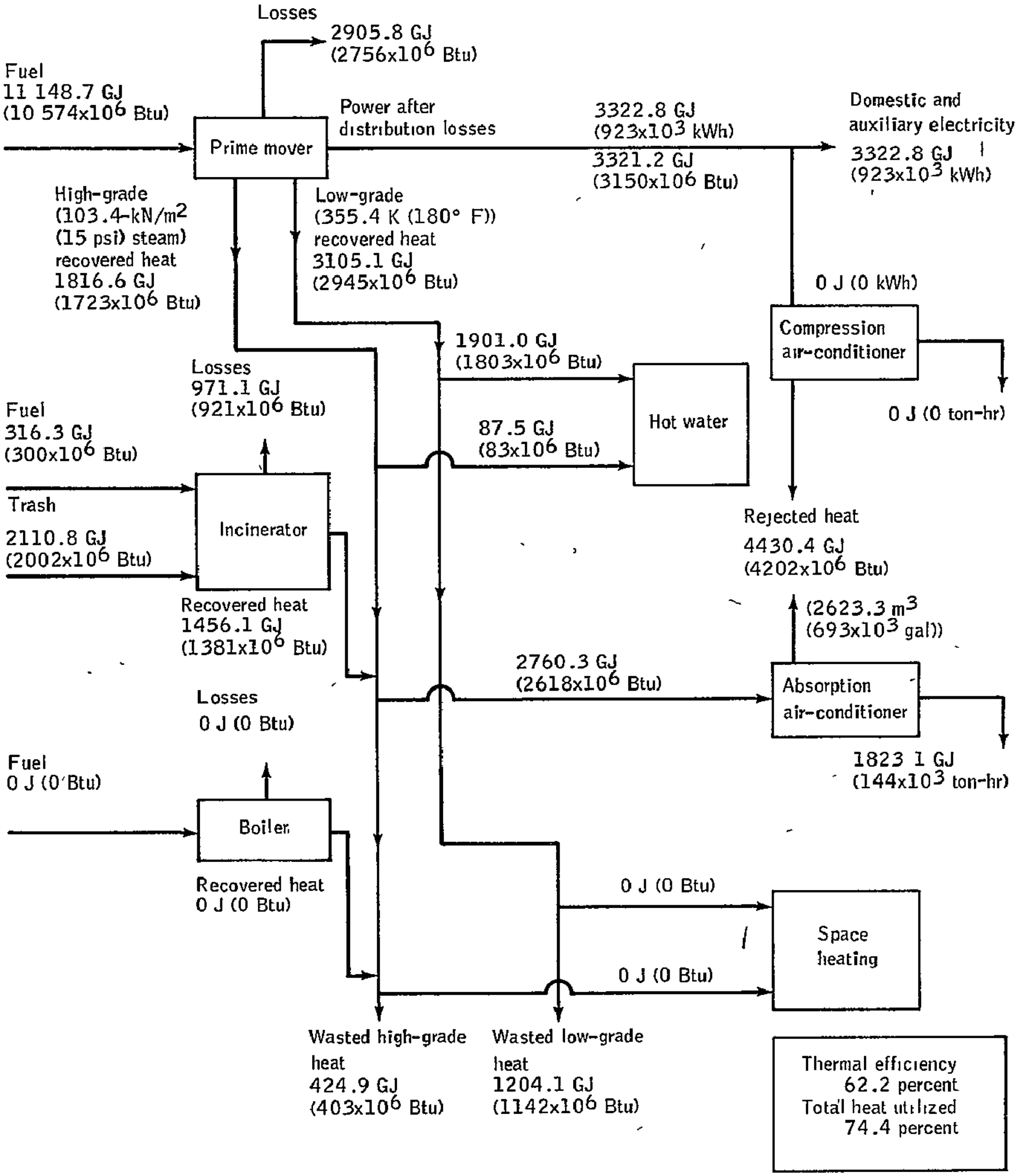
(c) Spring.

Figure 45.- Continued.



(d) Summer.

Figure 45.- Continued.



(e) Fall.

Figure 45.- Concluded.

