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DESIGN TECHNIQUES FOR MODULAR INTEGRATED UTILITY SYSTEMS

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MODULAR INTEGRATED UTILITY SYSTEMS

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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Appendix on Illustration of A Thermal Storage Technique by James O. Rippey, NASA Lyndon B. Johnson Space Center

16. Abstract

An overview of the baseline modular integrated utility system is presented, and a review of work accomplished on the project from its conception to the present time is described. Particular attention is directed toward design techniques and the extensive energy analyses and cost evaluations that ultimately determined the design structure of the test project. Features basic to the integrated utility system, such as solid-waste incineration, heat recovery and usage, and water recycling/treatment, are compared in terms of cost, fuel conservation, and efficiency to conventional utility systems in the same mean-climatic area of Washington, D.C. The larger of the two apartment complexes selected for the test showed the more favorable results in the three areas of comparison. Restrictions concerning the sole use of currently available technology are hypothetically removed toward the end of the paper to consider the introduction and possible advantages of certain advanced techniques in an integrated utility system; recommendations are made and costs are estimated for each type of system.

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DESIGN TECHNIQUES FOR MODULAR INTEGRATED UTILITY SYSTEMS

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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.

COORDINATED TECHNICAL REVIEW

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

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SUMMARY

From 1972 to 1975, the NASA Lyndon B. Johnson Space Center worked on developing design techniques for the modular integrated utility systems. The purpose of a modular integrated utility system is to provide an alternative to conventional utility systems, which supply residential energy needs at the costs of depleting scarce fossil fuels and water and adversely affecting the environment. Although a modular integrated utility system is not considered universal to the extent that it can replace conventional utilities entirely, it is designed to provide electrical power, heating and air-conditioning, solid-waste disposal, and various water-treatment services in a single integrated plant and in a manner cost-competitive with existing systems.

This paper describes the development of design techniques, which began with the definition of system hardware options and the selection of those options most applicable to the integrated utility concept. Ground rules were delineated which provided reasonable design bounds consistent with anticipated 1980-technology capabilities. Methods were derived for the development of utility load profiles, for the preparation of a computer program to aid in equipment selection and energy- and water-usage analyses, and for the development of cost-estimating techniques to compare the modular integrated system with conventional utility systems and services. These techniques have been used to analyze various modular integrated system possibilities; for example, the variations in energy savings and costs in relation to various factors such as project type, density, and size.

Moreover, the application of advanced technology as applied to the modular integrated utility system has indicated a positive potential for increased energy and water conservation.

INTRODUCTION

In the summer of 1972, the Urban Systems Project Office (USPO) at the NASA Lyndon B. Johnson Space Center (JSC) began conducting conceptual and preliminary design studies to find alternate methods of providing utility services. The major portion of this work has been performed under the auspices of the Department of Housing and Urban Development (HUD) in a project known as the Modular Integrated Utility System (MIUS). The purpose of the HUD MIUS project is to design and demonstrate technical, economic, and institutional aspects of an onsite utility system that integrates the functions of electric-power generation, heating and air-conditioning, solid-waste disposal, potable-water treatment, and wastewater processing in a single plant. The intent is to optimize the performance of a total utility system by recovering waste or by-product thermal energy from power-generation processes and solid-waste disposal for use in space heating and cooling and hot water and by reusing treated wastewater for purposes other than human consumption. These techniques are expected to conserve natural resources, fossil fuels, and water; to minimize environmental impact; and to be cost-competitive with conventional systems and services.

Report Scope and Approach

This report is intended as an overview of the various design techniques for MIUS rather than a detailed description of each design technique. Further information concerning the design techniques described herein can be obtained from the reference sources and by inquiry to the USPO at JSC.

General techniques that have been developed by NASA JSC during the conceptual and preliminary design work are described in this report, such as several of the considered hardware options and the evolution toward a standard baseline design. Topics relative to this evolution include the design techniques for determining utility loads and equipment selection, the computer analyses of design parameters, the determination of energy and water utilization, and the estimation of system costs. A description of several simplifying procedures used to analyze a wide variety of potential MIUS applications is included with general comments concerning the applicability of the MIUS concept to various residential projects.

Constraints imposed by the HUD ground rules on the MIUS project to restrict the design equipment to currently available state-of-the-art materials (articles of commerce) are hypothetically removed toward the end of the report to present a discussion of theoretical considerations and possibilities for an MIUS design based on more advanced technology.

Market Potential

The HUD MIUS program is intended to encourage implementation of the concept by private and public utility-service organizations through initial HUD-sponsored development and demonstration. The MIUS concept is an extension of the total energy concept initiated in the 1960's, and many total-energy plants now operate at various facilities, such as office buildings and garden-apartment complexes, in the United States. These plants incorporate the concepts used in MIUS power generation, including the recovery of what had been previously considered waste heat to provide heating and absorption air-conditioning.

Several conceptual designs of MIUS have been examined for various applications, which include a hospital, a school, a high rise apartment complex, and a shopping center in addition to the office buildings and garden-apartment complexes already mentioned. These studies were followed by an examination of MIUS applicability to a new 100 000-population community. Specifically, the new town of Columbia, Maryland, was used as a model, and considerable attention was given to the long-term (20 years) effect of phased development of the town on the optimum technique for incrementally increasing the utility capabilities. As a result of the studies, the characteristics of a baseline MIUS system were derived, and it was concluded that an energy saving of between 20 and 35 percent could be achieved using the MIUS instead of a conventional utility system, depending upon the application.

Meanwhile, a market study was conducted to determine the availability of potential MIUS applications. An apartment complex having between 300 and 1000 dwelling units was found representative of a good market potential for MIUS applications. A more detailed study consequently was conducted for 496- and 992-unit apartment complexes, which resulted in a preliminary baseline MIUS design.

Subsequently, HUD project managers sought developers who would prepare project proposals demonstrating the MIUS concept and requested that NASA engineers aid in evaluating these proposals.

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

DEVELOPMENT OF A BASELINE MIUS DESIGN

This section provides an orientation to MIUS design which will facilitate understanding later sections. Descriptions are given of the hardware options considered for the MIUS designs, of the ground rules developed to limit system design options, and of the baseline MIUS design that emerged.

Hardware Options

As indicated previously, the MIUS conceptual design work began with the analysis of a series of building types, which included a garden-apartment complex, an office building, a shopping center, and other facilities. The result of this work was the development of design techniques and concepts and energy analyses that were applicable to different types of facilities. As work progressed, various options were considered for MIUS subsystems. Criteria such as efficiency, integration potential with other subsystems (for example, heat recovery from one system for use in another), and cost were used to evaluate the options. The major restriction imposed on final selection, however, was the HUD ground rule concerning the current commercial availability of equipment.

The subsystem options fall into the four basic categories of electric-power generation, air-conditioning, solid-waste disposal, and wastewater treatment. Because of the current-commercial-availability restriction, hardware options associated with these four categories were reduced to the following: reciprocating engines (using diesel fuel or natural gas) or steam turbines for electric-power generation, compression or absorption chillers for air-conditioning, incineration (with offsite disposal of residue) for solid-waste disposal, and biological and/or physical-chemical methods for treatment of wastewater.

Space heating and domestic hot-water heating would be supplied using heat recovered from power generation and incineration processes in conjunction with a supplementary boiler if required. After analyzing reciprocating engines and steam turbines, the conclusion was drawn that the reciprocating engine was more efficient and, therefore, better suited for MIUS requirements because of the higher efficiency in the size range under consideration.

The use of compression versus absorption chillers was analyzed in the following manner: (1) total dependence on compression chillers; (2) total dependence on absorption chillers; (3) use of a fixed percentage of each type of chiller; and (4) use of a variable percentage of the two types of chillers, depending upon the application. The most efficient approach was found to be the last.

The treatment of potable water would be accomplished in some conventional manner, depending upon the raw water source used. A surface water source, for example, would require clarification, filtration, and chlorination treatments.

Following these initial conceptual design studies, the MIUS concept was examined for possible application to a 100 000-population new community, and characteristics for a baseline MIUS system were derived. A more detailed design study then was performed for an apartment complex, which resulted in a preliminary baseline MIUS design configuration.

Ground Rules

In the designing of an MIUS system, ground rules were established that limited the system design options. The ground rules incorporated the requirements verbally imposed by HUD program managers and included logical conditions dictated by sound engineering judgment. Some variation in the ground rules may be desirable depending upon the application of the MIUS, and some variations may be necessary to satisfy state and local regulations not covered by Federal requirements.

The following is a list of ground rules used in the preliminary baseline MIUS design studies for the 496- and 992-unit apartment complexes.

Optimization approach.- Selection parameters for system and subsystem alternatives will be economics, fuel and water consumption, reliability, and environmental impact. Economics will be the primary selection parameter, and alternatives will be evaluated using the discounted-cash-flow technique. If the results of economic selection will cause substantially adverse effects on consumables usage, on reliability, or on environment, the conflict will be identified and a decision will be made based on the relative significance of the four selection parameters. The level of system optimization will be limited by the articles-of-commerce ground rule.

Reliability considerations.- The MIUS will be designed using reliability standards comparable to conventional systems.

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

Electrical power.- The energy source will be fuel oil. The electrical system will be operationally independent from the existing utility grid but remain serviceable by it in emergency situations. However, the reliability of the independent system will be comparable with that of the conventional system. Power will be generated at 60 hertz, three phase. A 30-day fuel storage capacity will be provided, and heat-recovery equipment will be compatible with the heating, ventilation, and air-conditioning (HVAC) subsystem.

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

HVAC guidelines.- A circulating four-pipe hot- and chilled-water system will be used, and maximum use will be made of recovered heat for heating and cooling. Compression chillers will be used to supplement cooling needs if sufficient recovered heat for total absorption cooling should be unavailable. Similarly, boilers will be used for supplemental space heating if sufficient recovered heat is not available and if heat obtained from solid-waste incinerators is also unavailable.

Solid waste.- Solid-waste disposal will be effected by incineration. The use of supplemental fuel will be minimized. Solid waste will not be imported to or exported from the apartment complex; however, ultimate disposal of the incinerator residue will be made in a landfill remote from the complex. A 3-day solid-waste storage capacity will be provided in cases of system failure and to avoid incineration during weekends. The incineration schedule may conform to HVAC requirements if desired, but heat-recovery equipment must be compatible with the HVAC subsystem.

Potable water.- The 1962 U.S. Public Health Service standards for drinking water will be applicable to potable water. Domestic hot water of potable quality will be brought to 338.71 K (150° F) using recovered heat. Adequate pressure and storage for firefighting purposes will be provided, and the potable-water treatment and firefighting capabilities will be designed so that they may be added to or removed from the MIUS as desired.

Wastewater treatment.- Wastewater treatment techniques will be consistent with recycling requirements for nonpotable use and/or for disposal in the external environment. Treated wastewater may be used for firefighting, heat rejection, grounds irrigation, and other MIUS processes. Human contact with treated wastewater will be minimized. No consideration will be given to storm water.

Control and monitoring.- The MIUS will be capable of unmanned operation for reasonable periods with provisions for a communications link to a facility manager and/or a maintenance engineer in case of operational problems or unanticipated failures. Continuous surveillance and control of MIUS operations will be achieved using the most cost-effective techniques requiring minimal operator intervention. The control/monitoring subsystem will be capable of surveying and scheduling requirements for routine manual intervention, such as for loading solid wastes and adding chemicals.

Utilities distribution.- Whenever practicable and where permitted, utility distribution will be accomplished underground via common trenches.

BASELINE MIUS DESIGN

As indicated previously, the most detailed MIUS designs were rendered for the 496- and the 992-unit apartment complexes. The designs, documented in reference 1, are summarized in this section.

Architectural Plan

The model for these complexes was derived by a team of architects working under NASA contract. This team conducted surveys in different regions of the country and, from them, developed a model that was representative of a viable project.

The site plan for the 496-unit complex is illustrated in figure 1. Figure 2 is an architectural rendering that shows the MIUS plant in relation to the surrounding apartment complex. The site covers an area of 45 325 square meters (11.2 acres) and includes one 10-story high rise building and nineteen 3-story garden-apartment buildings of two types — one type intended for families and the other type for adults only. (Additional detail concerning the buildings is contained in ref. 1.) To obtain the 992-unit complex parameters, the site plan was doubled.

Because of the effects of weather on heating and air-conditioning demands, a median-climate location within the continental United States (i.e., Washington, D.C.) was selected for the model. Weather data from this city were used to model the structure, the characteristics, and the typical utility usages of site buildings, and a computer analysis was performed for the following utility loads: electrical power, heating and air-conditioning, solid waste, and water usages. From these data, an integrated system was designed. Figure 3 is an illustrated overview of the baseline MIUS system.

System Overview

The system uses diesel generators to produce electricity and incinerators to dispose of solid wastes. Both processes produce steam as a byproduct, which may be used in three ways: (1) to heat a domestic hot-water loop; (2) to supply heat for space heating as required via a hot-water loop; and (3) to provide energy for an absorption chiller. The domestic hot-water loop is preheated for the recovered steam by a lower grade of heat recovered from the engine lubricating oil. The absorption chiller is supplemented by a compressed chiller to provide chilled water for space cooling. Unused steam is rejected to a cooling tower, which also provides heat-rejection capabilities for the chillers and for the hot-water loop. Provision is made to store thermal energy from the chilled- and hot-water loops in a water tank. The principal effect of this storage is to allow a reduction of the peak electrical load required for compression cooling and, thereby, to reduce the demand for power-generating equipment. (The thermal storage technique used is presented in the appendix.)

As discussed in reference 1, the system treats potable water by conventional means; that is, by chemical clarification, filtration, and chlorination. Sewage is treated 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 holding tank and used in the cooling tower for heat rejection and blowdown, for makeup and blowdown in other MIUS processes, for fire protection, and for irrigation of the apartment-complex grounds. Excess tertiary-treated wastewater is discharged to a conventionally treated wastewater outfall.

Comparisons were made of the consumables usage of the MIUS and that of typical conventional systems and services. The results of the comparison are summarized in figure 4. The conventional systems and services were developed specifically for comparison with MIUS concepts in the community study. (These comparisons are described in detail in appendix E of ref. 2.) The water saving indicated in figure 4 results from the use of treated wastewater in the cooling tower and in grounds irrigation. The solid-waste weight reduction for offsite disposal results from onsite incineration. An efficiency ratio of 3.326 208 J/J (11 360 Btu/kWh), including transmission and distribution losses, was assumed for conventional power delivered.

The 992-unit complex showed an increase in energy savings from 30 to 32 percent over the 496-unit complex. Costs for providing the MIUS utility concept rather than a conventional one compared more favorably for the 992-unit apartment complex than for the 496-unit apartment complex, for which the comparative costs appeared to be approximately the same over a 20-year period.

The effects of various weather conditions on MIUS design were compared and evaluated. Specifically, the effects of the cold, dry weather of Minneapolis, Minnesota, were compared with the hot, wet climate of Houston, Texas, and with the hot, dry climatic conditions of Las Vegas, Nevada. These comparisons were used in evaluating the design of the MIUS 496-unit apartment complex. No significant changes in the MIUS were required for the complex because of the variations in weather. The amount of energy saved, when compared with a conventional system, increased slightly with latitude because of the more effective utilization of recovered heat in winter. However, the energy savings amounted to less than a 2-percent increase between Houston and Minneapolis. Some cost differences were attributed to local cost indexes, but all costs were comparable to conventional utility costs.

DESIGN APPROACH

This section is a discussion of the general approach used to design an MIUS. The discussion applies only to preliminary or conceptual work rather than to specific detailed hardware design such as piping layout, pumps, tanks, and so forth. The typical features of an MIUS are reviewed first, and a summary of the general design procedure follows.

Electrical power must be generated and distributed to satisfy various building equipment and occupant electrical demands and to power ancillary MIUS equipment such as pumps, cooling towers, and so forth. Heat recovered from the prime mover exhaust, the water jacket, and the oil cooler is added to the heat recovered from waste incineration. This recovered heat is used first for domestic hot water and then for space heating as required. Additional heat recovered at a sufficient temperature level is used for absorption cooling to satisfy air-conditioning requirements when needed. If the amount of cooling available from recovered 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 is used to provide additional absorption cooling. A boiler is used to satisfy any space-heating or hot-water requirement that cannot be met using recovered heat. However, a boiler is never used to satisfy a cooling load.

A wastewater-treatment facility is integrated with other equipment to provide treated water for heat rejection in wet cooling towers and to supply other process makeup water for the MIUS plant. Potable-water treatment is optional and may be included depending on requirements at the specific site.

Several options are available to tailor an MIUS for specific applications and load profiles. For example, incinerator-operation profiles and capacity can be adjusted to provide waste heat during peak-demand periods. The size and type of the prime mover can be varied to optimize reliability and fuel efficiency. Storage provisions for hot and chilled water can be added to reduce electrical generating capacity and to improve heat utilization. For most MIUS applications, boilers can be eliminated either by using thermal storage equipment or by intermittently firing the incinerator without solid waste.

DESIGN TECHNIQUES OVERVIEW

The first step in MIUS design is to analyze utility loads and the population of the buildings to be serviced. Electrical-power loads, solid-waste production, and water demands are estimated as a function of residential, commercial, or other uses. Occupancy rates and other population-dependent parameters, such as family versus adult-only living requirements or the age range and affluence of the occupants, are considered. The building structure is modeled and weather information is gathered for the specific location: these data are input to a computer program, which develops heating and cooling loads and determines the amounts of energy required by the MIUS. Simultaneously, loads are determined for conventional systems, which neither recover heat from electrical-power generation, incinerate solid waste, nor recycle water. The results of these computer analyses allow the completion of an MIUS design. Capital and operating costs for the MIUS are then determined and compared with the costs of conventional utilities.

