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April 1976

INITIAL COMPARISONS OF MODULAR-SIZED, INTEGRATED UTILITY SYSTEMS AND CONVENTIONAL SYSTEMS FOR SEVERAL BUILDING TYPES

hudmius

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

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS 77058

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The results of a study of the application of a modular integrated utility system to six typical building types are compared with the application of a conventional utility system to the same facilities. The effects of varying the size and climatic location of the buildings and the size of the powerplants are presented. Construction details of the six building types (garden apartments, a high rise office building, high rise apartments, a shopping center, a high school, and a hospital) and typical site and floor plans are provided. The environmental effects, the unit size determination, and the market potential are discussed. The cost effectiveness of the various design options is not considered.

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HUD-MIUS Program

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 Atomic Energy Commission, the Department of Defense, the Environmental Protection Agency, the National Aeronautics and Space Administration, and the National Bureau of Standards. 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 except as noted below all comments were resolved with HUD.

1. The basis for the various NASA design assumptions should be discussed. For example, many water saving devices can be used in buildings served by conventional utilities and are not considered unique to MIUS, although the developer using MIUS may have more incentive to reduce water consumption. The main advantage would be to reduce the capacity of the water source and potable water treatment facilities, not necessarily to accomplish zero water discharge. Adequately treated waste water is available for indirect reuse by others when discharged to a natural water body.

2. The objectives and criteria of the study seem to need more definition in order to justify the selection of some subsystems and components, particularly with respect to water management. What time frame was considered? Was it effluent standards, some aspect of the Houston environment, or a general philosophy of MIUS objectives which dictated and balanced the cost of minimizing water discharge?

3. Complete descriptions of the conventional systems for each conceptual design are not included and need to be presented. This is presently done only for the garden apartments in table IV.

4. The report has no references; they should have been used in many instances. The primary examples would be identification of sources of external data, such as electrical load profiles, used in the analysis, and the citation of sources where the reader could find documented descriptions of analytic procedures used to provide the quantitative results that are contained in this report. In a technical report of this type, all quantitative results must be supported, either by reference, if taken from an external source, or by a sufficiently complete description of the manner by which it was obtained. (References that were specifically requested in this comment are not available as published documents for distribution to the general public.)

5. Pages 17 (Buildings Types) and 18 (Distribution by Construction Type): This whole section on the determination of unit size is less than clear as to purpose and as to conclusions. It is not at all clear how one can conclude, from the fact that apartments will represent the greatest percentage of monetary investment in construction (1975-1985), that ". . . if an MIUS is to be designed to meet a particular set of utility requirements, it should be designed to meet the utility requirements of apartments." In addition, by limiting the scope of MIUS application to single "point designs," the scope of the market for various types of combinations of these is not addressed at all. It should be mentioned that, since these combinations are not considered here, the present conclusions could change based on a market examination of large scope. The connection between any conclusions based on the data presented here and the NASA community study efforts should also be mentioned, since they are related.

Finally, it is not clear, even if the conclusion about designing MIUS to meet the utility requirements of apartments is true, how the MIUS unit size has been determined, since nothing in this report justified a conclusion that a "typical" apartment complex or a unique

MIUS design is for same. Specific references to the sources of all cited data should be made.

6. Pages 48 (fig. 12) and 49 (fig. 13): Clarify which, if any, water-saving devices are involved in the MIUS configuration in conjunction with the 16.8 X 10^6 gal/year "water in" value. If none, then note that this value is inconsistent with the value given in figure 13 (about 95 X 10^3 gal/day which is about equal to 34.7 X 10^6 gal/year) and in any case is inconsistent with the 65 X 10^3 (23.7 X 10^6 gal/year) value given in table II. The inconsistencies should be resolved.