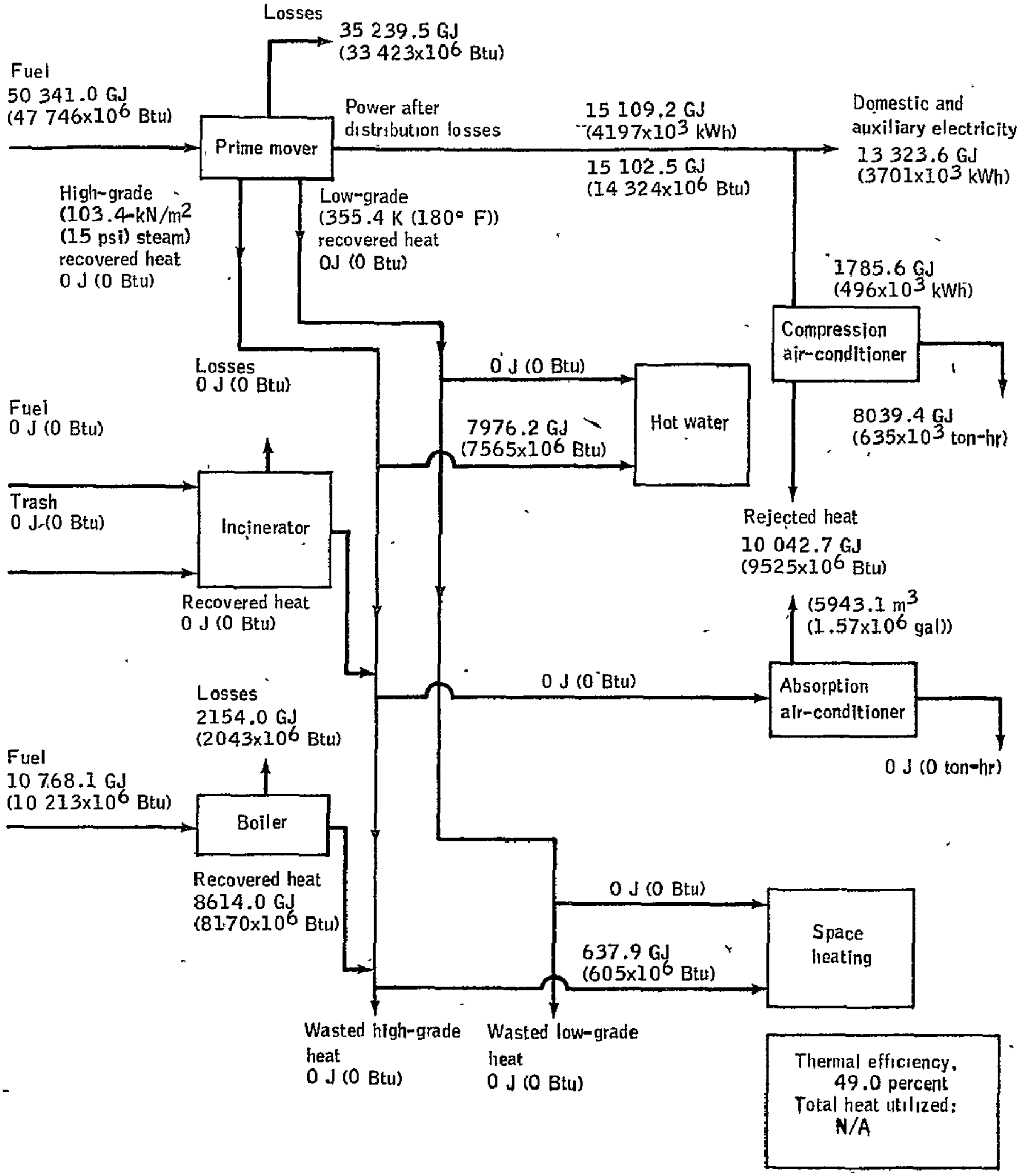
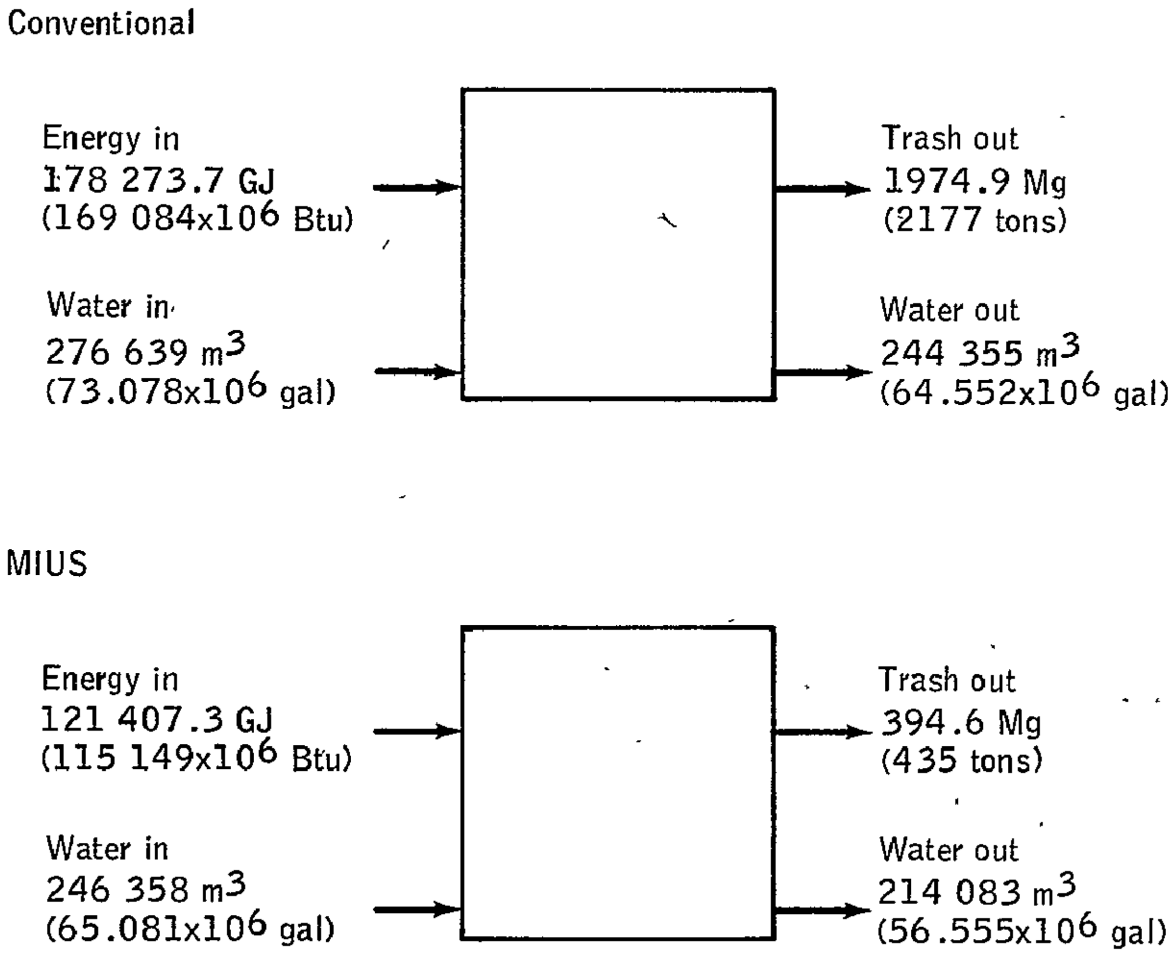


Figure 46.- Washington 300-unit conventional system: annual.