Loads Development

As indicated in the previous paragraph, loads are developed based on computer analyses of various system elements. These analyses will be described subsequently in more detail.

Electrical loads.- Electrical loads are developed for each building to be served by the MIUS. Loads development is based on published information, such as that found in references 3 and 4. Profiles consist of hour-by-hour demand in joules (kilowatts), which are compiled in two parts. The first part includes loads in environmentally conditioned spaces that affect heating and cooling loads in the buildings served. For example, in an apartment building, these loads would include lighting, small appliances, air-handling motors, refrigerators, electric ranges, and so forth. The second part of the profile includes the auxiliary loads that consume electricity but do not affect heating and cooling loads. The principal contributor in this regard is the equipment associated with the MIUS plant; that is, items such as compression chillers, hot- and chilled-water pumps, and pumps used in the water-treatment subsystem.

Solid waste.- The generation of solid waste is estimated for each building based on published reports, such as references 5 and 6. The quantity of solid waste and the energy content varies with the building use.

Water usage.- Potable-water demands also are determined from published surveys made by industrial associations, private and governmental research organizations, and other agencies. Typical data sources are cited in references 7 and 8. Parameters that affect potable-water consumption are property valuation and location; user education, occupation, and age; and number of occupants per dwelling unit. For a residential unit, water usage includes domestic demands such as kitchen, laundry, bath, and toilet and exterior demands such as swimming pools, lawn irrigation, and automobile washing. Average daily demands and hour-by-hour profiles are developed separately for hot and cold water. Outdoor water usage varies, of course, with the seasons, which necessitates averaging profiles for each of the four seasons.

The wastewater subsystem loads are identical to the potable-water loads with the exception of exterior-load demands. However, the wastewater subsystem must treat MIUS blowdown loads, particularly those from the heat-rejection system. Treated wastewater is used for irrigation; MIUS-process water (especially that used in heat rejection) can be used for fire protection. Fire protection water storage is based on the requirements set forth in reference 9, the National Board of Fire Underwriters Handbook. Heat-rejection requirements are determined by the MIUS design. Irrigation requirements vary with site and climate.

Heating and cooling.- Heating and cooling loads are determined by computer analysis, which will be described later. The basic inputs to this determination are derived from building modeling and local weather profiles. The principal factors involved in building modeling include heat-transfer coefficients and areas of the roof, walls, and windows; indoor environmental design conditions; building location and orientation; ventilation and infiltration criteria; occupancy profiles; domestic hot-water requirements; and electrical-load profiles. As a result of these analyses, hour-by-hour heating and cooling loads are obtained for average days in the four seasons, and maximum loads are determined for design peak winter and summer days.

Equipment Selection

As indicated previously, a HUD-imposed ground rule restricted the MIUS to currently available hardware.

Electrical equipment.- Specific prime movers can be selected before computer analysis or a series of candidate prime movers may be specified, in which case the computer will select the engine using the least energy. Generally, engines are selected that will provide high reliability and meet the peak electrical requirements. The number and size of prime movers are selected so that good load efficiency is maintained. To assure reliability, backup and standby prime movers are required also.

Solid-waste equipment.- The selection of an incinerator is based on the amount of solid waste generated, on the amount of sludge anticipated from wastewater loads, on the desired number of operating hours per day, and on the number of operating days desired per week (usually 6 or 7 days). It is generally practical to schedule burning periods to coincide with the greatest (peak) demand for recovered heat from the utility system; however, such scheduling is not necessary with a thermal storage system.

Water-treatment equipment.- Essentially no differences exist in the selection of water-treatment equipment for the MIUS except for size constraints. Plants are designed for capacities 130 percent of the average annual demand. This factor was determined from the results of surveys conducted and published by governmental and industrial agencies.

Heating and cooling.- The number and size of chillers, cooling towers, and boilers are determined by computer analysis as discussed in the following sections.

MIUS Design Procedure

The overall MIUS design procedure is illustrated in figure 5. The initial step is facility model definition, which is derived from the architectural design of the facility. From this model, the buildings are characterized in terms of U-values, area, orientation, occupancy profiles, ventilation rates, and so forth. A preliminary estimate is made of system loads, such as solid-waste quantity and type, domestic and auxiliary electrical loads, and other factors. These preliminary loads and building characterization data are input with design weather data into the Energy System Optimization Program (ESOP) for analysis to determine peak loads and equipment requirements. The ESOP design analysis provides the information required to select MIUS equipment and to refine system loads. Another ESOP analysis is then performed using the updated equipment-selection information and mean-weather data to obtain seasonal and annual system-performance information. Performance analyses and energy balances are performed; and, if required, equipment selection is updated again to optimize annual performance. Competitive system configurations can be evaluated further on the basis of economic considerations.

The primary purpose of thermal storage is to reduce electrical-power-generator capacity requirements and thereby reduce capital costs. Accordingly, generators are sized to satisfy peak electrical demands, not including compression air-conditioning. The excess generator capacity during offpeak periods is used to produce chilled water for use during peak periods (appendix). During the space-heating season, excess hot water is stored in the same tank for later use. The storage tank is sized according to cooling-storage requirements. Several iterations using design and mean-weather data often are required to size the storage facilities, the HVAC equipment, and the prime movers accurately and to provide meaningful annual energy-consumption estimates.

ESOP Description

The ESOP, described in detail in reference 10, consists primarily of subroutines that model and integrate each of the MIUS subsystems and subroutines to predict HVAC and water system loads. The program is divided into five general analytical components in addition to input/output components, as illustrated in figure 6.

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

HVAC loads.- The HVAC-loads component predicts the hourly heating and cooling loads of the buildings to be serviced by the MIUS as a function of indoor and outdoor environmental conditions, solar effects, building construction and geometry, domestic electric-power profiles, and occupancy profiles. Loads are calculated for each building and totaled for an entire complex to obtain 24-hour load profiles for a mean day in each season.

Energy requirements.- The energy-requirements component determines the hourly, daily, seasonal, and annual energy requirements for the MIUS complex. Load information from the HVAC-loads component, heat-recovery and fuel-requirement data from the solid-waste component, and waste-heat data from the power-generation component are used to determine energy utilization and requirements for HVAC-related equipment, such as boilers, cooling towers, and so forth. Thermal storage is an optional feature in this component.

Power generation.- The power-generation component calculates the energy requirements of specific prime-mover systems to provide electrical power, as defined by the energy-requirements component. The power-generation component also defines the amount and type of waste heat available from the prime-mover system for the energy-requirements component. These two components are interfaced because of the electrical-power demands of the compression air-conditioning that is needed to supplement the absorption air-conditioning (which is provided with recovered heat).

Conventional utility system.- The conventional-utility-system component of the program calculates the energy required by a conventional commercial utility system to provide the same services as the MIUS. The conventional system modeled in the program consists of a central power-generation facility, all compression air-conditioning components, and a gas-fired boiler for space heating and hot-water heating.

Computer Input and Output Summary

The ESOP basically consists of a loads component and an energy-analysis component. The inputs to the loads component consist of data related primarily to building and environmental parameters, whereas the inputs to the energy analysis component contain data related primarily to MIUS equipment and to outputs from the loads component. The input data can be categorized as follows.

Loads-analysis data.- The loads-analysis data can be subcategorized into building characterization, water-loads analysis, and environmental parameters.

Building characterization includes such data requirements as (1) U-values for walls, roof, and glass; (2) glass-type factors (for solar admittance into building); (3) wall, roof, and glass areas; (4) occupancy profiles; (5) domestic electricity profiles (inside the conditioned area); (6) auxiliary electricity profiles (outside the conditioned area); (7) ventilation rates; and (8) design interior temperature and enthalpy profiles.

Water-loads analyses include data concerning the number of occupants per building and the type of building under consideration.

Environmental parameters consist of (1) hourly profiles of the outside dry-bulb temperature, (2) site latitude and longitude, (3) building orientation, (4) atmospheric clearness index, and (5) outside air enthalpy profiles.

Energy-analysis data.- Inputs to the energy-analysis component involving MIUS equipment include electrical-power-generation capacity, water and energy uses, and energy analyses.

Electrical-power generation includes (1) generator-rated capacity; (2) engine-rated capacity; (3) fuel heating values; (4) fuel-load curves (for oil coolers, water jacket, and exhaust jacket); (5) waste-heat-load curves; and (6) steam cycle data, if required.

Water and energy uses are considered separately for heat excesses of 405 K (240° F), of 350 K (170° F), and of 311 K (100° F), as well as for wastewater effluent.

Energy analyses are considered in terms of solid-waste data and HVAC data. Solid-waste data include solid-waste contents and amounts, heat value of solid waste, fuel requirements, waste-heat-use profiles, and heat-recovery efficiency.

The HVAC data are concerned with boiler efficiency, absorption/compression split, coefficient-of-performance profiles for absorption and compression chillers, heat-rejection water requirements, and thermal storage.

Output data also are summarized for the loads- and the energy-analysis components. System loads are provided automatically from the loads component to the energy-analysis component during one execution of the program. Detailed loads output is provided hourly by the program for each building type as are the totals for the entire facility. Output from the energy-analysis component is provided hourly for 1 mean day per season and totaled for each season. These output data basically indicate fuel requirements and provide a detailed accounting of all energy flows.

Output data for loads analysis and the energy analysis can be summarized as follows.

Loads-output analysis.- The loads-output analysis includes the hourly heat gain from walls, roof, windows, ventilation, hot water, electricity, and other sources; the total hourly space-heating demand; the total hourly air-conditioning demand; all power, potable-water, and hot-water requirements; and totals of these requirements for the entire facility served by the MIUS.

Energy-output analysis.- The energy-output analysis includes all generator data, such as engine output, fuel consumption, thermal efficiency, generator output, and so forth; the number of generators required; the waste heat available and its sources; and all boiler heat and fuel. The analysis becomes quite complex because it involves such considerations as the amounts of absorption and compression air-conditioning, the waste heat not used at each of the three temperature levels (405, 350, and 311 K), the waste heat actually used at the three temperature levels, and the waste-heat and wastewater requirements that have not been met. Thermal storage must be taken into account as well as cooling tower requirements and the amount of wastewater available for reuse. Solid-waste disposal costs and effluent and the seasonal and annual fuel-consumption rates finally form a basis for comparison of the MIUS and a conventional system.

Energy requirements are analyzed and consumables usage is measured primarily with the ESOP. First, the ESOP is used to determine peak equipment loads for equipment sizing. Analysis is performed for summer and winter seasons using hourly weather data that represent two standard deviations (above and below the mean). January is considered representative of the winter season, and July weather data are used for the summer season. After the design loads are determined, preliminary prime mover selections are made and used for subsequent energy analyses using mean-weather data. Mean-weather data for the months of January, April, July, and October are used to analyze weather for the winter, spring, summer, and fall seasons, respectively.

Two formats have been developed to present the MIUS energy and consumables data. The first format (fig. 4) presents comparative summaries of annual energy requirements, water consumption, wastewater, and solid-waste effluents for the MIUS and the conventional system as applied to the 496-unit apartment complex in Washington, D.C.

The second format (figs. 7 and 8) presents more detailed comparative energy-analysis data of the same apartment complex and is actually an energy-use flow chart that shows the sources and uses of all the energy consumed by the two types of utility systems on a seasonal and an annual basis. Figure 7 shows the total annual results for the baseline MIUS illustrated in figure 4. Comparable results for the conventional system, which provides the same services as the MIUS, are shown in figure 8. Data also can be presented for each of the seasons. Energy inputs in figures 7 and 8 are shown on the extreme left, and values are shown that represent the heat value (in joules and in Btu's) of the fuels and solid wastes entering the systems. In all cases, the term "fuel" refers to a purchased fuel. Losses are shown to include the heat content of exhaust gases in addition to distribution losses. Two vertical lines near the center of the charts represent waste-heat loops at the various temperatures shown. Services provided by the systems are shown to the right of the vertical lines. For each service, the required amount of waste heat or electricity and the quantity of the service provided to the facility are indicated. Thermal storage does not appear on the flow charts because it has an insignificant effect on fuel consumption and such data would be meaningful only on an hourly basis inasmuch as the primary benefit of thermal storage is to reduce daily peak demands (appendix).

The heat rejected by the air-conditioning condensers and the water required by the cooling towers are indicated on the charts. The unused recoverable heat, the thermal efficiency, and the percentage of waste heat used are shown at the bottom of the charts. Thermal efficiency 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 solid waste in the conventional system was not considered and that nowhere in the analysis is energy required for eventual disposal of incineration residue. Such a requirement is considered beyond the scope of preliminary design analysis because residue disposal is site-dependent and, therefore, external to the MIUS design.

COSTS

After design and energy analyses are completed, costs for the MIUS and a conventional system are compiled and compared. References 1 and 2 describe the costing tasks in detail; but, because some of the methods used can become tedious and complex, an overview is presented that describes major approaches to the costing activity.

MIUS Costs

The MIUS costing has been divided into the following seven major cost elements: electrical power, water supply, wastewater collection and treatment, HVAC (including domestic hot water), solid-waste collection and incineration, and miscellaneous costs, such as controls and housing, which relate to more than one functional area. A crew for the entire system is costed separately. For each element category, with the exception of the operating crew, cost estimates are made in terms of initial capital costs, annual operating costs, and annual maintenance costs, as appropriate. The operating crew includes skilled, semiskilled, and service workers, and the cost is estimated accordingly. A cost data base for the major cost elements was developed in terms of several groups, or subelements. A discussion of these major cost elements and subelements is provided in the following paragraphs. An example of the cost data base for the engine-generator sets and peripheral equipment is also provided.

It should be noted that costs are somewhat location-dependent and that a method was devised that took this variation into account. Costs were developed using Chicago as a reference base. Labor and materials costs for a specific location were then related to Chicago costs using cost indexes developed from references 11 to 13. Fuel costs were found to vary and an index was developed for fuel from data published in The Oil and Gas Journal and Platts Oilgram. Typical indexes are shown in table I.

Electrical power.- The first major cost element discussed is electrical power. The electrical-power data base was developed in terms of the following groupings of costs.

Group 1: Engine-generator sets with local controls; heat-recovery equipment; interconnected water, steam, and lubricating oil piping; primary switchgear and transformers; wiring; a day fuel tank; installation of the listed equipment; warranties; manuals; and initial lubricating oil for the engines. An example of the cost data base for this group is illustrated in figure 9.

Group 2: A standby engine-generator set without heat recovery and having a minimum of accessories.

Group 3: Underground fuel-storage tanks with all the pumps and plumbing required for connection to the day tank, the incinerator, and the boiler.

Group 4: Underground electrical distribution to the serviced buildings including transformers and switchgear. Depending on the site requirements, metering costs were included or omitted. Building wiring is not included in these costs, and trenching costs for the wiring are included under "Miscellaneous costs."

Group 5: The operation and maintenance (O&M) costs, which include fuel, lubricating oil, engine repair, miscellaneous supplies, and purchased maintenance. The O&M labor costs are not included here but are listed under "Operating crew."

Water supply.- Water-supply costs are optional and depend on the MIUS site requirements. The data base for this equipment was developed in terms of the following groupings of costs.

Group 1: A pumping station at the water-supply source (a river, lake, or well). Associated equipment includes housing, plumbing, redundant pumps, and electrical equipment.

Group 2: A pipeline and right-of-way from the water-supply source to the MIUS site.

Group 3: A treatment plant that includes equipment necessary to bring water to 1962 U.S. Public Health Service standards for drinking water.

Group 4: Elevated storage with pumps or ground storage with continuously operating distribution pumps.

Group 5: Local distribution to the serviced buildings. Costs include all piping and installation, but trenching is not included.

Group 6: Fireplugs where fire protection is provided for the potable-water supply system.

Group 7: The O&M costs for water supply, which are chemicals, purchased maintenance, and replacement supplies. The O&M labor is included under "Operating crew."

Wastewater collection and treatment.- The wastewater collection and treatment cost data base was considered in terms of the following groups of costs.

Group 1: Collection equipment, including piping (but not trenching), lift stations, and manholes.

Group 2: Primary and secondary treatment plant costs including raw wastewater pumping; sediment tankage; flow-equalization tankage; rotating disk equipment; a secondary clarifier; and miscellaneous tankage, pumping, and plumbing (including sludge transfer).

Group 3: Tertiary-treatment equipment, which includes advanced physical-chemical treatment equipment, pumps, tankage, vacuum-filter equipment, and sludge-transfer equipment.

Group 4: Right-of-way and outfall development costs.

Group 5: Fire protection, when not included with the potable-water system equipment. Equipment will include tankage, pumps, piping, fireplugs, and interconnect plumbing.

Group 6: The O&M costs for wastewater collection equipment, which include chemicals, maintenance supplies, and purchased maintenance.

HVAC (including domestic hot water).- Domestic hot-water equipment was included in the HVAC cost element because recovered thermal energy is used in both applications; in some conceptual designs, the thermal-energy distribution piping for space heating and domestic hot water is common. The HVAC and domestic hot-water cost data base was developed in terms of the following groups of costs.

Group 1: Absorption and compression water chillers.

Group 2: Low-pressure steam boilers.

Group 3: Cooling towers.

Group 4: Redundant chilled-water distribution pumps.

Group 5: Redundant hot-water distribution pumps.

Group 6: A thermal-storage tank.

Group 7: Thermal-storage pumps.

Group 8: Interconnect plumbing, valves, and heat exchangers within the MIUS buildings.

Group 9: Hot- and chilled-water distribution from the MIUS building to the serviced buildings.