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INITIAL COMPARISONS OF MODULAR-SIZED, INTEGRATED UTILITY SYSTEMS AND CONVENTIONAL SYSTEMS FOR SEVERAL BUILDING TYPES

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SUMMARY

The results of six modular integrated utility system conceptual design studies applied to a garden apartment complex, a high rise office building, a high rise apartment building, a shopping center, a high school, and a hospital are reviewed in this report. These studies were conducted by the Urban Systems Project Office at the NASA Lyndon B. Johnson Space Center for the Department of Housing and Urban Development. The main purposes of the studies were to determine the performance of a modular-sized, integrated utility system (MIUS) used in the facilities cited and to compare this performance to that of a conventional utility system. All studies incorporated Houston, Texas, weather data as the environmental conditioning base. The size and location of the garden apartments design were varied to examine their effects on performance. In parallel with the design study, new construction was surveyed to determine where a modular integrated utility system could be applied for the largest market potential. Finally, the environmental effects of the design were established.

The studies indicated that an MIUS design could be expected to save from 18 to 36 percent in energy needs, compared to a conventional system, and to reduce the trash load to be removed from the site by 80 percent. The heating and air-conditioning system would be one in which heating is supplied in large part from waste heat recovered from solid-waste incineration and power generation and in which, on the average, 50 percent of the air-conditioning is supplied from waste heat. Water consumption can be reduced by reusing the treated waste water in the cooling towers, and this saving can be 50 percent for systems without water-saving devices in the building complex. With water-saving devices, zero water discharge can be approached. Additional energy savings of 10 to 20 percent are available by detailed

selection of building improvements such as high frequency lighting and ventilation.

The unit size determination effort indicated that the largest percentage of new construction, based on dollar value, is for single-family dwellings. Apartments, on the same dollar basis, represent a very significant 14.7 percent of new construction and constitute the second largest value. The basic findings of the study on the environmental impact of a modular integrated utility system are that local thermal emissions and air pollution will be increased but that total thermal and air pollution in the city will be reduced.

INTRODUCTION

During the summer of 1971, the NASA Lyndon B. Johnson Space Center (JSC) conducted a study on the application of NASA technology to commercial housing with the objectives of conserving natural resources, abating pollution, improving construction, and increasing household safety. As a result of this study, the Department of Housing and Urban Development (HUD) requested that NASA undertake further studies in this field. To carry out these studies, the Urban Systems Project Office (USPO) was organized in March 1972 at JSC. The program goal was to integrate utilities into modular-sized, combined plants that treat waste water, recycle solid wastes, generate electrical power, and use recovered thermal energy for space and water heating and for air-conditioning. The modular-sized, integrated utility system (MIUS) would be designed to balance the requirements for environmental quality and for conservation of natural resources while still providing the required services at minimum total cost.

To meet study goals, the USPO first developed a number of point designs to establish the basic requirements for the various building types to which an MIUS could be applied. The following six types of buildings were studied.

1. Garden apartment complex
2. High rise office building
3. High rise apartments
4. Shopping center
5. High school

6. Hospital

To ensure accurate data on the kinds and amounts of services required by each of these building types, the architectural support contractor, Clovis Heimsath Associates, Inc., performed surveys of buildings already constructed, under construction, or being considered for construction in Houston, Texas. As a result of this survey, typical plans of each building type to be studied were chosen. These buildings varied in size and services provided but served as elemental building blocks of a new community that was planned for study of an MIUS application. (This community study is the subject of another report.) Each of the USPO subsystems engineering study groups concurrently determined the scope of service required by the various types of buildings through literature, surveys, and interviews with apartment owners, with utility companies, or with other applicable sources.

The combined results of the construction survey and the service requirements survey served to identify the service demands (or "loads") for each service in each building type for a specific location. An MIUS configuration that would meet interrelated service demands was established. Operational characteristics of the subsystems were determined under various load conditions. The provision by the MIUS and by conventional systems of identical services to the simulated buildings was then analyzed for comparison purposes.

While preliminary design studies were being undertaken for specific cases, some additional design studies were made to contribute further to the understanding of the MIUS concept. These additional studies included the effects of varying the apartment complex size and of moving the apartment complex to various other locations in the United States. The effects of changing the insulation in the walls and roof were also evaluated, as were the potential effects of the MIUS on the environment. An environmental effects study reporting these effects was a portion of the overall study effort. While the technical aspects of an MIUS were being studied, a parallel effort was begun to determine the type of complex that would provide the widest market potential for an MIUS plant. Throughout the subject effort, various unique equipment selections were integrated into conceptual designs to determine their effect on total system performance. In most cases, the cost effectiveness of these designs will not be considered in this report.