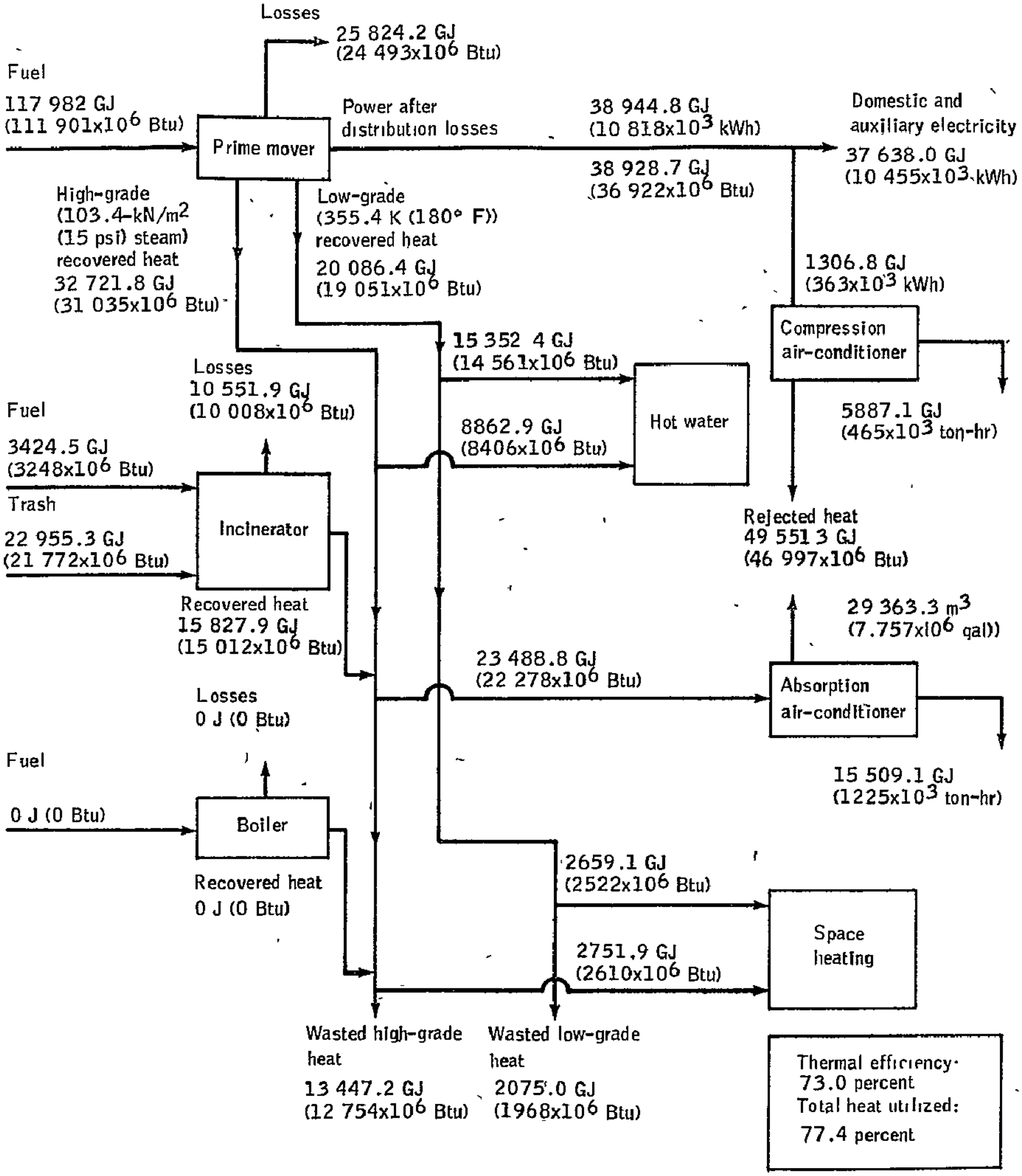
Energy savings: 31.9 percent

Water savings: 10.9 percent

Effluent water reduction: 12.4 percent

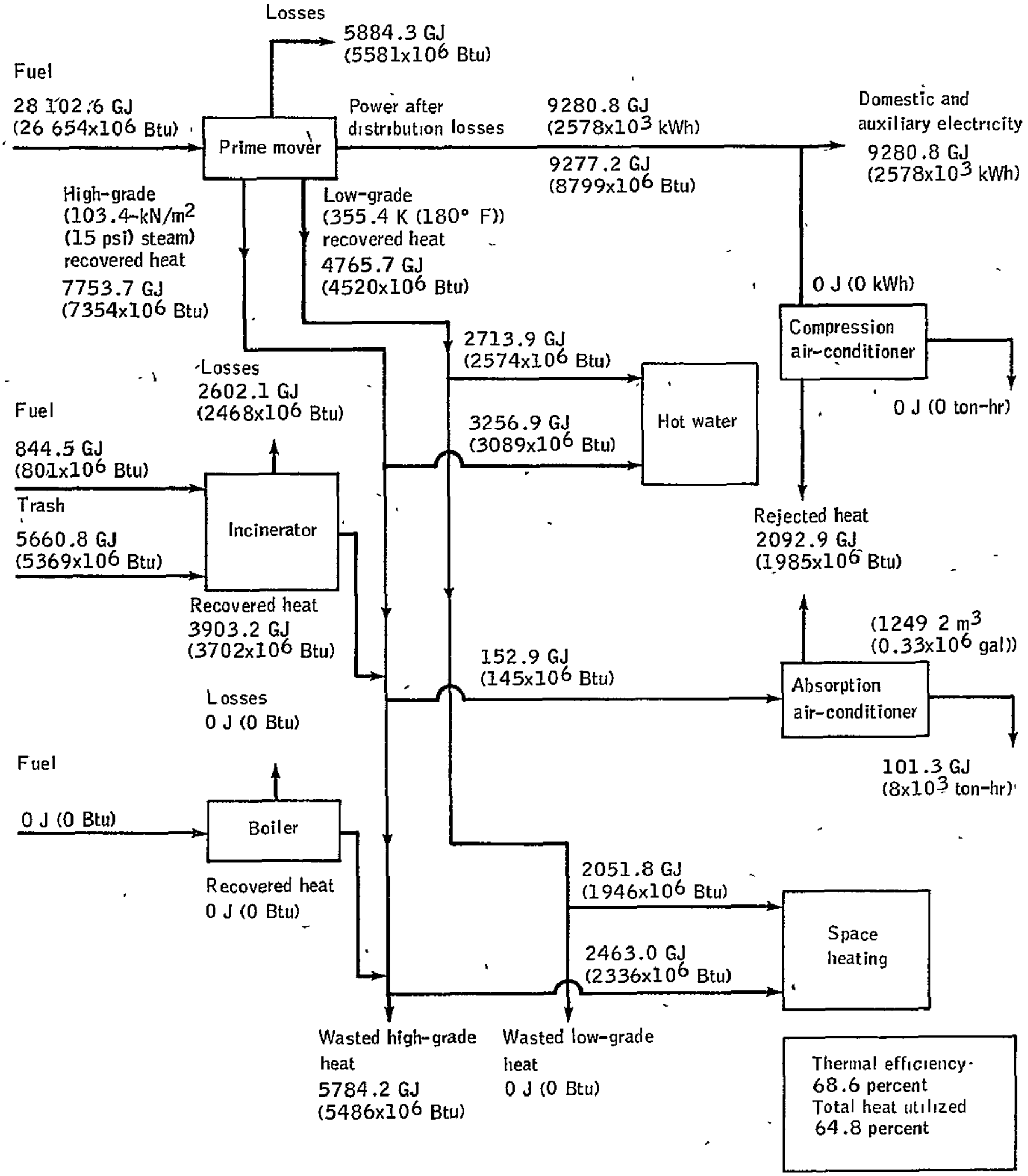
Trash reduction: 80.0 percent

Figure 47.- Annual summary: Washington 1000-unit complex, comparison of the MIUS and the conventional system.