Group 10: The O&M costs, which include fuel, purchased maintenance, and miscellaneous supplies.

Solid waste.- A cost data base for solid waste was developed in terms of the following cost groups.

Group 1: Incinerators with heat-recovery boilers, interconnect steam and water plumbing, loading and ash-removal equipment, and other accessory equipment.

Group 2: Collection equipment.

Group 3: The O&M costs, which include fuel, purchased maintenance, miscellaneous supplies, and costs for offsite disposal of incinerator residue.

Miscellaneous costs.- This category includes costs that apply to more than one functional area of the MIUS and are analogous to what is termed "general plant costs" of an electric utility having a generating plant, a transmission system, and a distribution system. A cost data base was determined for this element in terms of the following cost groups.

Group 1: Control equipment. The conceptual MIUS designs developed included a control and data display for the entire MIUS.

Group 2: The MIUS building.

Group 3: Tools.

Group 4: Land costs.

Group 5: Trenching costs.

Group 6: The initial fuel load.

MIUS operation crew.- A cost data base for the MIUS operating crew was developed in terms of one small staff of qualified personnel, which would include one engineer and a selected number of semiskilled employees and service workers.

Cost (Initial) Data Base

Figure 9 provides an illustration of the cost (initial) data base developed for the MIUS studies. Costs are shown as a function of capacity for two types of engines: an opposed-piston, two-cycle diesel unit and an in-line (or "V") piston, four-cycle diesel unit. The two top curves in the illustration include all costs in "Group 1" under "Electrical power." The bottom curve represents cost data for engine-generator sets only. The top curves were developed from several cost data sources. For these two top curves, costs for peripheral equipment were based on a system having a minimum of three engine-generator sets with heat recovery. Although these data were given for oil-fired fuel engines, estimates may also be developed for gas-fired engines in locations where natural gas is available. The primary differences between the two engine types would be reduced engine fuel efficiency and elimination of diesel fuel tankage.

Data similar to those used in the initial costing of engine-generator sets must be obtained for all elements of the MIUS and then compiled for a particular design. The initial materials and labor costs do not represent the total initial outlay for an MIUS. Design costs, architectural fees, general contractor costs, overhead, and profit will add an additional 30 to 60 percent to the initial cost of an MIUS installation. Typical values used for these estimates were based on data found in references 11 to 13 and are 19.2 percent of the base cost of materials and labor for general contractor profit and overhead; this estimate includes 7.5 percent for architectural fees for the MIUS building and 10 percent for the cost of materials and labor for engineering. Once an MIUS is operational, there are additional expenses; operating funds, property taxes, and insurance costs must be included. Financing costs and/or return on invested capital further add to the continuing cost analysis of an MIUS.

Conventional Systems and Services Costs

For purposes of cost analysis, the conventional system has also been divided into major cost elements: electrical power, water supply, wastewater collection and treatment, HVAC (including domestic hot water), solid waste collection and incineration, miscellaneous costs, and operating crew. For each element, estimates include, as applicable, initial charges for providing the service at the site, annual rates and taxes based on monthly utility usages as determined in the design analyses, and annual O&M costs not included in the other rates.

The following costs may be incurred within the above elements.

Electrical power cost may include powerlines, underground distribution costs, transformer stations, initial assessment charges, initial connection charges, and miscellaneous costs.

Water supply costs include supply lines, an elevated storage tank, a water-treatment plant, initial assessment charges, initial connection charges, and distribution costs.

The costs incurred in wastewater collection and treatment include trunklines, a treatment plant, collection equipment, lift stations, outfall provisions, and initial assessment and connection charges.

There is typically no initial outlay required for obtaining solid-waste disposal service.

The HVAC services are costed essentially in the same manner as for an MIUS.

SIMPLIFYING PROCEDURES

To facilitate rapid analysis of a wide variety of sites for MIUS applicability, a procedure was devised that allows for simplifying the site characteristics, performing the computer analysis, and defining the general characteristics of an MIUS to serve the site. These characteristics include the major pieces of equipment, energy and water utilization, and the cost.

The capability to analyze a number of sites rapidly was facilitated by standardizing much of the data used in the analysis. The following list of computer input items was standardized with constant values.

1. Heating value of solid-waste material

2. Percentage of moisture in solid waste

3. Percentage of noncombustibles in solid waste

4. Incinerator supplementary fuel rate

5. Incinerator startup fuel requirement

6. Heating value of incinerator supplementary fuel

7. Solid-waste generation per person

8. Hours of incinerator operation

9. Boiler efficiency

10. Percentage of air-conditioning provided by absorption in a fixed-ratio system

11. Heating value for prime mover fuel and boiler fuel

12. Coefficient of performance for absorption air-conditioning

13. Coefficient of performance for compression air-conditioning

14. Profile (24 hour) of cooling tower water-temperature differential

15. Cooling tower evaporation loss

16. Cooling tower drift loss

17. Cooling tower blowdown loss

18. Temperature of domestic hot water

19. Temperature of water supply

Engine-generator data were developed for some selected engines in the form shown in figure 10. The buildings most applicable to projects envisioned for MIUS residential facilities were standardized as typical buildings that could be used in a variety of combinations. Figures 11 and 12 are typical of the information obtained for one such combination — a garden apartment occupied by single adults. Finally, weather data were assembled for 12 locations in the continental United States. In addition to the standardized data, information such as that on the typical form shown in figure 13 is required as input data to the computer program. The form specifies the site location; engine type; solid-waste-disposal data; thermal storage instructions, if applicable; and the complement of building types. The factors indicated allow the buildings to be scaled to the size desired. The results of the computer analysis are recorded as shown in figures 14 and 15. Figure 14 indicates loads, and figure 15 is a consumables comparison with a conventional system.

The computer program can automatically determine loads and consumables usage for a conventional system that consists of off-site power generation and a central heating and air-conditioning plant using boilers and compression chillers. If some other conventional configuration for heating and cooling is desired, the program output provides sufficient information to determine its characteristics.

To perform costing, data such as those illustrated in figure 16 are gathered. The results of the costing are recorded as shown in figures 17 and 18. The MIUS and conventional systems costs then can be compared on a form similar to that shown in figure 19. Figure 20 shows a typical schedule for this type of rapid analysis. It is, of course, possible to analyze more than one project simultaneously by staggering them.

COMMENTS ON MIUS APPLICABILITY

The simplifying type of analysis described in the preceding section was performed for several residential project concepts. This section elaborates on certain general conclusions drawn from these analyses as they might affect MIUS applicability. The principal items of interest are the amount of energy the MIUS saves over a conventional system and the relative costs of the MIUS and conventional systems.

The amount of energy saved is a function of a few factors relative both to the MIUS and to the conventional system. For the MIUS, the principal factor is the amount of otherwise wasted heat energy that can be recovered and used; a few specific concerns dictate this amount. First, the quantity of usable heat is a function of the degree to which the site buildings are amenable to a central hot- and chilled-water system, and this amenability depends principally on the dwelling-unit density. For example, if the density is low, such as in a development of single-family dwellings, the cost of providing central service is prohibitive; whereas, in a high rise apartment building, such a central system is a cost-effective approach. The heat requirement then must be considered. During midsummer, virtually all parts of the United States require sufficient cooling to use the heat for absorption chillers. However, during the winter, the usable fraction of heat generated by the engines and the incinerator is proportional to the coldness of the climate; that is, this heat can be used more effectively in northern locations.

The MIUS energy is also a function of apartment-complex size in that larger engines are generally more efficient in the larger complexes. However, a balancing point exists at which, for large complexes, the cost of distributing hot and chilled water would become a detriment.

The energy that the MIUS saves over the conventional system is, of course, also dependent on the particular conventional system selected. The main considerations are the efficiency of the power-generation and transmission system and the type of heating and cooling systems selected. For example, central boilers are more efficient than strip heaters, and central cooling systems are more efficient than individual units. Heat pumps may be more effective than either concept.

Several factors are illustrated by the following examples. A project that consisted of approximately 100 single-family dwellings, 50 apartments, and a small commercial area was found to have an approximate 15-percent energy savings when compared with a conventional system. This comparison was based on the assumption that individual heat pumps would be used in the single-family dwellings of the MIUS and the conventional systems. For the conventional system, a central boiler and compression chillers would be used for the apartments and the commercial area. For another project, a complex of 750 apartments and townhouses, all of which were assumed to be on a central heating and cooling loop, the energy savings was found to be more than 30 percent. The dwelling-unit density of the latter project was approximately 3 to 4 times as great as that of the former project.

The effect of different conventional systems on energy savings is significant. It was calculated that a project of 500 townhouses would realize an energy savings of 32 percent if a conventional central boiler and a compression cooling system were assumed; whereas, if conventional all-electric individual units were used, the energy savings would amount to approximately 42 percent.

Cost comparisons are a function of several variables. For an MIUS, probably the most significant variable is the distribution of hot and chilled water. As mentioned previously, the cost of such distribution for an MIUS in a low-density project can become prohibitive. For conventional systems, the principal variables are those associated with rate structures for electricity, water, and solid-waste disposal. These variables are highly dependent upon location and can make the difference between a cost-effective or a cost-prohibitive MIUS.

Significant cost-comparison effects can also be achieved by adding or removing water-treatment facilities. Generally, it is not economical for the MIUS to process potable water and provide fire protection water because the cost of these capabilities is significantly greater when applied on a relatively small scale rather than on a typical municipal scale, and municipal water is usually available. Additionally, the cost of treating wastewater may be greater for the MIUS depending on the quality of the treatment. It is intended that MIUS wastewater receive tertiary treatment, whereas most treatment plants currently provide only secondary treatment. The economy of scale works against the MIUS in wastewater treatment as illustrated in appendix E of reference 2.

Another significant effect on cost is the operating personnel. Ideally, the MIUS must be designed to operate with as few personnel as possible. The greater capital cost of the MIUS must be offset by reduced operating costs. This counterbalance is achieved somewhat by reductions in fuel, but it must not be lost by requiring large numbers of operators. A noteworthy factor in analyzing costs is the ability to project future costs reasonably. Because the

MIUS concept uses less fuel but requires more capital investment per service than a conventional system, projecting costs is particularly significant in that the attractiveness of the MIUS concept is enhanced when the cost of fuel increases rapidly enough to offset the initial higher cost of capital equipment. However likely this expectation may be, uncertainties still exist in cost projections which add a degree of indefiniteness in a long-term economic assessment of an MIUS installation. In any event, the MIUS must pay for itself in reduced operating costs.

ADDITIONAL CONSIDERATIONS

Fuels and heat pumps are basic considerations that can add to or detract from the cost-effectiveness and the energy savings of the MIUS concept.

Fuels

The MIUS, as envisioned in the HUD project, is based upon the use of internal-combustion engines, which must use either fuel oil or natural gas — both of which are diminishing resources. Therefore, although the MIUS requires less energy, as the system has been envisioned it requires a particular energy source that may not help to solve the overall energy problem. This fact can be illustrated by data developed for a project consisting of a 725-dwelling-unit complex of apartments and townhouses and an 18 580-square-meter (200 000-square foot) commercial area. This MIUS project, assumed to be located in the Washington, D.C., area, was found to save approximately 45 percent of the energy required for a conventional system. However, for a typical area in Maryland, where electrical power is produced by a combination of oil and coal and where natural gas is no longer available, it was found that the MIUS required more oil than the conventional system. Furthermore, future projections for the area indicate that the use of oil in conventional power generation will diminish as nuclear power becomes more available. Consequently, the energy-consumption situation worsens as illustrated in figure 21. The data presented in this figure and in figure 22 were partially obtained from reference 4 and partially from Boston Gas and Electric Company personnel.

One way of improving the situation would be to import solid waste from the surrounding area for use as a fuel. Two possibilities exist for this concept. One approach is to burn the waste to produce steam for a turbine, and the other method is to pyrolyze the waste to produce fuel that is usable in an internal-combustion engine. Based on an importation estimate of approximately 27 215 kilograms (30 tons) of solid waste per day, which was determined to be reasonable for the particular area under study, the turbine system would increase the fuel savings to about 55 percent, whereas the pyrolysis system would increase the savings to approximately 70 percent. The effect of these advanced techniques on oil conservation is illustrated in figures 21 and 22. The pyrolysis system in particular shows an oil usage closer to conventional usage. Although pyrolysis is not yet a proven technique, considerable development work is underway, and a satisfactory technique is anticipated to be available within a few years.

Potential Use of Water Heat Pumps

For the particular project discussed in the previous section, it was determined that enough recovered heat from the standard MIUS configuration was unused so that approximately 300-K (80°-F) water could be circulated in winter and summer to serve water heat pumps in surrounding single-family dwellings. Therefore, if conventional air-to-air heat pumps were replaced by water heat pumps, additional recovered heat would be available, which could reduce the electrical bills for surrounding houses and produce additional MIUS revenue. A reduction in electrical usage is achieved by an increased efficiency of the heat pumps to a coefficient of performance of approximately 3.0. It is estimated that the winter electrical bill for 150 houses in the Washington, D.C., area could be reduced by approximately $40 000, or $267 per house. The water would be circulated in the fire-water line, which would entail having an additional return line and an additional potable-water line. The cost of such a system was estimated to be $150 000 to $200 000. Considering the winter savings alone, this estimate indicates a payback time of 4 to 5 years.

COMMENTS ON ADVANCED TECHNOLOGY

As indicated previously, the MIUS design work done for the HUD was accomplished under a ground rule that restricted MIUS components to currently available state-of-the-art equipment. This restriction included changing conventional building practices in the facilities to be served by the MIUS. However, with some development work, it is evident that more efficient and flexible integrated utility systems would be made feasible in a few years by removing the "state-of-the-art" constraint.

To this end, a study of a hypothetical advanced integrated utility system was conducted to assess the potential of some constraint-removed techniques. A functional schematic of a hypothetical system is presented in figure 23 and is based on technology that should be available around 1980. The system was designed using as a model the same 992-unit apartment complex described in a previous section. A brief description of the system follows, which includes the design approach used and a summary of some of the results. A more detailed description of the study is available in reference 14.

The advanced system design uses a pyrolytic process for disposal of solid waste. The pyrolyzed fuel produced is used in fuel cells to generate electricity. The remainder of the required electrical power is produced in high-efficiency gas turbines using a closed Brayton cycle. Heat is recovered from the fuel cells and from the Brayton cycle engines and supplemented with heat produced by solar collectors on apartment building roofs. Similar to the baseline MIUS design, the heat is then used in three ways. First, it is used to provide heat for domestic hot water and space heating. Second, it is used in absorption air-conditioning, which is supplemented by compression air-conditioning. Third, any unused heat is rejected to a cooling tower which, in turn, provides heat rejection for the chillers. Provision is made to store thermal energy for space heating and cooling in a water tank. As in the baseline MIUS system, the principal effect of such storage is to allow for a reduction of the peak electrical loads, especially that required for compression cooling, and thereby for a reduction in the required electrical-generating capacity (appendix).

The system treats potable water by conventional means and depends on a raw water source. It treats sewage by a physical-chemical system that simultaneously aids in improving environmental quality by scrubbing the sulfur dioxide and oxides of nitrogen in the plant stack gases while using sulfur dioxide as a part of the wastewater-treatment process. This technique provides tertiary-quality water. Dewatered sludge is transferred to the pyrolysis unit for disposal. Similar to the baseline MIUS, a portion of the treated wastewater is stored in a holding tank and reused for cooling tower heat rejection and blowdown, for makeup and blowdown in other MIUS processes, for fire protection, and for irrigation of the apartment complex grounds.

The general approach used in designing the system is as follows. The amount of solid waste available for pyrolytic processing is determined, so that the amount of fuel produced for fuel-cell electrical-power generation can be calculated. The fuel cells then are sized accordingly, and the amount of electricity they can produce is subtracted from the total amount required, which gives an indication of the sizing required for Brayton cycle capacity. The amounts and temperatures of recoverable heat from both power-generation processes are determined. Then, the amount and temperature of the heat available from solar collectors on the roofs of all the buildings in the complex are determined and added to the amount and temperature of heat recoverable from the other power-generation processes. The heat required for domestic hot water, space heating, and absorption cooling is determined for winter and summer peak conditions and for average conditions during the four seasons of the year.

Insufficient recoverable heat was available to satisfy the cooling demands of the peak and average summer conditions by using absorption air-conditioning alone. Consequently, the required compression cooling capacity was determined, and the amount of additional electricity required by the Brayton cycle was calculated. However, because of the use of thermal storage, the installed power-generation capacity did not have to be increased.

The water system was designed with a considerably reduced capacity over conventional requirements by using low-water showers and toilets. The wastewater-treatment effluent was reduced further by reuse in MIUS processes and in irrigation. The amount of sulfur dioxide required in the wastewater-treatment process selected was reduced by the amount available from the stack gases, and ultimate disposal of the sludge was performed in the pyrolysis unit, which affected unit sizing.

Architectural techniques that would conserve energy in the apartment complex were also investigated. Techniques that appear feasible include increasing the overall size of buildings (that is, reducing the surface-to-volume ratio), adding double-pane glass with low-infiltration windows and doors, adding infiltration barriers in the walls, shading windows externally, and using fluorescent lighting.

Energy and water utilization was determined for the model advanced system and compared with (1) a typical present conventional system and (2) the baseline MIUS design described previously, using available off-the-shelf hardware. The analysis indicated that the particular advanced integrated utility system could conserve about 19 percent more energy than the baseline MIUS. Furthermore, the advanced system could serve the apartment complex by using approximately 46 percent less energy than a typical current conventional system. When the architectural energy-saving techniques are introduced into the apartment complex, it can be served with utilities that use approximately 55 to 60 percent less energy than a current conventional system without any significant need for change in lifestyle. The amounts of potable water required and treated wastewater returned to the environment can be reduced by approximately 44 and 47 percent, respectively.

Considering the current and foreseeable uncertainties in fuel availability, it is noteworthy that, for the advanced system, external-combustion engines have a multifuel capability as does the fuel cell with appropriate preprocessing. These systems can use several forms of fossil or synthetic fuels as they are available.

Although no attempt has been made to develop costs for the advanced integrated utility system, based on previous MIUS studies, the capital and maintenance costs of the system will undoubtedly be high, but this initial cost will be offset by a combination of (1) reductions in operating cost because of substantially reduced fuel requirements and (2) increases in fuel cost that will significantly add to the operational costs of conventional utilities and eventually cause these utility costs to be higher than they would be for the integrated utility system.

On the basis of this illustrative example, it was concluded that advanced integrated utility systems could have a significant potential for reducing both energy- and water-resource utilization and could represent a worthwhile area for future investigation by Government and industry.

CONCLUDING REMARKS

This paper has described the techniques and approaches developed for conceptual and preliminary MIUS design and analysis work. Discussions then have been presented of some of the conclusions derived using these techniques for a variety of possible MIUS applications. Finally, comments were made concerning the potential of using advanced technology in MIUS systems.

With regard to the design and analysis techniques, the following principal steps were indicated as prerequisite to the design of an MIUS.

In keeping with a ground rule to use currently available equipment, options for the various subsystems were analyzed and reduced to reciprocating engines (using either diesel fuel or natural gas) or to steam turbines for electrical-power generation. Compression or absorption chillers were to be used for air-conditioning; incineration was to be the method for disposing of solid waste; biological or physical-chemical methods were to be used in waste-water treatment; and recovered heat was to be taken from power-generation and incineration processes (supplemented by boilers, if required) for space heating and domestic hot-water heating. Ground rules then were developed to bound the design options using the cited equipment.

For any MIUS application, electrical, solid-waste, and water-load requirements had to be analyzed for the buildings the MIUS was to serve. Electrical-power-generation equipment and incinerator sizes had to be selected. A computer program then was used to model the building structure and the local weather so that subsystem functions could be integrated. Water and heating/cooling loads also were developed so that the relative amounts of energy used by the MIUS and the conventional systems could be determined. From the computer analysis data, then, came the MIUS design to satisfy specific energy and water usages. The MIUS capital and operating costs were determined and compared with the costs of a conventional system.

Energy and cost are the two primary concerns in comparison of the MIUS and a conventional system. Several key factors were found to affect these concerns.

1. Energy savings were found to depend largely on the amount of otherwise wasted heat that the MIUS is able to recover and use. This recovery and utilization of heat appears to be, in a large part, a function of the dwelling-unit density and the climate.

2. Energy utilization is affected by project size in that larger engines are generally more efficient than smaller ones.

3. Energy-savings comparisons depend on the particular conventional systems available at a site in that some conventional power and HVAC systems are more efficient than others.

4. The MIUS costs are greatly affected by the size of the HVAC hot- and cold-water distribution system, which is a function of project density.

5. Conventional rate structures vary greatly with location and contribute significantly to MIUS versus conventional cost comparison.

6. Generally, it is not economical for the MIUS to process potable water or to provide fire protection water because the scale is relatively small.

7. The higher capital cost of the MIUS must be overcome by reducing operations costs. This reduction can be achieved by using less fuel and fewer operators.

The MIUS, as envisioned in the HUD project, must use either fuel oil or natural gas, both of which are diminishing resources. Although the MIUS does use less energy, in many areas of the country it will use more of these two fuels than does the conventional system. This problem can be alleviated by importing and/or pyrolizing solid waste from surrounding areas and using it as a fuel to produce steam for a turbine. In this way, MIUS costs will be reduced also. Another technique for saving energy and reducing cost is to use excess recovered heat to circulate approximately 300-K (80°-F) hot water to serve water heat pumps in surrounding single-family dwellings in winter and summer.

Significant additional energy and water savings can be achieved by using advanced technology. An example of a system using pyrolysis, fuel cells, a closed Brayton cycle, solar collectors, sulfur dioxide and oxides of nitrogen to scrub plant stack gases and simultaneously treat wastewater, low-water-use showers and toilets, and architectural building modifications has been investigated. The results indicate the possibility of reducing energy usage by approximately 55 to 60 percent and water usage by approximately 45 percent compared to conventional systems. The estimates show significantly more efficiency than those achieved using existing equipment. Furthermore, the advanced system can use several forms of fossil or synthetic fuels, as available.

Lyndon B. Johnson Space Center
National Aeronautics and Space Administration
Houston, Texas, February 8, 1977
953-36-00-00-72

REFERENCES

1. Wolfer, Barry M.: Preliminary Design Study of a Baseline MIUS. NASA TM X-58193 (To be published).

2. Fulbright, B. E.: MIUS Community Conceptual Design Study. NASA TM X-58174, 1976.

3. Energy Parameter Handbook. GATE Information Center, Southwest Research Institute (San Antonio, Tex.), June 1971.

4. The 1970 National Power Survey. Federal Power Commission, Washington, D.C., Dec. 1971.

5. Solid Waste Management in Residential Complexes. U.S. Environmental Protection Agency, Washington, D.C., 1971.

6. Solid Waste Handling and Disposal in Multistory Buildings and Hospitals. Vols. I to IV. U.S. Environmental Protection Agency, Washington, D.C., 1972.

7. Bailey, J. R.; Benoit, R. J.; et al.: A Study of Flow Reduction and Treatment of Wastewater From Households. U.S. Dept. of Interior, Federal Water Quality Administration, Washington, D.C., Dec. 1969.

8. Linaweaver, F. P., Jr.; Geyer, John C.; and Wolff, Jerome B.: Report V on Phase Two of the Residential Water Use Research Project: Final and Summary Report on the Residential Water Use Project. The Johns Hopkins Univ., Dept. of Environmental Engineering, June 1966.

9. Fair, Gordon M.; Geyer, John C.; and Okum, Daniel A.: Water and Wastewater Engineering. Vol. I.: Water Supply and Wastewater Removal. John Wiley & Sons, Inc., 1966, p. 13-6.

10. Stallings, R. D.; Ferden, S. L.; and Riley, E. S.: Energy Systems Optimization Program Users Guide. Update IV, vols. I and II. NASA TM-4048, 1974.

11. Building Construction Cost Data 1974. Robert Snow Means Co., Inc. (Duxbury, Mass.), 1974.

12. 1973 Building Cost File, Central Edition. McKee-Berger-Mansueto, Inc., Construction Publishing Co., Inc. (New York), 1973.

13. Process Plant Construction Estimating and Engineering Standards. Richardson Engineering Services, Inc. (Downey, Calif.), 1973.

14. Wolfer, Barry M.: The Potential Benefit of an Advanced Integrated Utility System. NASA TM X-58170, 1975.

APPENDIX

ILLUSTRATION OF A THERMAL STORAGE TECHNIQUE

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The following is a discussion of a thermal storage system (TSS) technique for cooling with particular emphasis on allowing for reduction in the installed electrical generating capacity. The illustration is for the baseline modular integrated utility system (MIUS) design for the 496-unit apartment complex. (The loads for the 992-unit complex are, of course, simply doubled.)

The design summer day total cooling loads and absorption/compression loads resulting from the baseline study are shown in figure 24. The absorption chillers would be supplied 103-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 selected on the peak requirement during the design day; i.e., 859.7 kilowatts (244.6 tons) absorption and 1273.3 kilowatts (362.3 tons) (plus 34.1 kilowatts (9.7 tons) distribution losses) compression.

The design summer day electrical load components are shown in figure 25. 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 p.m. to 11 p.m. The introduction of the cold thermal storage capability allows only two prime-mover/generator sets to be used as shown at 104 percent of the rated load for 3 hours. Such equipment can be operated at overload conditions for short periods without adverse effects. Accordingly, chilled water is supplied for space cooling and storage in the more efficient early morning hours until a level in storage is reached (5623 kilowatts (1600 tons)) to meet the remainder of the design day requirements. Figure 26 shows the revised design summer day cooling requirements with storage available. The compression capacity was raised from 1307 to 1406 kilowatts (372 to 400 tons) to ensure that storage would be completed before the demand period on storage occurred.

TABLE I.- TYPICAL INDEX INFORMATION

Location	1973 building cost file M&L[a] composite	1974 means		Means/Chicago		Fuel and lubrication (gasoline (July 30, 1974))	Index
		Labor	M&L	Labor	M&L		
General location							
Mid-Atlantic	92.8	99	96	90.0	92.3	42.9	94.0
Northeast	100.3	99	97	90.0	93.3	41.9	92.0
Southeast	76.1	68	75	61.8	72.1	40.9	89.7
Midwest	85.6	91	91	82.7	87.5	44.4	97.5
Specific location							
Chicago, Ill.[b]	100.0	110	104	100.0	100.0	45.6	100.0
Erie, Pa.	--	100	100	--	--	--	--
Lansing, Mich.	--	100	100	--	--	--	--
Minneapolis, Minn.	96.3	101	100	--	--	--	--

[a]M&L = materials and labor.

[b]Chicago is considered as a mean here; Chicago diesel fuel price as delivered has been taken at 9.036¢/liter. (34.2¢/gal) based on the October 17, 1974, Platts Oilgram, which shows a 0.792¢/liter (3¢/gal) profit and delivery cost estimate.

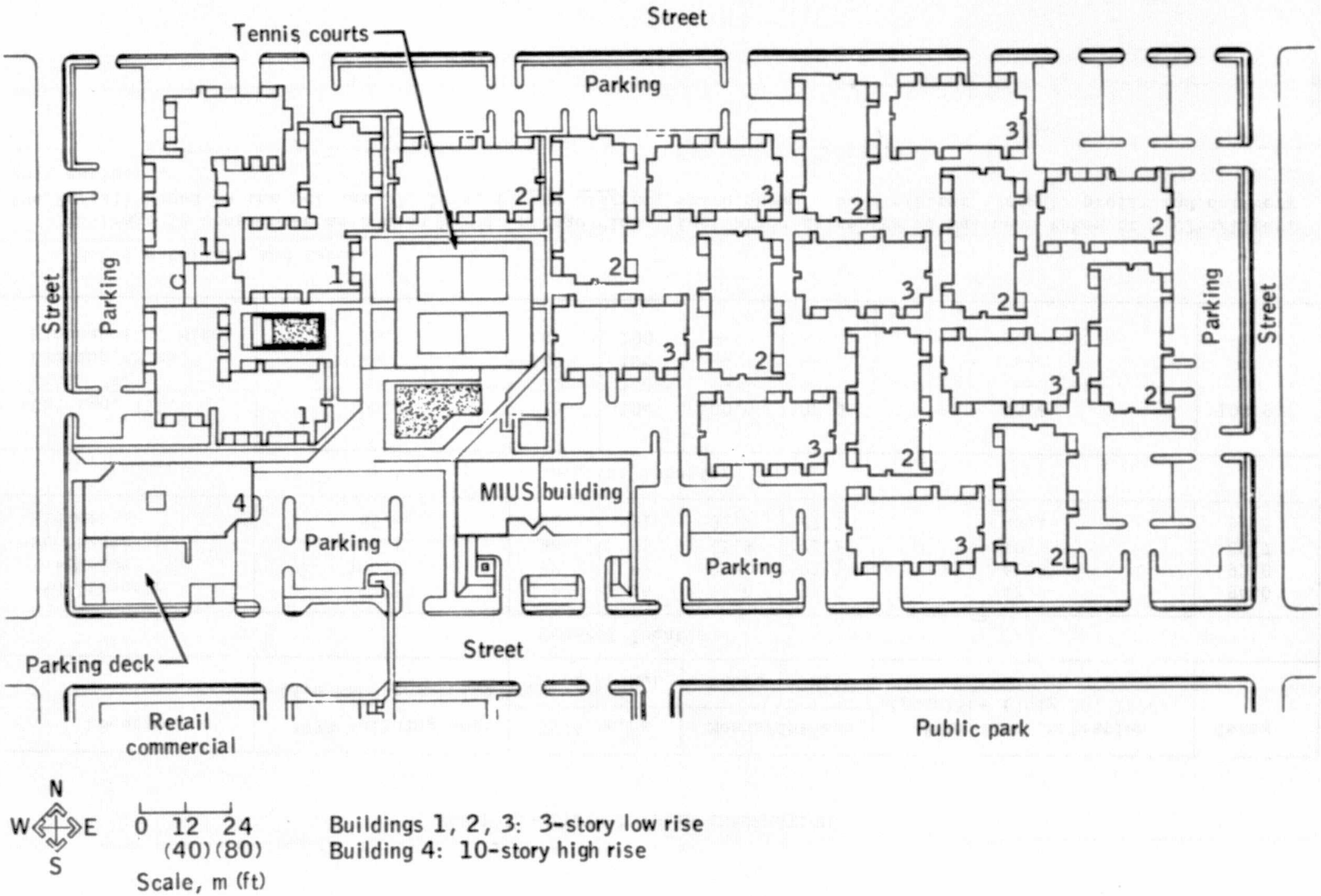


Figure 1.- A 496-unit apartment complex site plan.

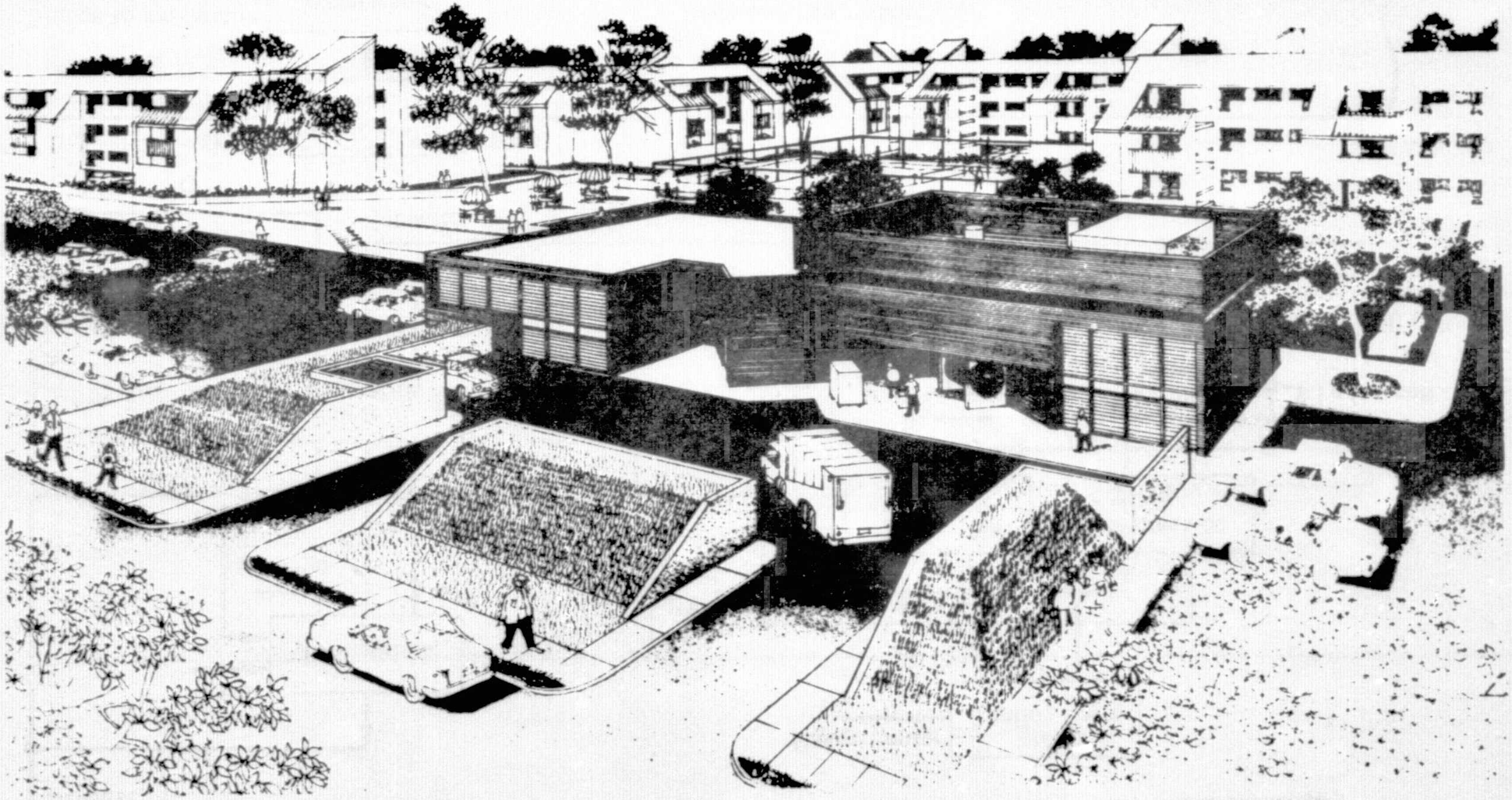


Figure 2.- Architectural rendering of an MIUS plant.