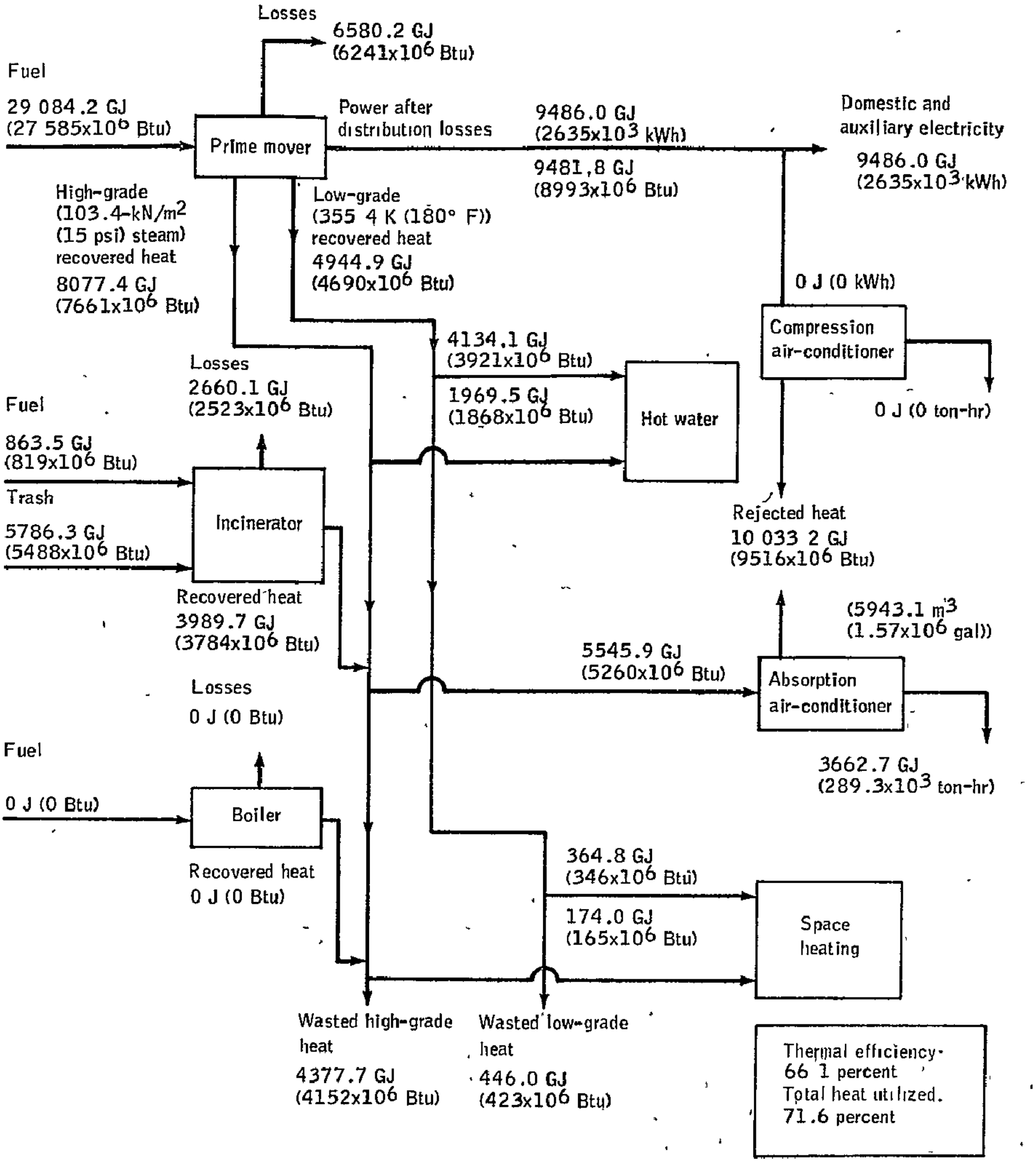
(a) Annual.

Figure 48.- Washington 1000-unit MIUS.



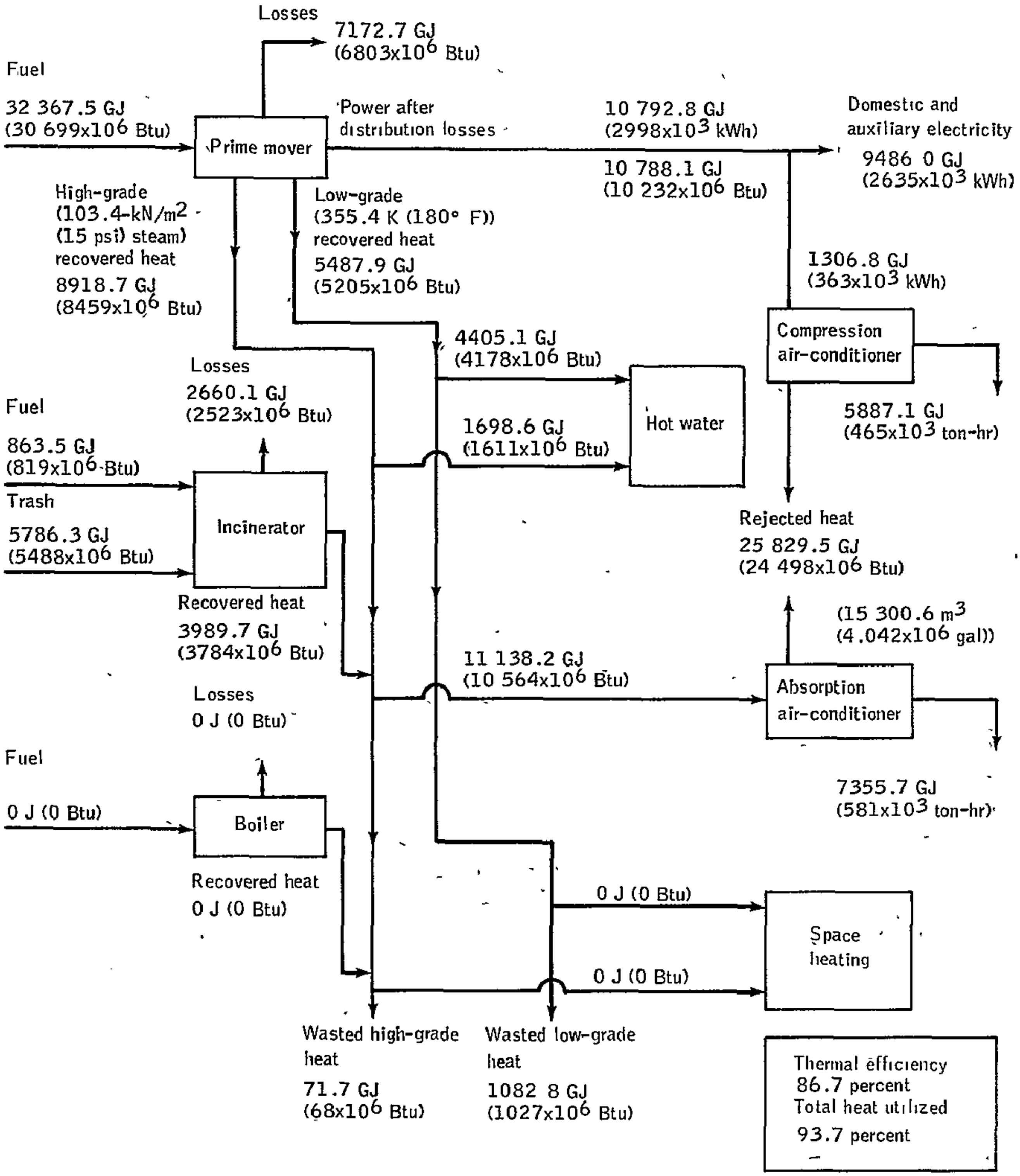
(b) Winter.

Figure 48.- Continued.