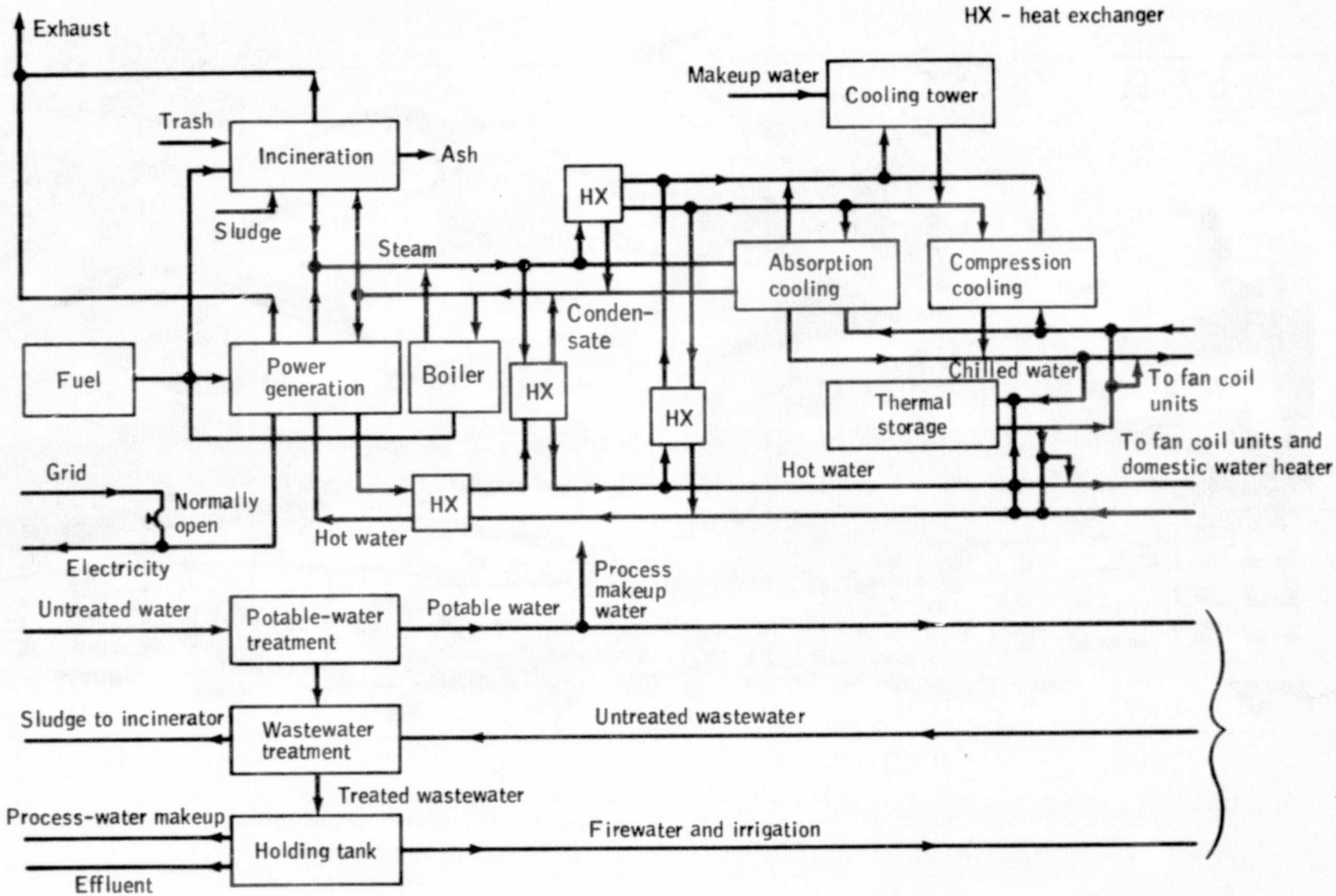
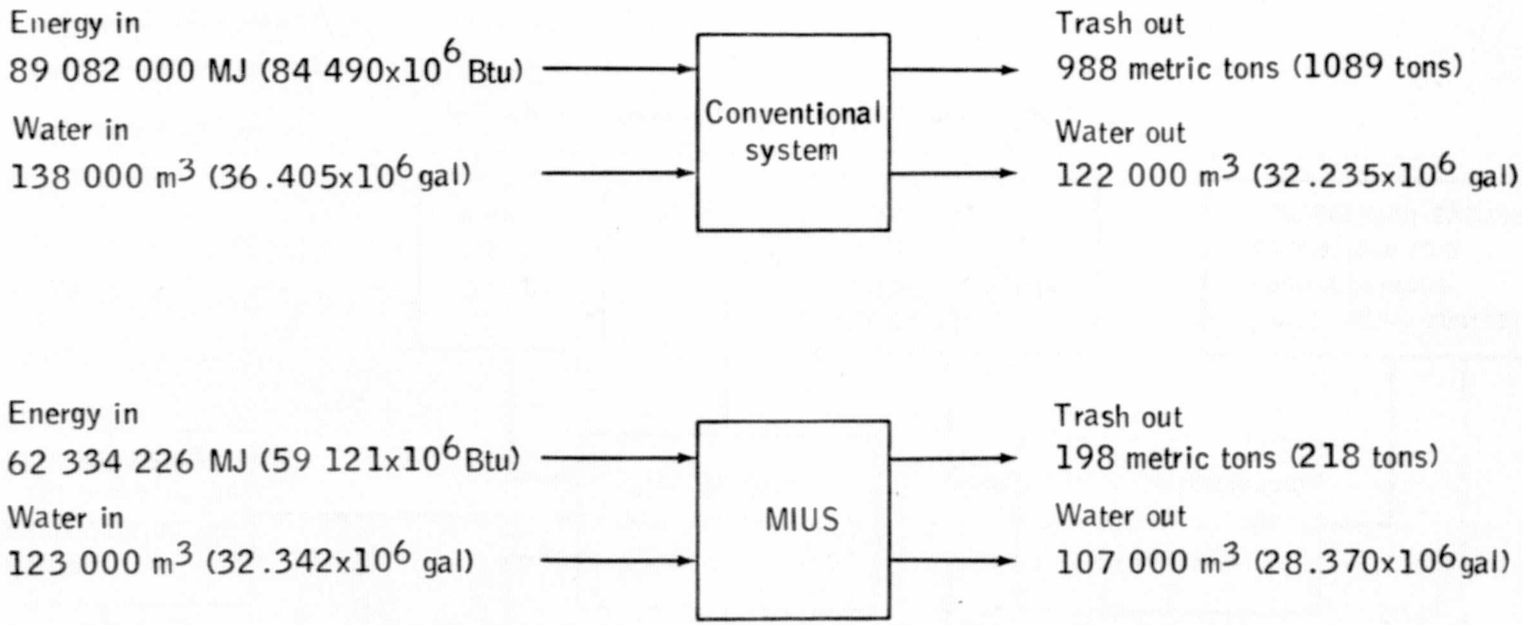


Figure 3.- Baseline MIUS overview.



Energy savings	30.0 percent
Water savings	11.2 percent
Effluent reduction	12.0 percent
Trash reduction	80 percent

Figure 4.- Annual consumables comparison for a 496-unit apartment complex in Washington, D.C.

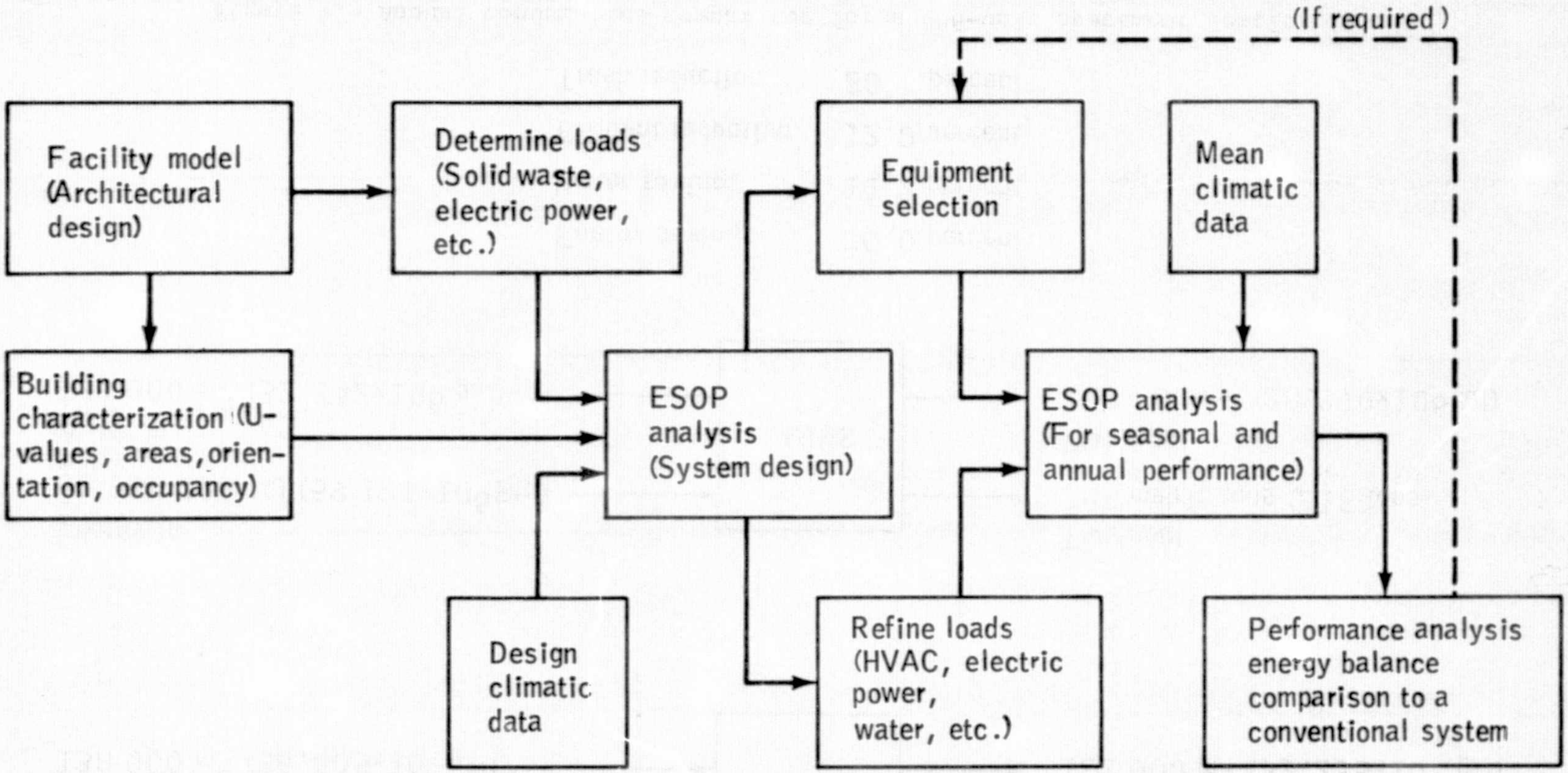


Figure 5.- Overall MIUS design procedure.

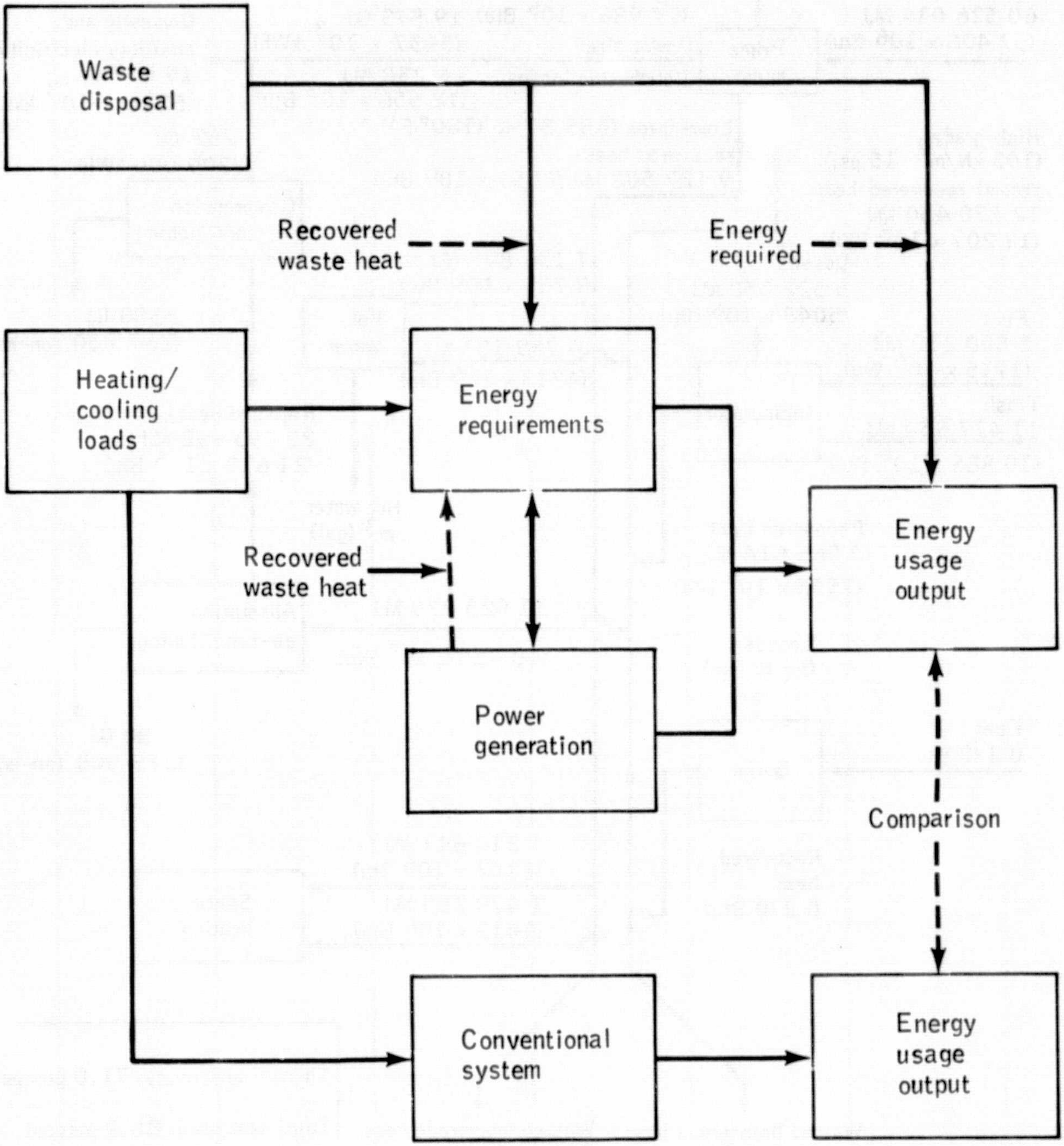


Figure 6.- Generalized ESOP flow diagram.

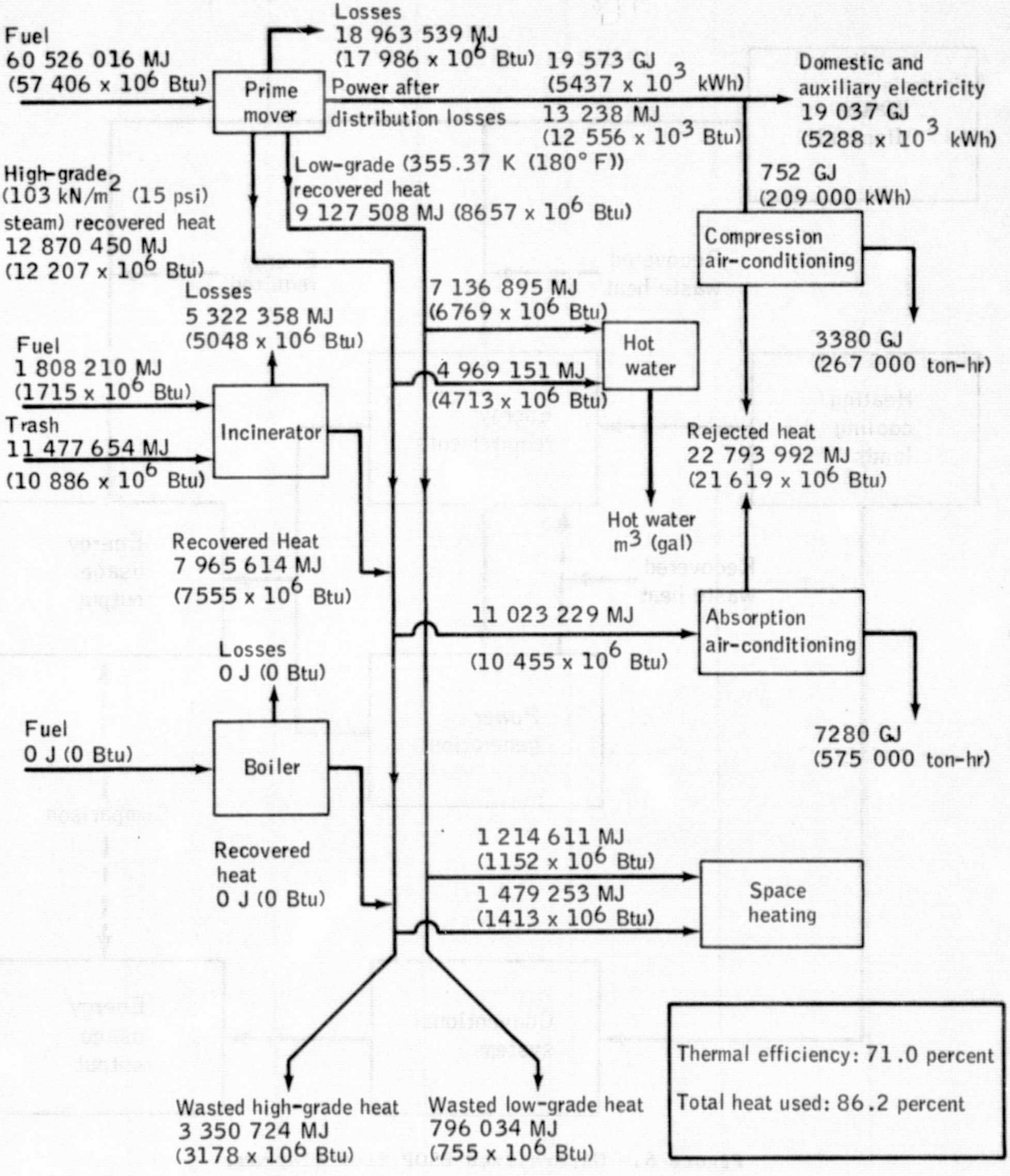


Figure 7.- Annual MIUS energy analysis for a 496-unit apartment complex in Washington, D.C.