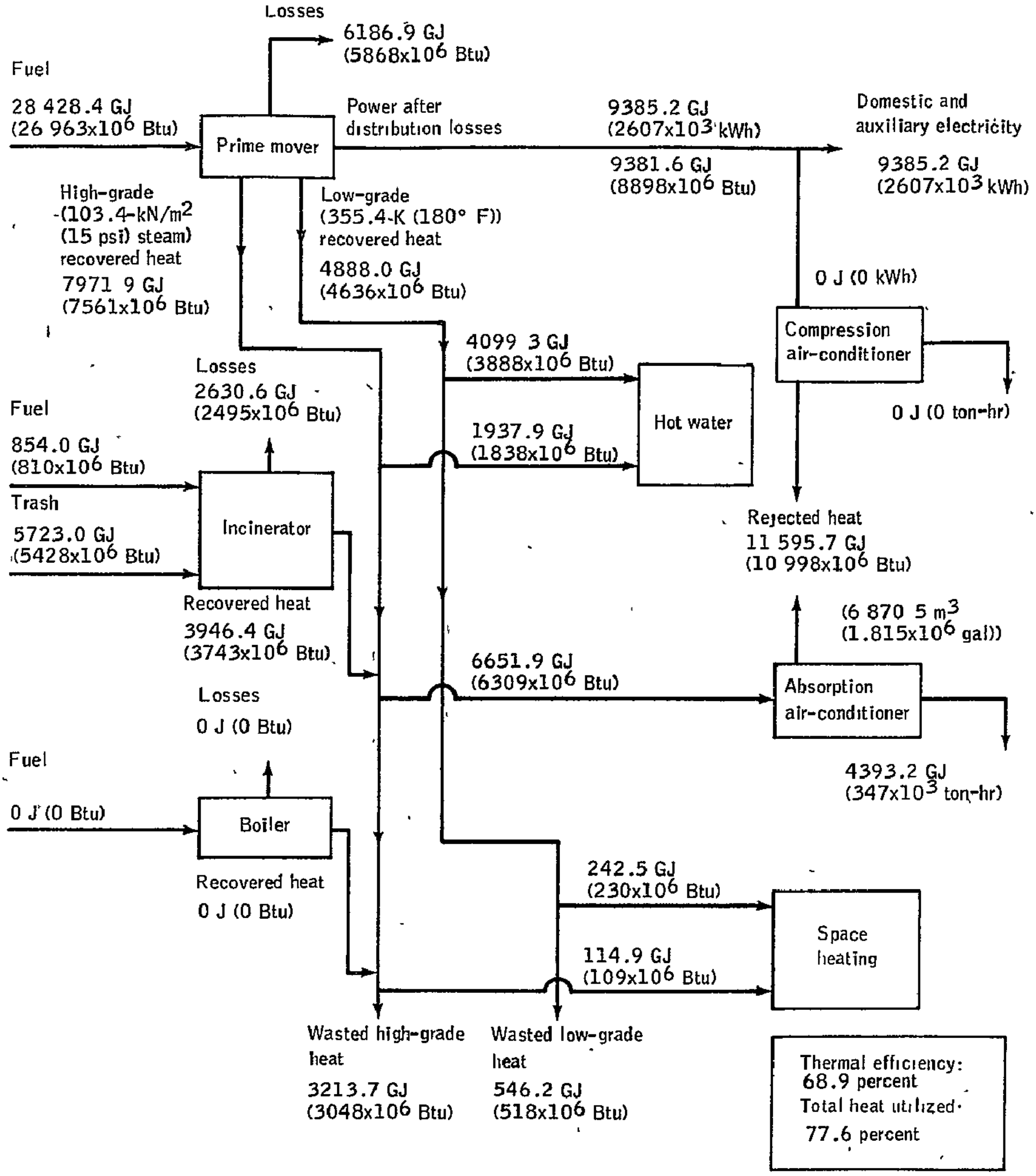
(c) Spring.

Figure 48.- Continued.



(d) Summer.

Figure 48.- Continued.



(e) Fall.

Figure 48.- Concluded.