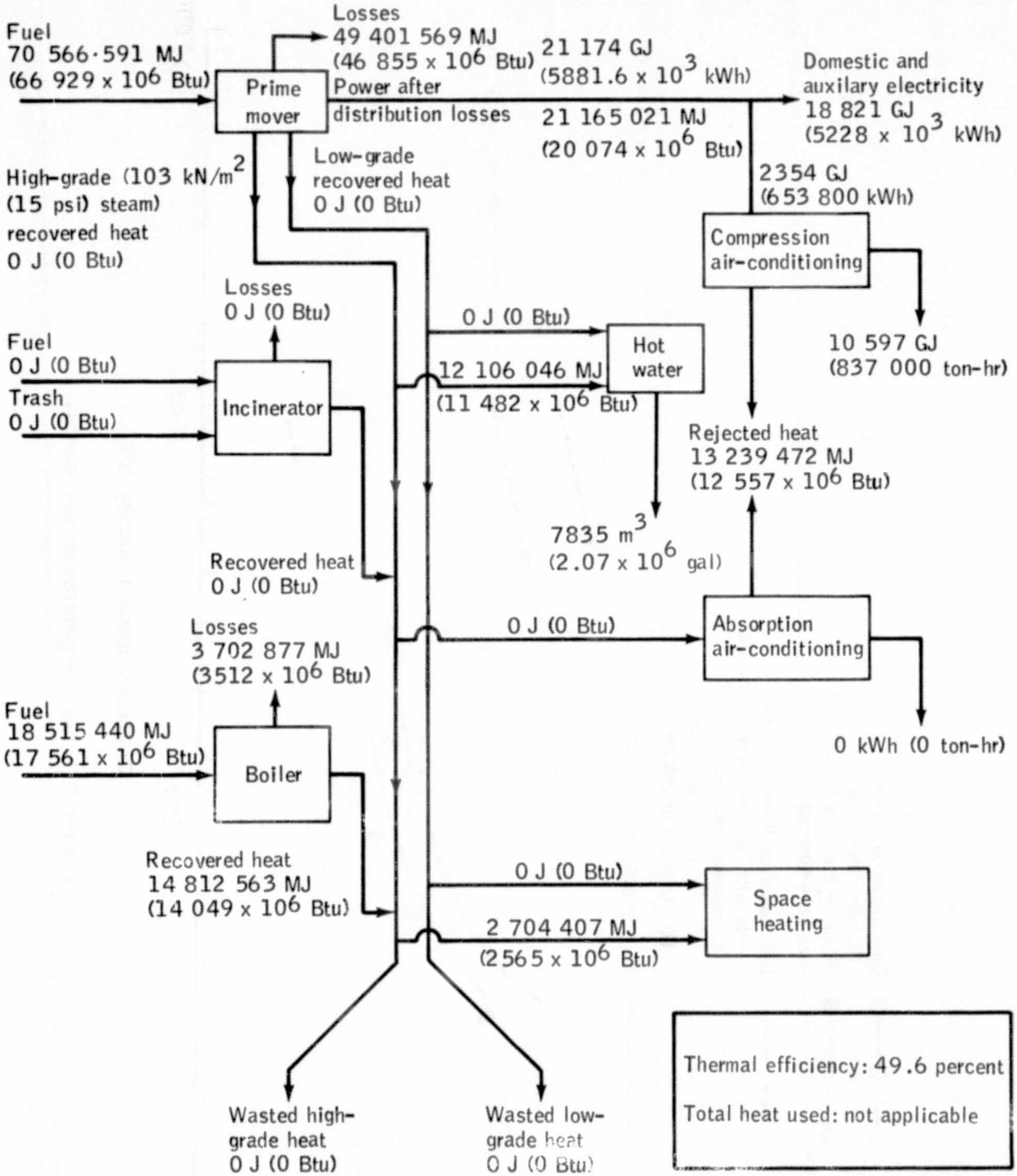


Figure 8.- Annual conventional-system energy analysis for a 496-unit apartment Washington, D.C.

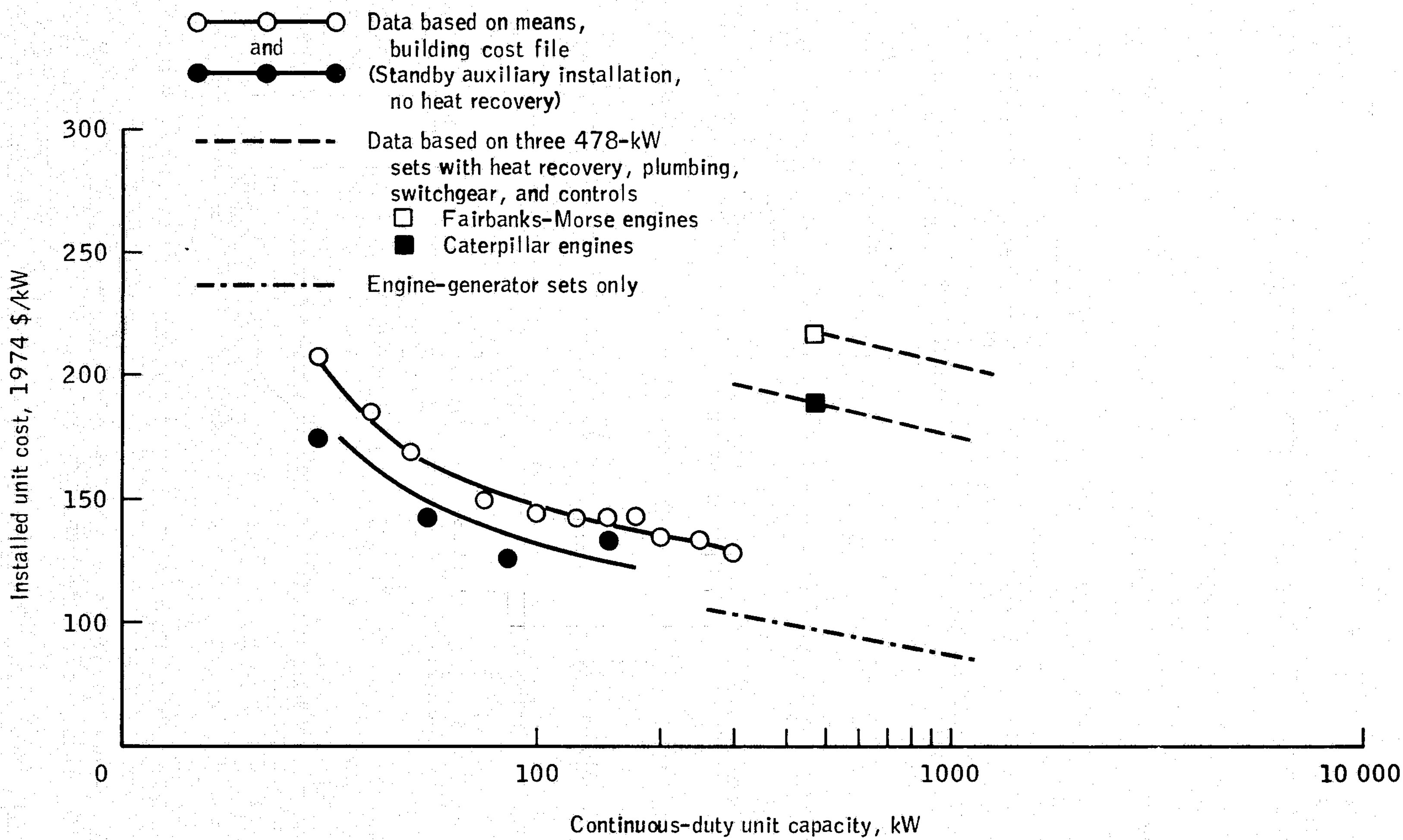


Figure 9.- Engine-generator set costs.

ENGINE GENERATOR DATA

Electrical demand, J (kW)	Percent of rated load	Specific fuel consumption, J/J (Btu/kWh)	Heat-recovery data, J/hr (Btu/hr)			Conversion efficiency	Number of engines
			Water jacket 394 K (250° F)	Exhaust 394 K (250° F)	Lubricating oil 358 K (185° F)		

Figure 10.- Example of engine-generator data sheet.

Low-rise singles apartment (Washington, D.C.)

Units, no.	36
Indoor dry-bulb temperature, K (°F)	296 (74)
Ventilation rate (outside air makeup), m^3/min (ft^3/min)	1.58 (56)
Inside air enthalpy, kJ/kg (Btu/lb)	64.4 (27.7)
Latitude, deg	39 N
Longitude, deg	77 W
Time zone	EST
Solar reflectance of ground	0.25
Atmospheric clearness number (1.0 = clear)	0.98
Direction building faces	South

Exterior tilt angles and surface areas

Walls and windows

Tilt angle from vertical, deg	Wall areas without glass, m^2 (ft^2)	Gross window area, m^2 (ft^2)	Azimuth angle, deg
0	265 (2853)	53.5 (576)	0 (N)
0	265 (2853)	53.5 (576)	90 (E)
0	265 (2853)	53.5 (576)	180 (S)
0	265 (2853)	53.5 (576)	270 (W)

Roof areas

Tilt angle from vertical, deg	Area, m^2 (ft^2)	Azimuth angle, deg
0	---	0 (N)
0	---	90 (E)
0	---	180 (S)
0	---	270 (W)
90	945 (10 173)	Horizontal

U-factors:

Walls	0.10
Windows	1.06
Roofs	.06

Solar absorptance of walls and roof	0.50
Construction type (light, medium, heavy)	Medium
Water loads:	
Potable water demand, m^3(gal)/day/person	0.3205 (84.7)
Hot-water demand, m^3(gal)/day/person	0.1743 (46.06)
Solid-waste loads:	
Heating valve, kJ/kg (Btu/lb)	11 622 (5000)
Generation rate, kg(lb)/day/person	2.27 (5)
Moisture, percent	40
Floor area, m^2 (ft^2)	2835 (30 519)
Ceiling height, m (ft)	2.5 (8)

Figure 11.- Example of completed form for a standardized building.

Time of day	Domestic electricity, kW/unit	Auxiliary electricity, percent domestic use	Occupants, persons/ unit	Metabolic rate, J/hr/occupant (Btu/hr/occupant)
1 a.m.	0.746	28	1.50	316 200 (300)
2 a.m.	.673	24	1.50	316 200 (300)
3 a.m.	.546	37	1.50	316 200 (300)
4 a.m.	.546	36	1.50	316 200 (300)
5 a.m.	.546	35	1.50	368 900 (350)
6 a.m.	.546	36	1.25	368 900 (350)
7 a.m.	.636	32	.97	421 600 (400)
8 a.m.	.763	27	.69	527 000 (500)
9 a.m.	.710	30	.44	527 000 (500)
10 a.m.	.655	33	.28	421 600 (400)
11 a.m.	.655	35	.28	421 600 (400)
12 m.	.655	36	.28	474 300 (450)
1 p.m.	.655	37	.56	421 600 (400)
2 p.m.	.655	38	.28	368 900 (350)
3 p.m.	.655	39	.36	368 900 (350)
4 p.m.	.655	41	.44	368 900 (350)
5 p.m.	.798	35	.66	421 600 (400)
6 p.m.	1.055	27	.72	632 400 (600)
7 p.m.	1.273	23	.83	527 000 (500)
8 p.m.	1.448	20	.83	421 600 (400)
9 p.m.	1.448	20	.94	421 600 (400)
10 p.m.	1.448	20	1.05	368 900 (350)
11 p.m.	1.175	24	1.25	368 900 (350)
12 p.m.	.875	28	1.50	361 200 (300)
Total	19.817			

Figure 12.- Example of completed data sheet for low-rise singles apartments.

Project number ____________ Date completed ____________

Task number ________________

Site-dependent data

Location selected

Atlanta ________	Las Vegas ________	Boston ________
Los Angeles ______	Chicago ________	Minneapolis ________
Denver ________	New York ________	Houston ________
Seattle ________	Kansas City ______	Washington, D.C. ______

Engine selected

Fairbanks-Morse 478 ______	Fairbanks-Morse 956 ______
Caterpillar 475 ________	Caterpillar 315 ________

Solid-waste data

Total population of complex ____________

Supplementary fuel selected ____________

Startup fuel selected ________________

Building description

Type	Number of buildings	Number of units	Floor area, m^2 (ft^2)	Wall factor	Glass factor	Ceiling height, m (ft)
Family high-rise						
100-unit						
18-unit[a]						
36-unit[b]						
Townhouse						
Commercial						

Special data:

Thermal storage system (TSS) data, if applicable

Heating and cooling data	Winter	Spring	Summer	Fall	Other data
Initial cooling in TSS, J/hr (tons/hr)					
Maximum cooling storage, J/hr (tons/hr)					
Initial heating in TSS, J/hr (Btu/hr)					
Compression chiller size, J/hr (tons/hr)					

Comparative heating and cooling data	Winter, 2σ	Summer, 2σ
Initial cooling in TSS, J/hr (tons/hr)		
Maximum cooling storage, J/hr (tons/hr)		
Initial heating in TSS, J(hr) (Btu/hr)		
Compression chiller size, J/hr (tons/hr)		

[a]Building 2.

[b]Building 1.

Figure 13.- Example of typical computer input form.

Loads description	MIUS	Conventional
Electrical:		
Peak power, kW		
Average power, kW		
Annual usage, J (kWh)		
Load factor, percent		
Heating and cooling:		
Design cooling, J/hr (tons/hr) . . .		
Design heating, J/hr (Btu/hr) . . .		
Waste disposal, kg/day (lb/day):		
Solid waste		
Sludge		
Total incineration		
Water loads, m^3/day (gal/day):		
Peak potable		
Average potable		
Peak wastewater		
Average wastewater		

Figure 14.- Example of loads results form.

Annual consumables	MIUS	Conventional	Percent savings
Fuel, J (Btu)			
Potable water, m^3 (gal)			
Wastewater effluent, m^3 (gal) . . .			
Trash effluent, metric tons (tons)			

Figure 15.- Example of consumables results form.

MIUS identification ____________ Location ____________

Fuel index ____________ Labor index ____________ Construction index ____________

Types of dwelling units:

Single family ______

Townhouses ______

Apartments ______

Number of buildings ______

Commercial dimensions, m^2 (ft^2) ______

Site dimensions, m^2 (acre) ______

Total residents ______

MIUS utilities

Electrical output	Equipment and fuel
Capacity, J/yr (kWh/yr) ______	Engine generators, no. ______ Size ______ kW ______
Peak kilowatts ______	Fuel required, m^3/yr (gal/yr) ______
Total kilowatts with heat recovery ______	Heat rate, J/m^3 (Btu/gal) ______
Total kilowatts without heat recovery ______	Fuel storage capacity, m^3 (gal) ______

Water usage and capacity	Wastewater usage and capacity
Rate (offsite), m^3/yr (gal/yr) ______	Wastewater, m^3/yr (gal/yr) ______
Peak usage, m^3/day (gal/day) ______	Peak usage, m^3/day (gal/day) ______
	Holding tank volume, m^3 (gal) ______
	Offsite disposal, m^3/yr (gal/yr) ______

HVAC and hot water data (central building equipment)

Centrifugal, J/hr (tons/hr) ______

Absorption, J/hr (tons/hr) ______

Fuel, m^3/yr (gal/yr) ______

Dimensions of site area, m^2 (acre) ______

Individual dwelling unit equipment ______

Primary trunklines, diameter and length, m (ft) ______

Boilers, no. ______

Cooling tower, peak J/hr (Btu/hr) ______

Site served ______

Solid waste

Solid waste, metric tons/day (tons/day) ______

Sludge, metric tons/day (tons/day) ______

Supplementary fuel, m^3/yr (gal/yr) ______

Solid waste, metric tons/yr (tons/yr) ______

Offsite disposal, metric tons/week (tons/week) ______

Conventional utilities

Electrical power, J/yr (kWh/yr) ______ 2σ peak, kW

Water, m^3/yr (gal/yr) ______ Peak daily ______

Wastewater, m^3/yr (gal/yr) ______ Peak daily ______

Solid waste, metric tons/yr (tons/yr) ______

HVAC (chilled-water equipment):

Centrifugal chillers, J (tons), total ______

Boilers (peak), J/hr (Btu/hr) ______ Boiler fuel, m^3/yr (gal/yr) ______

Cooling tower output capacity, J/hr (Btu/hr) ______

Individual dwelling unit equipment ______

Figure 16.- Example of typical conventional-system cost-evaluation data form.

Identification ____________________ Location ____________________

ELECTRICAL POWER

Parameter	Chicago cost	Index	Site cost
Equipment:			
Engine generator sets with heat recovery, transformers, switchgear, and all MIUS building equipment, kW each at $/kW			
Engine generator set without heat recovery, kW at $/kW			
Fuel storage and supply capacity, m^3 (gal)			
Distribution external to MIUS building			
Total capital:			
Fuel, m^3/yr (gal/yr) at $/$m^3$ ($/gal) Lube oil cost, mills/J (mills/kWh)			
Annual operating costs:			
Electric plant, distribution equipment, and fuel supply maintenance, mills/J (mills/kWh)			
Distribution system maintenance			
Annual maintenance			

(a) Sheet 1.

Figure 17.- MIUS cost-assessment forms.

Identification ______________ Location ______________ Capacity, m^3/day (gal/day) __________

WATER SUPPLY

Parameter	Chicago cost	Index	Site cost
Annual operating costs, $\$/m^3$ (\$/gal):			
Chemicals			
Electricity			
Labor and miscellaneous			
Subtotal operating costs			
Annual maintenance			

(b) Sheet 2.

Figure 17.- Continued.

Identification ____________________ Location ____________________

WASTEWATER

Treatment parameters	Chicago cost	Index	Site cost
Primary, secondary treatment, m^3/day (gal/day), peak			
Advanced treatment			
Collection cost			
Fire protection			
Total capital			
Annual maintenance			
Annual operating costs			

(c) Sheet 3.

Figure 17.- Continued.

Identification ______________________ Location ______________________

HVAC AND HOT WATER[a]

Building equipment description

Purpose	Number units single-family, detached	Number units townhouses	Number units duplexes (and similar)	Apartments	Commercial and other usages
Space heating					
Space cooling					
Hot water					
Fuel					

Note: Initial and annual O&M costs (excluding electricity) will be evaluated for comparison to MIUS costs. When equipment is identical for the MIUS and the conventional systems, installation costs will not be evaluated. Electricity is evaluated separately.

[a]Cooking — gas or electricity.

(d) Sheet 4.

Figure 17.- Continued.

Identification ____________________ Location ____________________

SOLID-WASTE SUBSYSTEM

Incineration and collection parameters	Chicago cost	Index	Site cost
Incinerator with heat recovery and all accessories			
Collection equipment,[a] $45.60/dwelling unit			
Fuel incinerator (operating)			
Operating fuel collection, m^3(gal)/yr/dwelling unit			
Offiste disposal			
Total capital			
Total operating costs			
Total maintenance costs			

[a]Not including replacement cost of short-life equipment.

(e) Sheet 5.

Figure 17.- Continued.

Identification ____________________ Location ____________________

Parameter	Chicago cost	Index	Site cost
Control subsystem:			
Capital			
Maintenance			
MIUS housing:			
Capital			
Maintenance at 1.5 percent of capital			
Miscellaneous:			
Trenching			
Pneumatic			
Tools			
Spare parts			
Initial fuel load			

(f) Sheet 6.

Figure 17.- Continued.

Identification ____________________ Location ____________________

OPERATING CREW

Personnel	Hr/week	Chicago rate and annual cost	Index	Site cost
Engineer supervisor				
Electric power				
Wastewater				
HVAC				
Solid waste				
Total employees				
Skilled (1)				
Semiskilled (3)				
Service				
Total				

(g) Sheet 7.

Figure 17.- Continued.

Identification ____________________ Location ____________________

OVERALL MIUS SYSTEMS COST ASSESSMENT

System/parameter	Capital cost	Annual operating cost	Annual maintenance cost	Notes
Electrical power				
Water supply/fire protection				
Wastewater				
HVAC, hot water				
Solid waste				
Controls				
MIUS housing				
Miscellaneous				
Operating crew				
System totals				

(h) Sheet 8.

Figure 17.- Continued.

OVERALL ITEMIZED MIUS COST ASSESSMENT
Identification ____________ Location ____________
Materials
Subcontractor labor
Subcontractor overhead
Subcontractor profit
General contractor overhead
Construction load and construction period adjustment
Engineering
Architectural (MIUS building) M&L
General contractor profit
Turnkey cost
Base annual O&M cost
Insurance at 1 percent of M&L
Property tax
Profit
Federal taxes
Annualized payment with interest
Annual outlay
Initial cost per dwelling unit
Average annual utility bill per dwelling unit
Average monthly utility bill per dwelling unit

(i) Sheet 9.

Figure 17.- Concluded.

Identification ______________________ Location ______________________

ELECTRICAL POWER

Site, J/yr (kWh/yr) ______________________ 2σ peak kW ______________________

Initial conditions (costs) for providing power to site:

Powerlines ______________ Underground distribution ______________

Transformer stations ______________ Other costs and services ______________

Initial assessment ______________

Initial connection charges:

Residential units ______________ Deposit ______________ Commercial units ______________ Deposit ______________

Loads assessment													
Number units	Building type	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Residential consumption/dwelling unit, J (kWh)													
Rates: ______________________													
Commercial (and other uses) consumption/establishment, J/kW/month (kWh/kW/month)													
Rates: ______________________													

Note: O&M: No assessment independent of rate structure will be made for conventional electrical power.

(a) Sheet 1.

Figure 18.- Conventional-system cost-assessment forms.

Identification ______________________ Location ______________________

WATER

Site, m^3/yr (gal/yr) ______________________ Peak daily, m^3 (gal) ______________________

(With fire protection) ______________________ (Without fire protection) ______________________

Water source ______________________

Initial conditions (costs) for providing service to site:

Supply line ______________ Elevated storage tank ______________

Treatment plant ______________ Distribution ______________

Initial assessment ______________________

Initial connection charges:

Residential units ______________ Deposit ______________ Period ______________

Commercial units ______________ Deposit ______________ Period ______________

Loads assessment													
Number units	Building type	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Residential consumption/dwelling unit, m^3 (gal)													

Rates: ______________________

Taxes: ______________________

Commercial (and other uses) consumption/establishment, m^3 (gal)													

Rates: ______________________

Taxes: ______________________

Note: O&M: No assessment independent of rate and tax structure will be made for the conventional water supply.

(b) Sheet 2.

Figure 18.- Continued.

Identification ______________________ Location ______________________

WASTEWATER

Site, m^3/yr (gal/yr) ______________________ Daily peak, m^3 (gal) ______________________

(With fire protection) ______________________ (Without fire protection) ______________________

Water authority ______________________

Initial conditions (costs) for providing service to site:

Trunks ____________ Treatment plant ____________ Collection ____________

Lift stations ____________ Outfall ____________

Initial assessment ______________________

Initial connection charges:

Residential units ______________________ Commercial units ______________________

Loads assessment

Number units	Building type	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Residential consumption/dwelling unit, m^3 (gal)													

Rates: ______________________

Taxes: ______________________

Number units	Building type	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Commercial (and other uses) consumption/establishment, m^3 (gal)													

Rates: ______________________

Taxes: ______________________

Note: O&M: No assessment independent of rate and tax structure will be made for the conventional water supply.

(c) Sheet 3.

Figure 18.- Continued.

Identification ____________________ Location ____________________

HVAC

Equipment	Capacity	Quantity required	Chicago cost	Index	Site cost
Centrifugal chillers, J/hr (tons/hr)					
Absorption chiller, J/hr (tons/hr)					
Cooling tower, J/hr (Btu/hr)					
Boiler, J (hp)					
Thermal storage tank, m^3 (gal)					
Chilled-water pumps, J/hr (tons/hr)					
Hot-water pumps, J/hr (Btu/hr)					
Interconnect plumbing for hot and chilled lines	—				
Distribution (external to MIUS building):					
High-density	--				
Trunklines	--				
Fuel oil, m^3 (gal)					
Total capital					
Total operating costs					
Total maintenance costs					

(d) Sheet 4.

Figure 18.- Continued.

Identification ____________________ Location ____________________

SOLID WASTE

Responsible agency ____________________

Initial conditions for providing service to site ____________________

Numbers of collection points:

Single-family, detached ____________________

Townhouses ____________________

Duplexes and similar buildings ____________________

Apartment buildings ____________________

Commercial and community buildings ____________________

Annual load, metric tons/yr (tons/yr) ____________________

Other charges ____________________

Rates ____________________

Taxes ____________________

(e) Sheet 5.

Figure 18.- Concluded.

Identification ______________________ Location ______________________

Service	MIUS		Conventional			
	Capital	Annual O&M	Initial charges	Annual O&M	Annual rates and taxes	Annual total
Electrical power						
Water supply						
Wastewater						
HVAC, hot water						
Solid waste						
Other services						
Operating personnel						

Notes:

Figure 19.- Example of MIUS/conventional costs comparison.

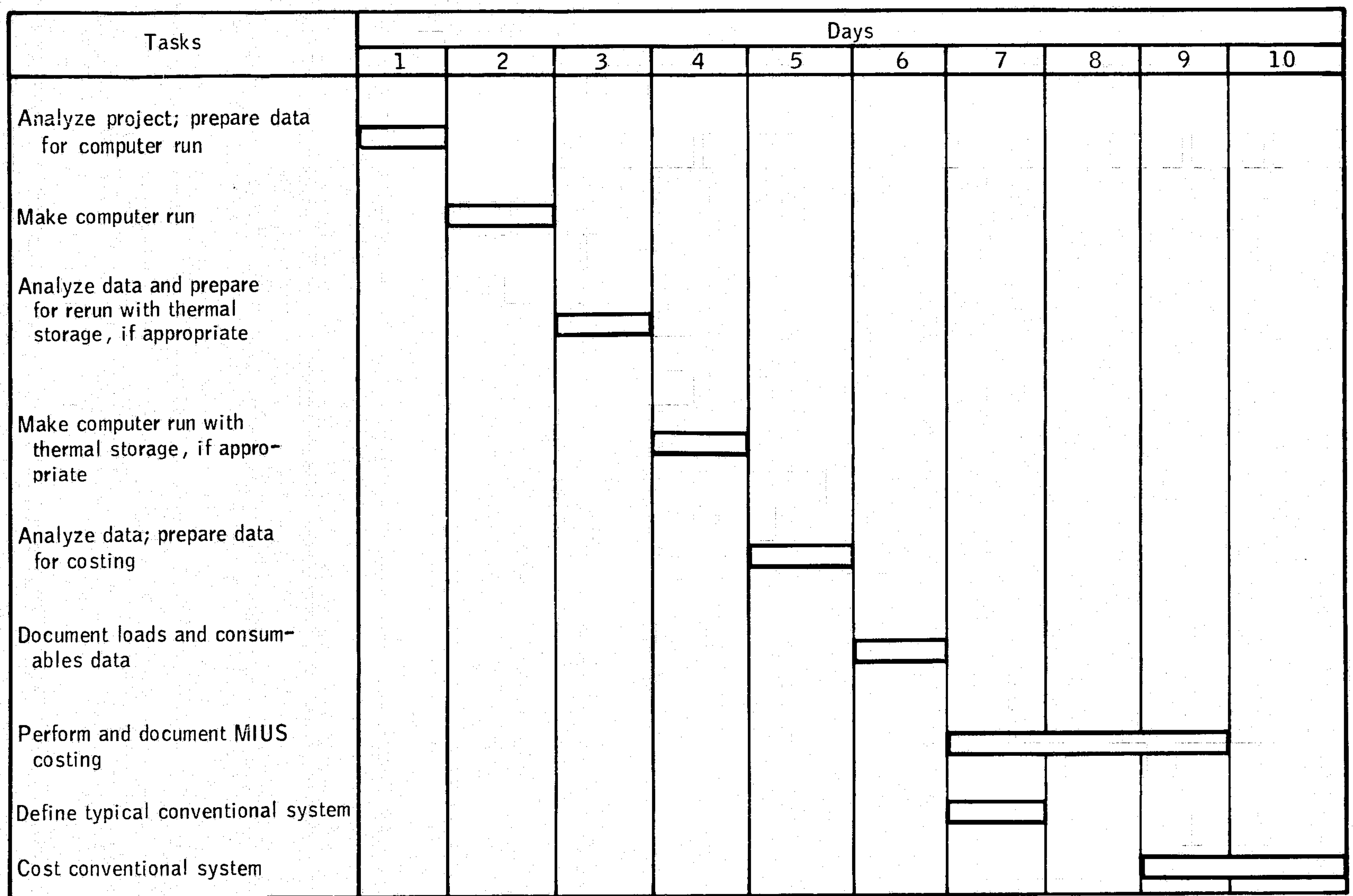


Figure 20.- Schedule for MIUS rapid analysis.

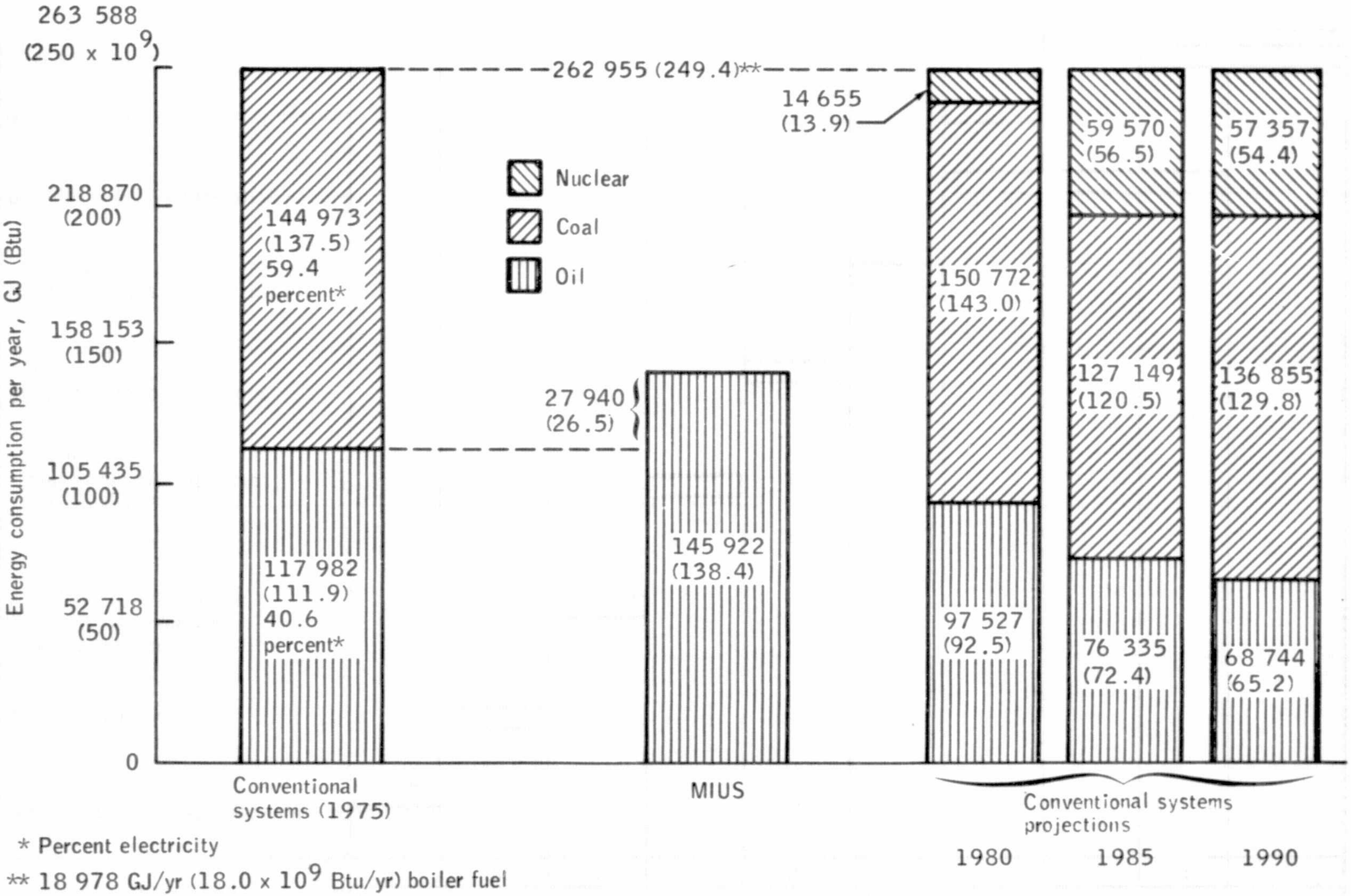


Figure 21.- Comparison of MIUS and conventional oil usage.