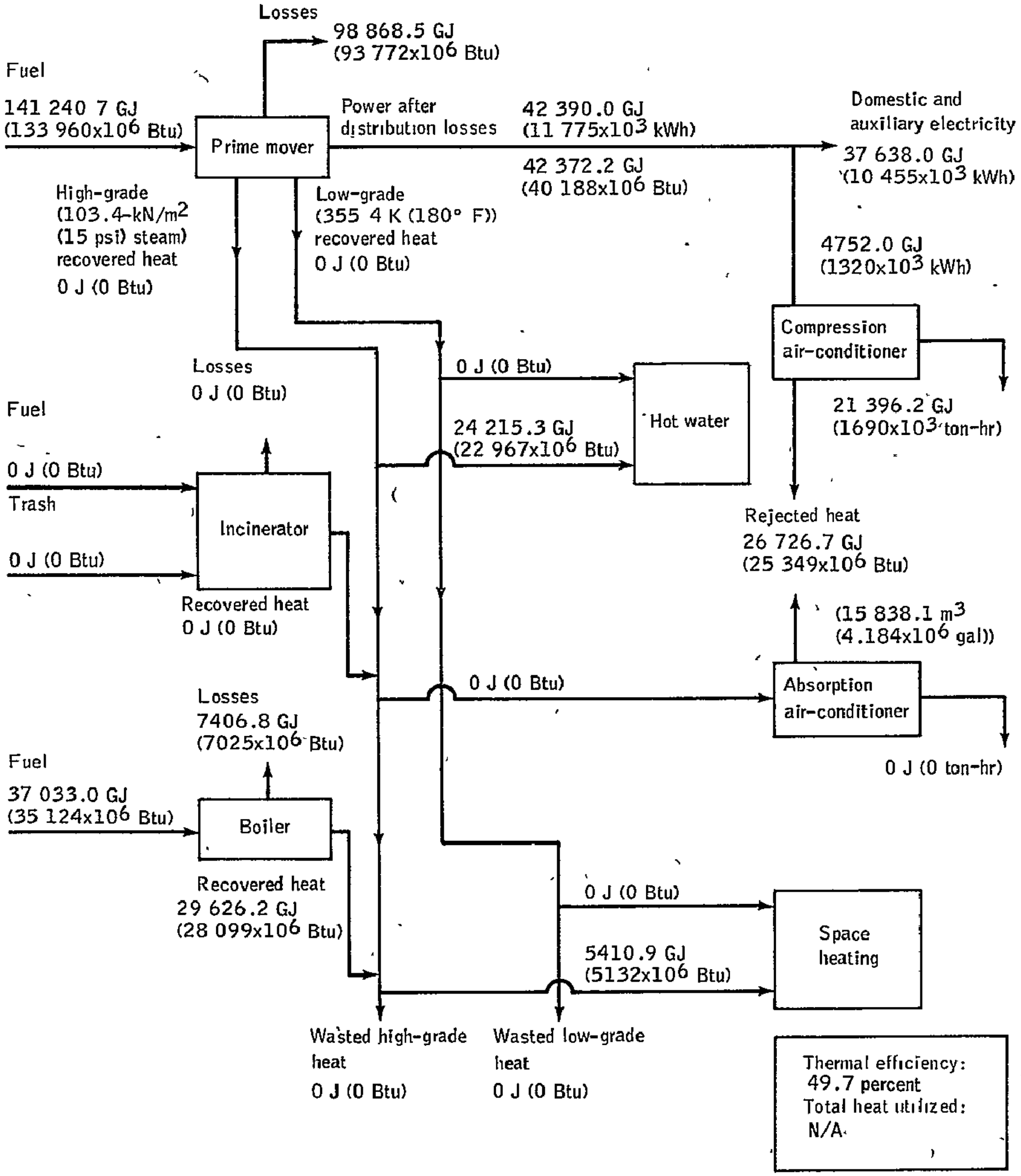
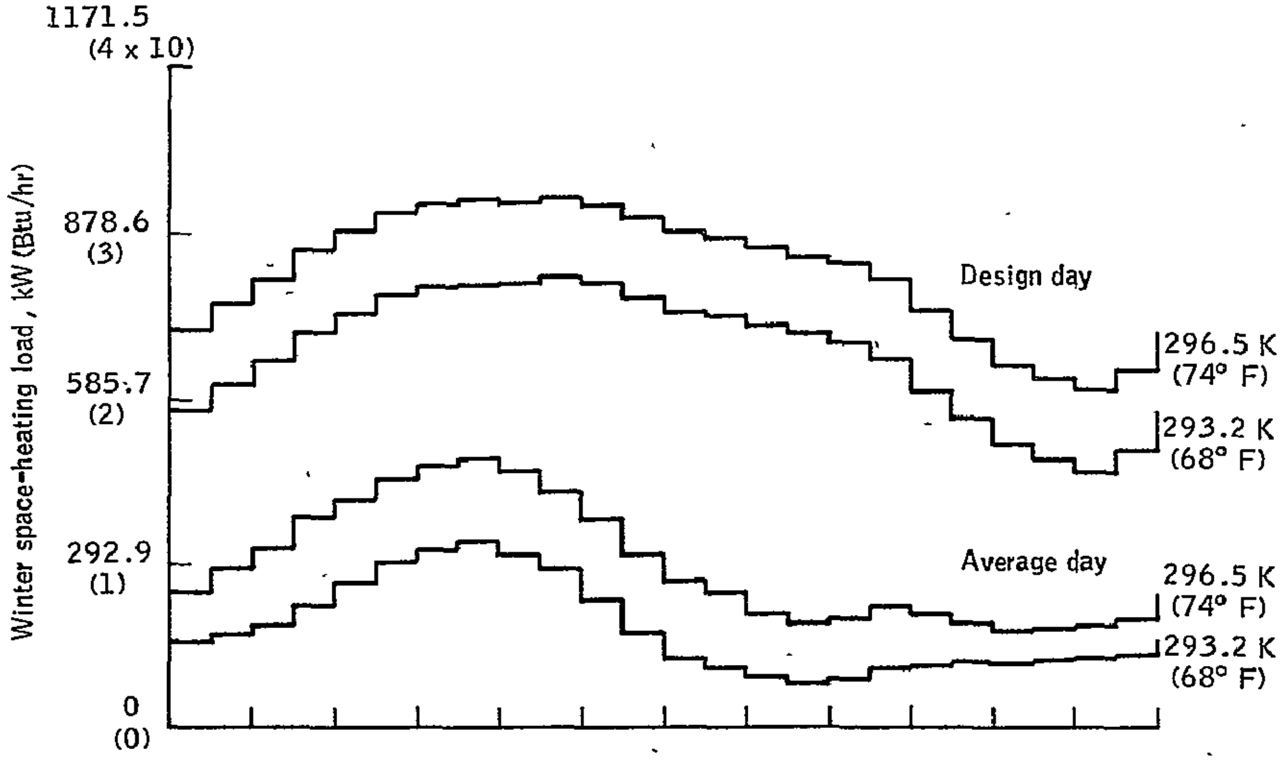
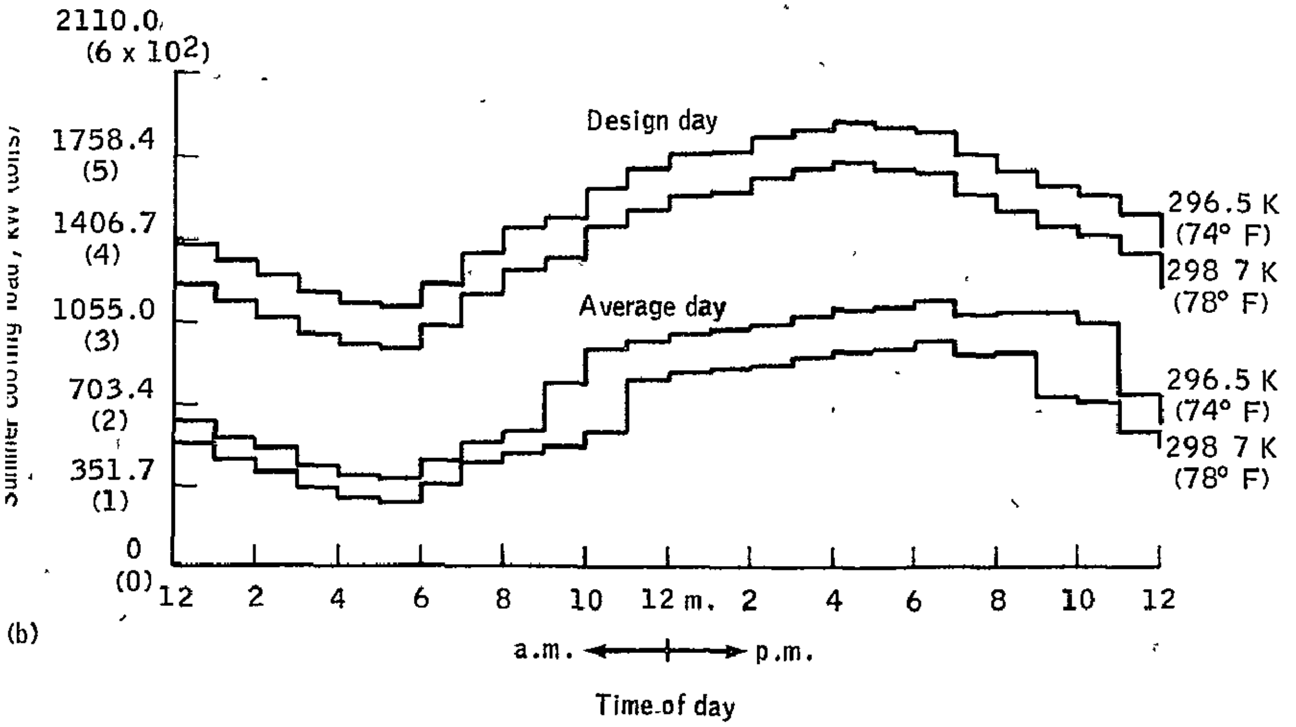


Figure 49.- Washington 1000-unit conventional system: annual.