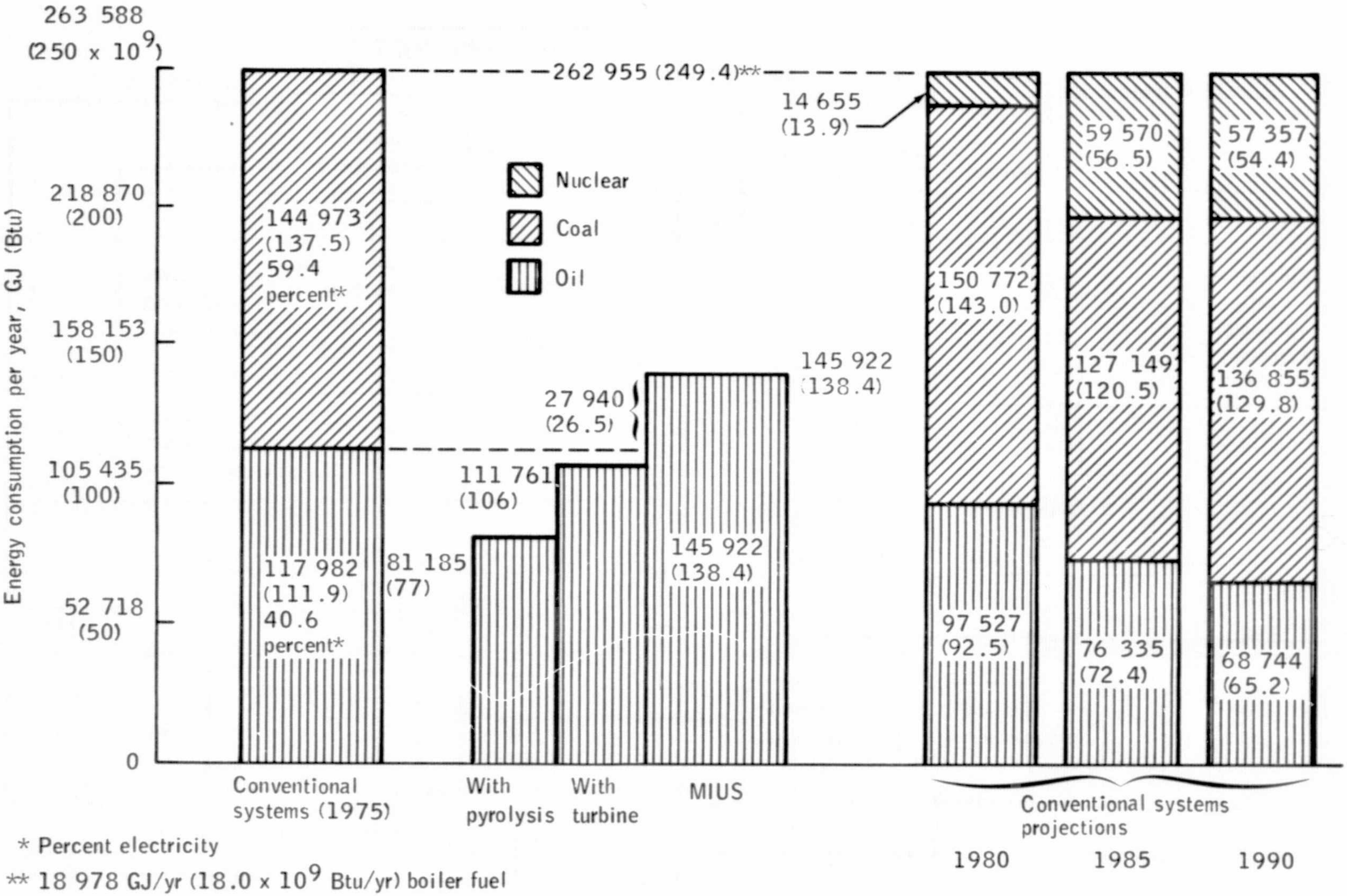


Figure 22.- Effects of importing solid waste as fuel on oil usage.

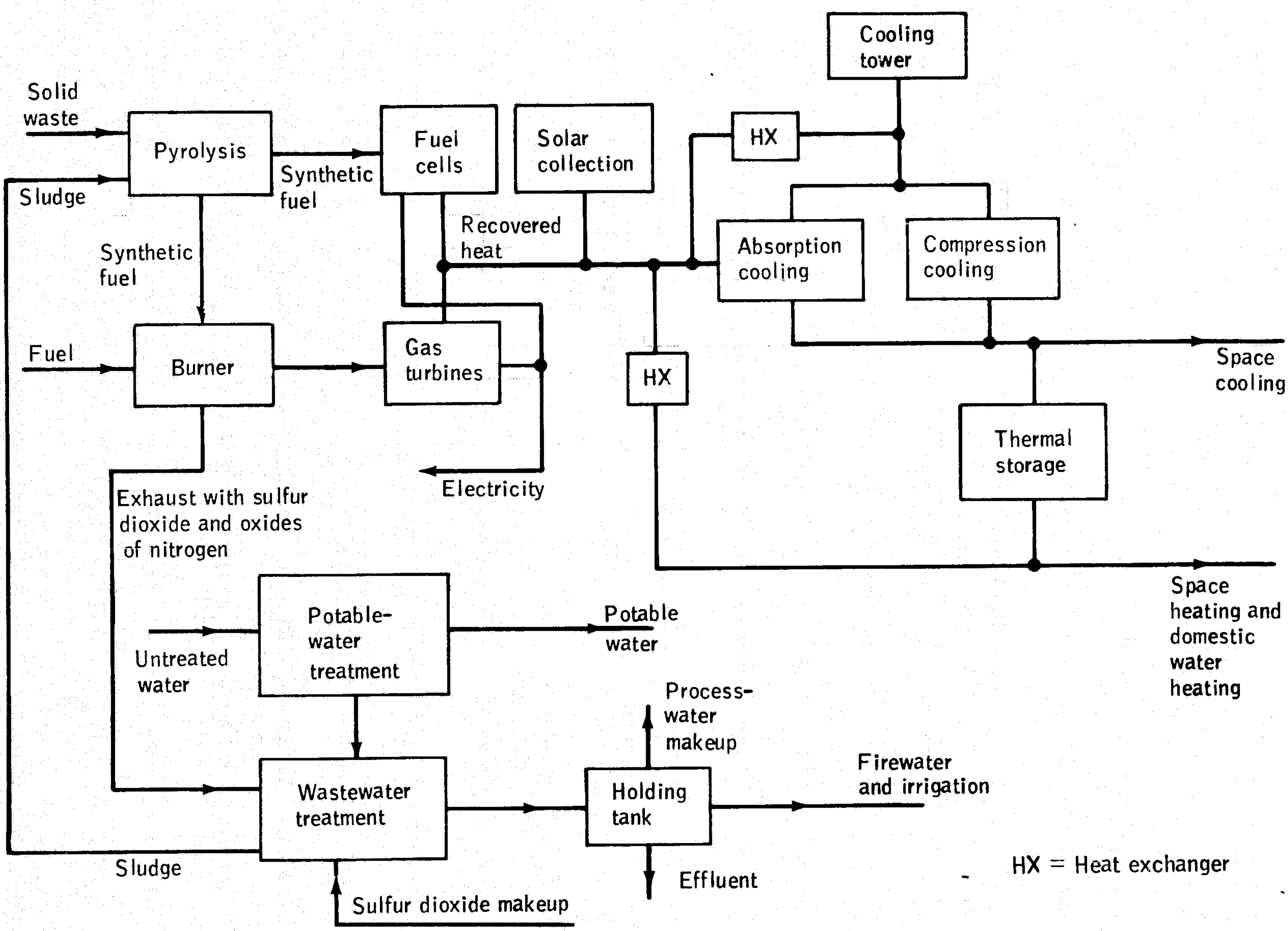


Figure 23.- Illustration of an advanced integrated utility system.

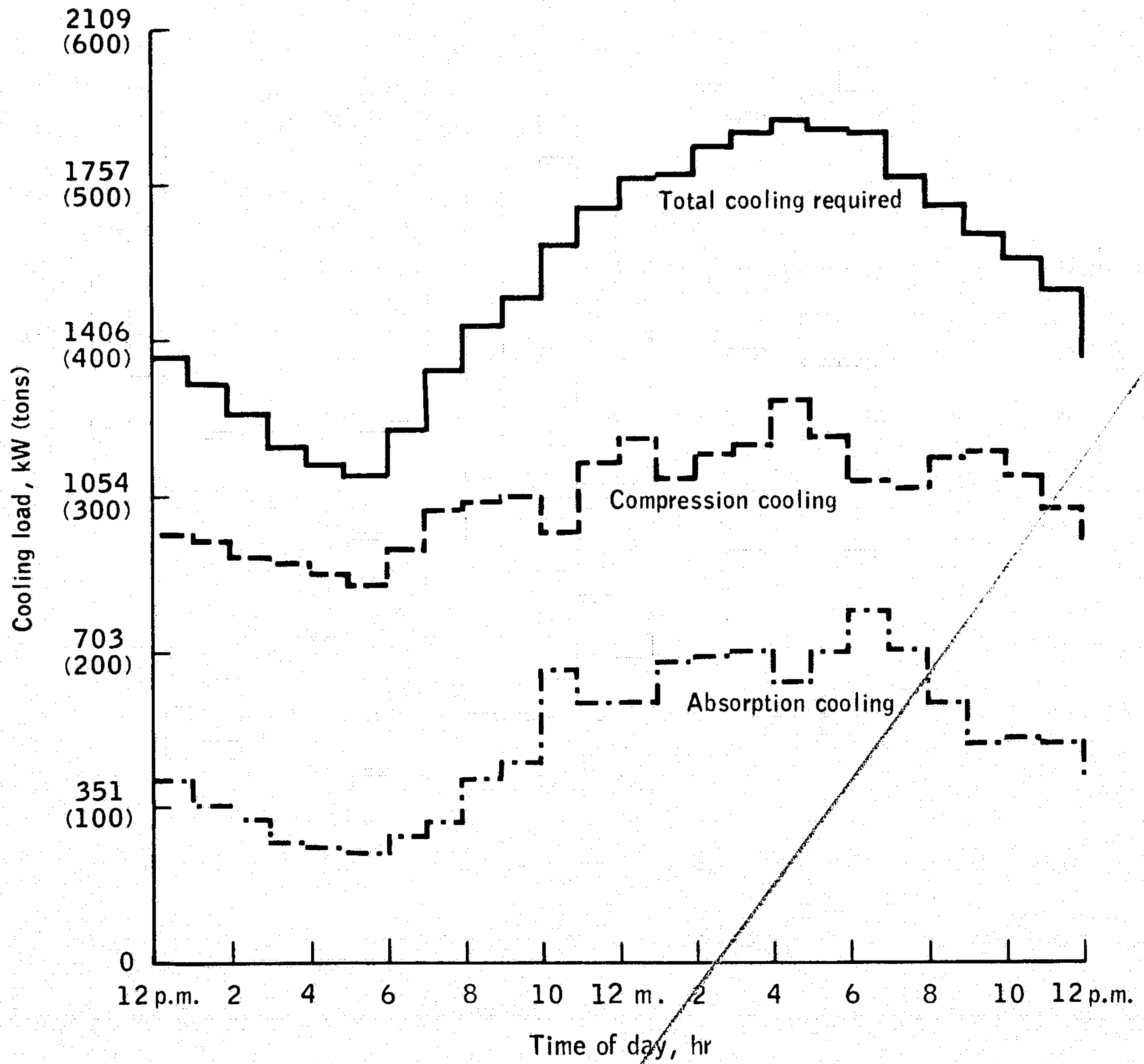


Figure 24.- Design summer day total cooling load and absorption/ compression loads without storage.

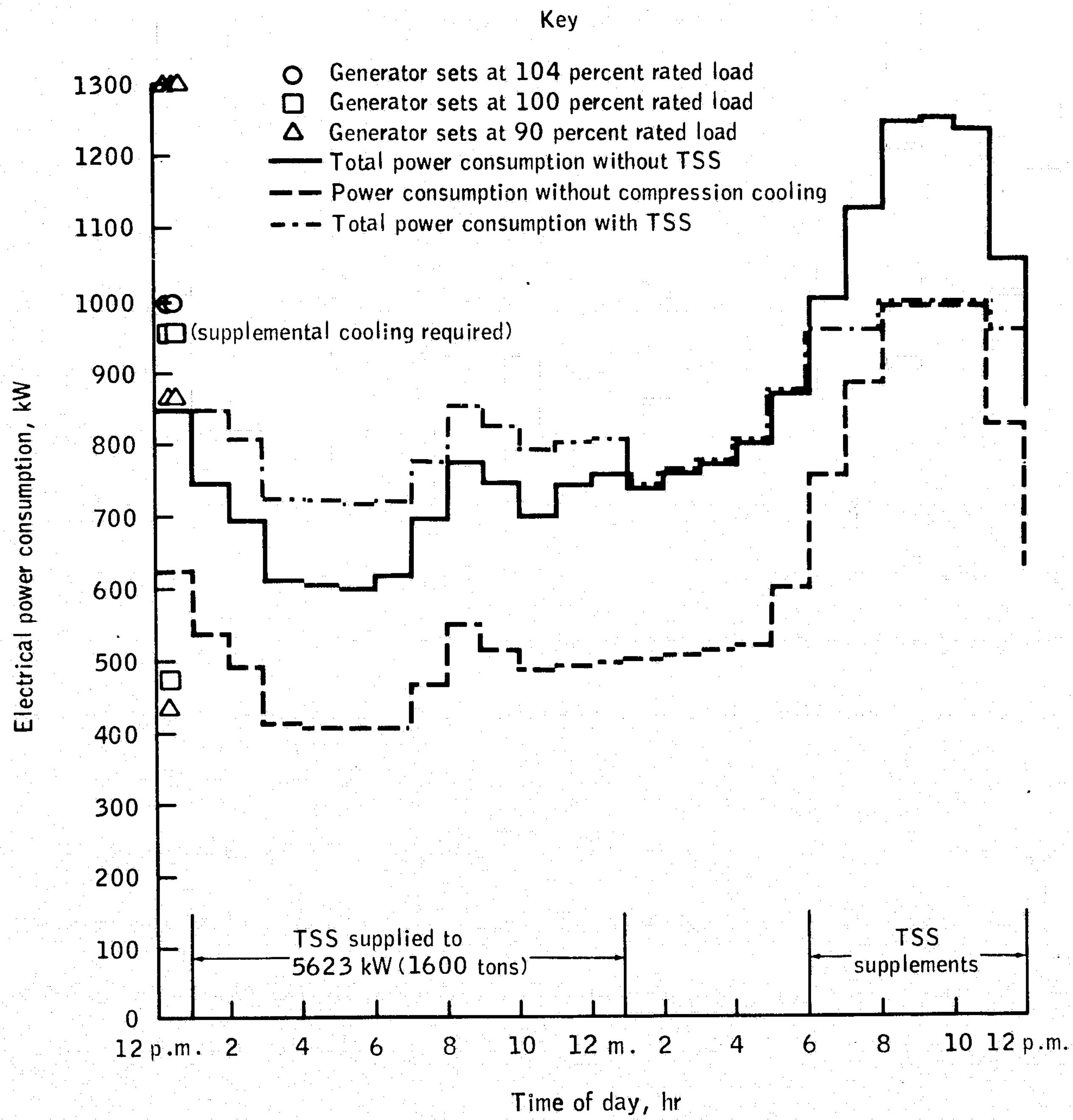


Figure 25.- Design summer day electrical consumption.

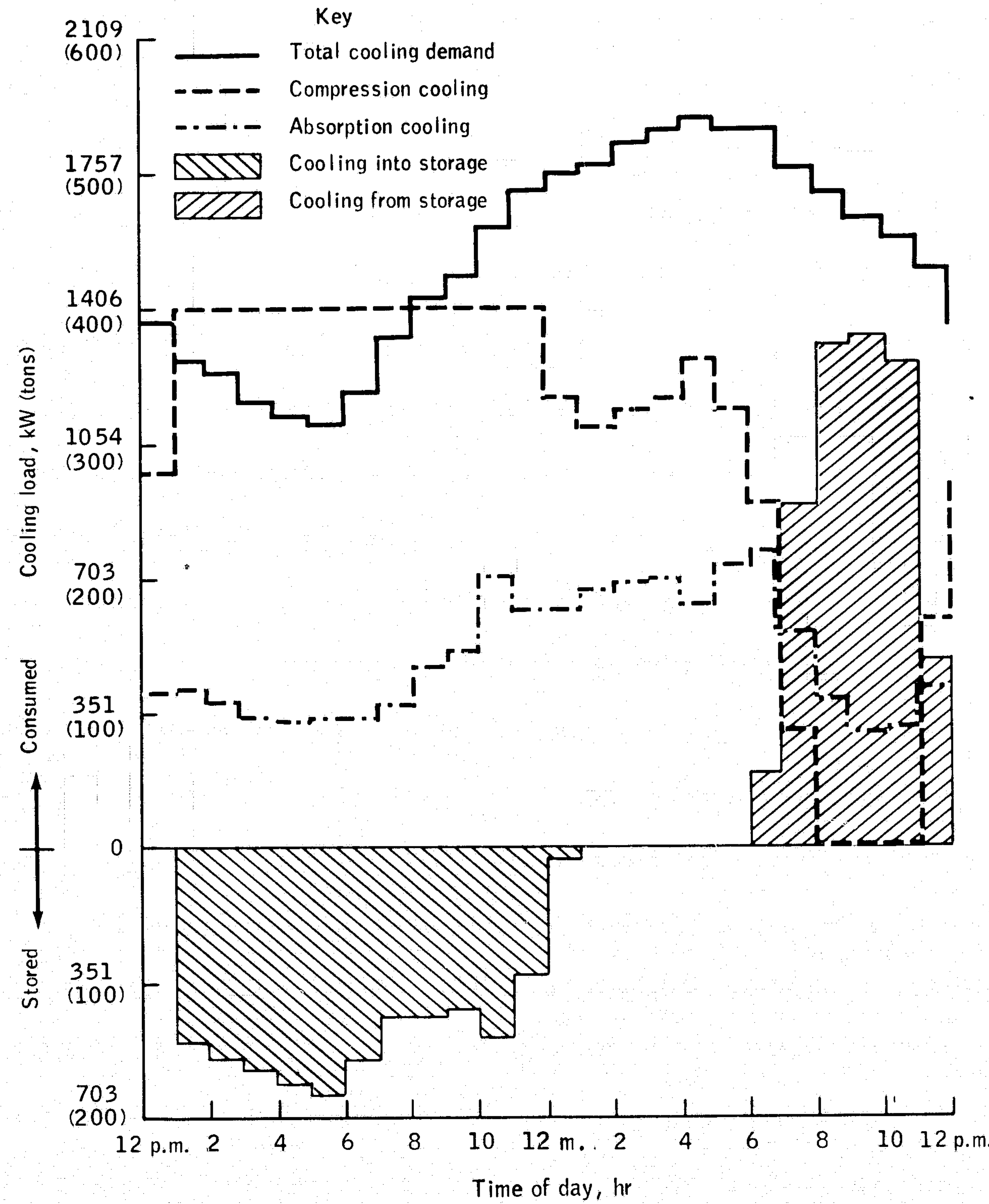


Figure 26.- Cooling load distribution using storage.

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