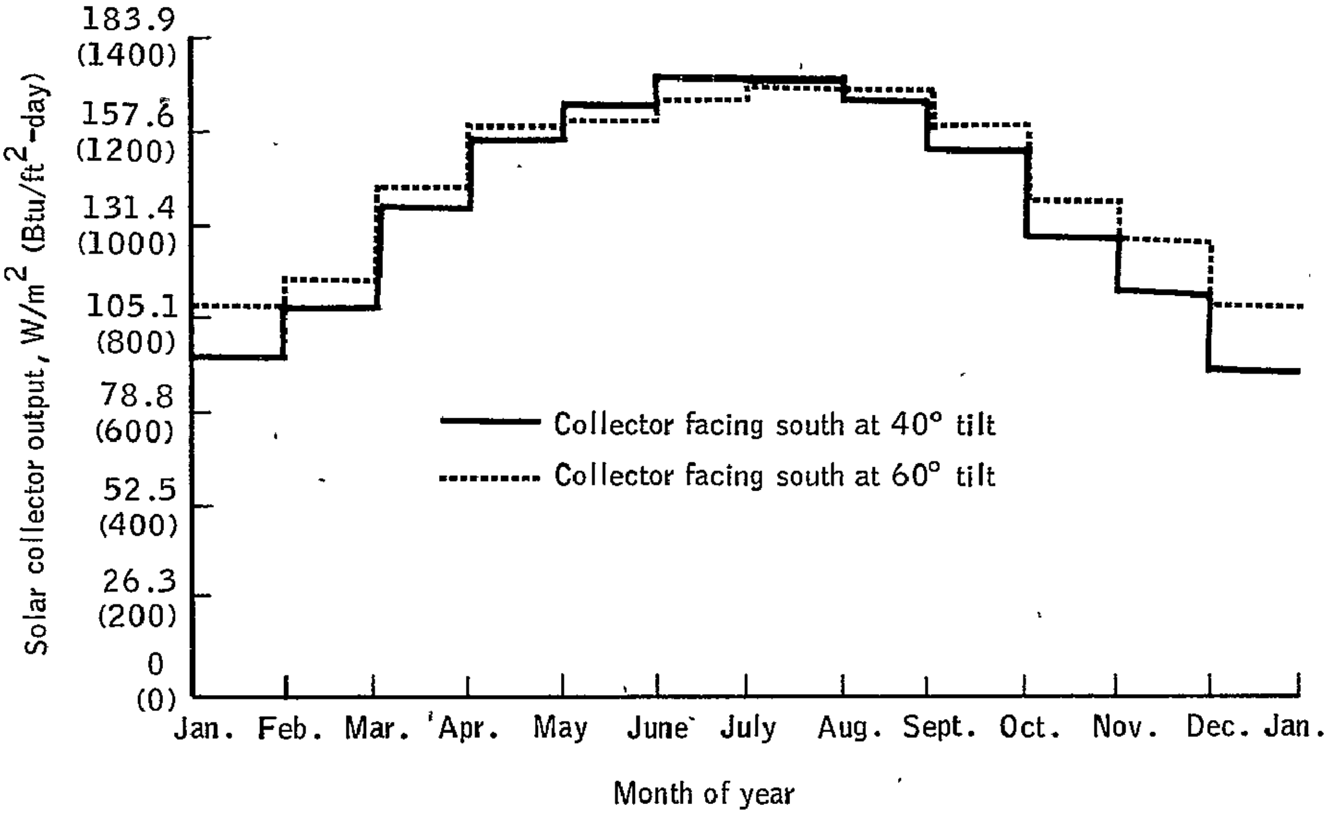


(a) Winter.

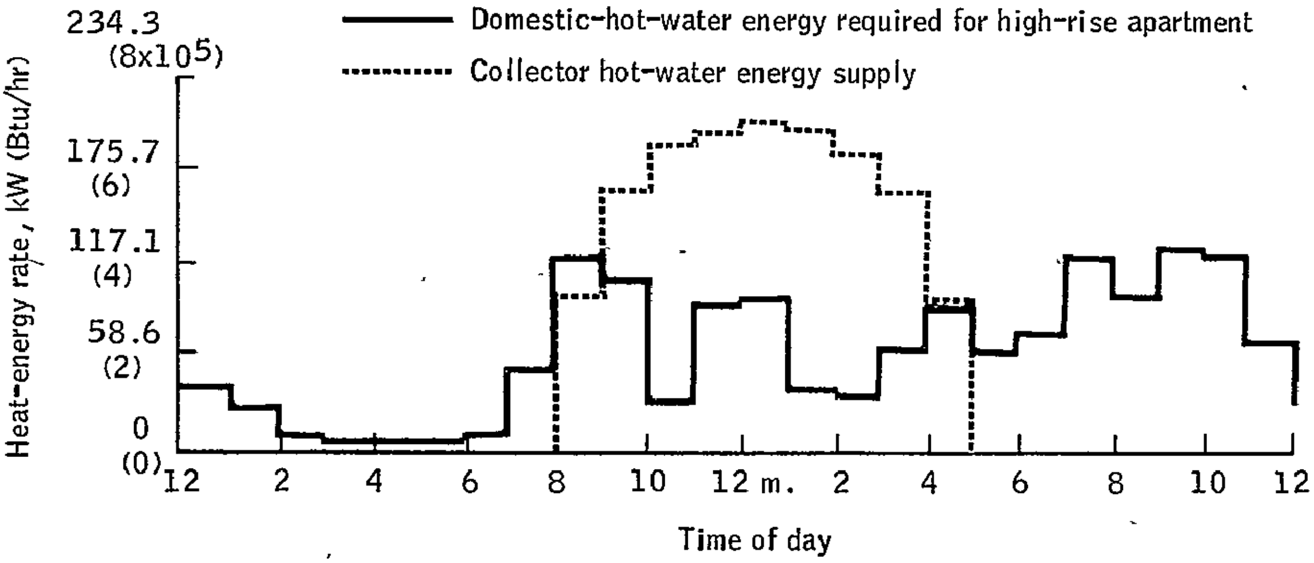


(b) Summer.

Figure 50.- Effect of controlling indoor temperature from 296.5 to 298.7 K (74° to 78° F) during cooling periods and to 293.2 K (68° F) during heating periods on winter and summer daily loads.



(a) Yearly heat gain for 50-percent-efficient flat-plate collectors in Washington, D.C.



(b) Average daily hot-water requirements and solar collector output.

Figure 51.- Solar collector parameters.

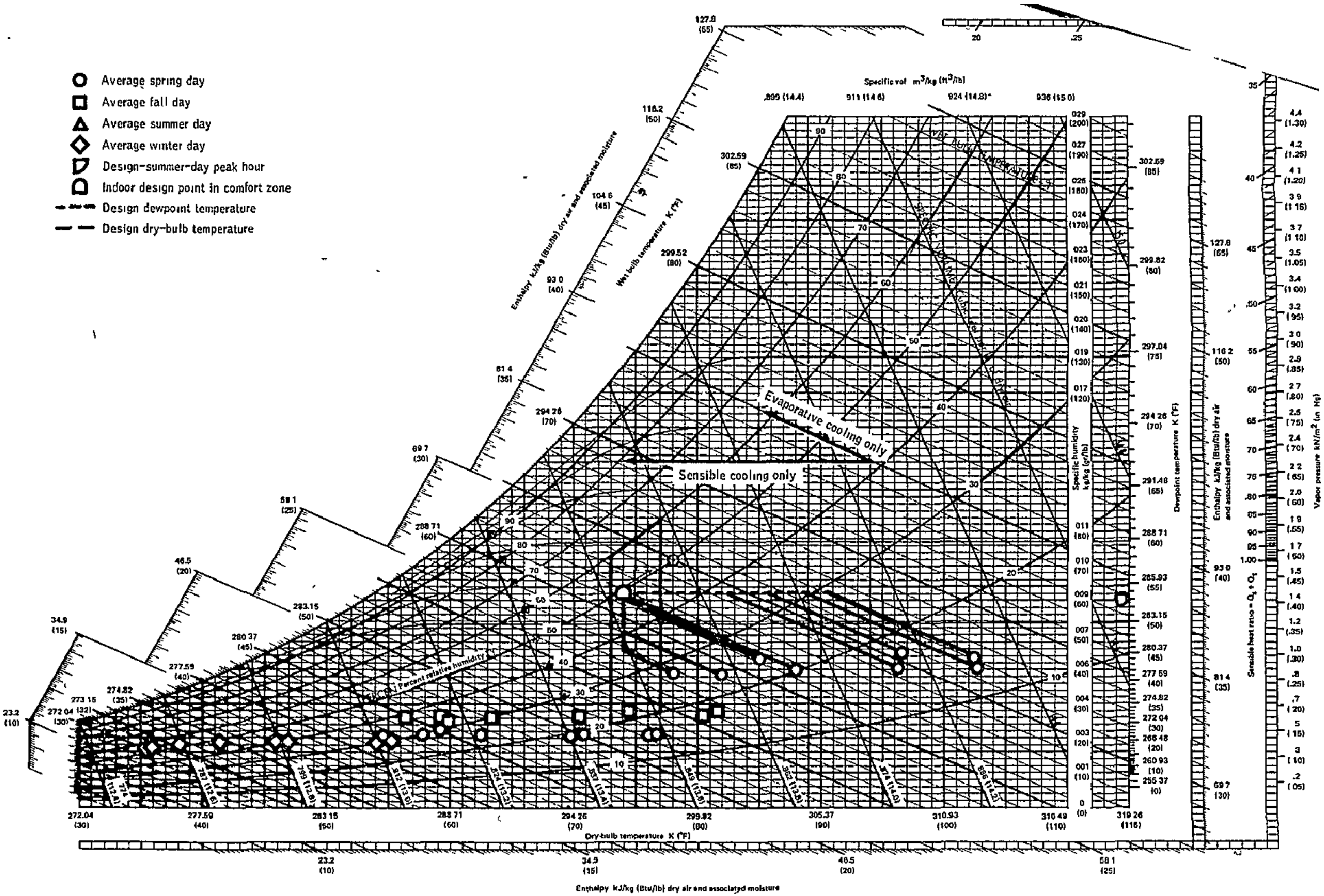


Figure 52.- Psychrometric chart for Las Vegas, Nevada.

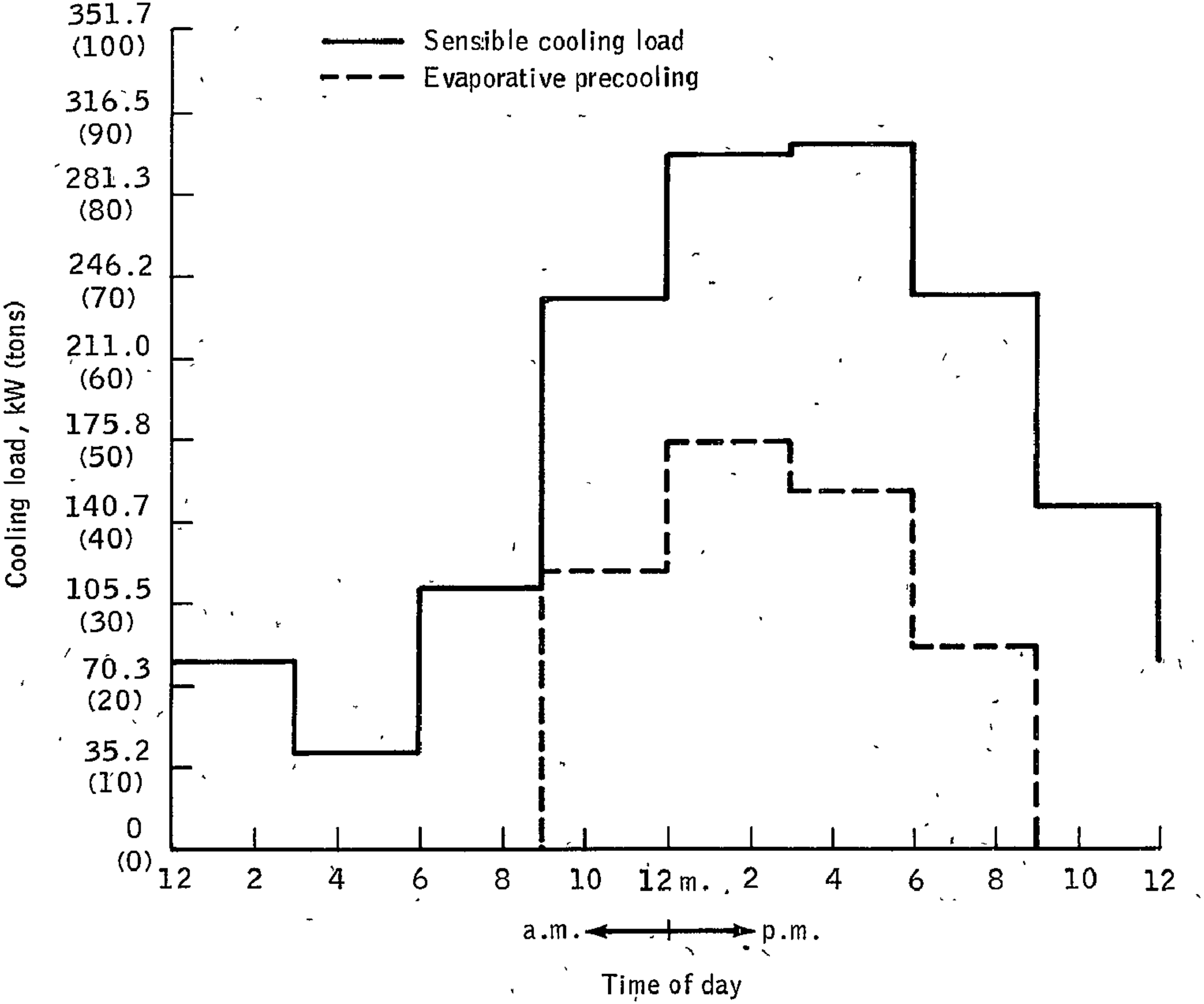


Figure 53.- Cooling loads due to ventilation for an average summer day in Las Vegas.