The results of these studies have been presented at formal meetings to the National Bureau of Standards, to the Environmental Protection Agency (EPA), to the Oak Ridge

National Laboratory, to HUD, and to several experts in various engineering disciplines who were selected by the National Academy of Engineering. The purpose of this report is to present an overview of engineering studies of integrated utility designs applied to various building types, and it is not intended to describe all phases of the subject activity.

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

STUDY ASSUMPTIONS

The criteria or assumptions established for this study are as follows.

1. The MIUS will provide the following services.

    a. Electrical power

    b. Heating, ventilation, and air-conditioning (HVAC)

    c. Potable water

    d. Potable water heating

    e. Solid- and liquid-waste disposal

2. The MIUS will have the equivalent reliability of conventional systems.

3. The services supplied by the MIUS will be based on performance data from studies of conventional buildings.

4. Effluents from the MIUS will be evaluated.

5. The meteorological conditions encountered will be based on an actual geographic location.

6. Peak design loads (electrical and HVAC) will be based on one standard deviation of the average of 10 years of weather data.

7. Number 2 diesel fuel oil or natural gas will be the MIUS fuel.

8. Each MIUS will be designed for single-point applications and not for multiple or combinations of applications.

The MIUS study logic is shown in figure 1. Included in figure 1, but not considered in this report, are several efforts that illustrate the integration into the overall program.

DESIGN APPROACH

The design approach for the provision of electrical power, heating and cooling, and waste treatment is discussed in the following paragraphs.

General Description

In the MIUS design, various types of hardware are integrated to provide all the usual utilities and services that would generally be obtained through conventional means. Electrical power is generated for building and MIUS internal loads. Heat, which is recovered from the prime mover and from solid-waste incineration, is used for several functions; these functions, in order of benefit, are domestic water heating, space heating, and absorption air-conditioning. When available heat is insufficient to satisfy air-conditioning demand, absorption units are supplemented by electrically driven compressive units; thus, the demand on the compressive chiller is variable, or "floating." Additional heat is obtained from the prime mover to drive the absorption unit when providing electrical power for the compressive peaking units. A boiler may be used as a supplement if additional capacity is required for space heating, or the incinerator may be fired with fuel-enriched solid waste for short periods. Solid waste is collected only from the buildings being served by the MIUS. The incinerator burning-time profile may be adjusted to provide waste heat at times of greatest demands. Heating and cooling is supplied to the buildings by hot-water and chilled-water distribution systems. The details in figure 2 are an indication of the level of building facility breakdown attempted in each of the subject designs. The detail is necessary to estimate transmission cost differential, et cetera.

A waste-water treatment facility is integrated with other equipment and provides treated waste water for heat rejection in wet cooling towers. The waste-water treatment system and an incinerator are sized to meet constant, yearround demand, although size may be increased for special situations. Operation and maintenance are not considered in this report; they would be required for a cost comparison between MIUS and conventional plants.

Loads

To design a utility service for any building complex, loads must first be established. The HVAC and solid-waste loads were the same for the MIUS-serviced and conventionally serviced buildings; however, electrical and water loads varied. A basic feature of the MIUS is to recover heat and use this heat in an absorption chiller to reduce the electrical load. Water-saving devices were considered on various building designs to evaluate the possibility of zero water discharge. The specific design loads for each building complex can be found under the discussion of each complex. In some instances, load profiles are scaled from measured data for particular facilities. In other instances, profiles are derived from those established by an average of measured data on a particular building type. For the illustrations included in this report, the curves depicting electrical loads represent base loads without air-conditioning and base loads resulting from "design day" peak cooling load profiles.

Performance Analysis

The key parameters considered in the performance analysis were energy and water use, solid- and liquid-waste disposal, and comparisons with conventional systems. In each of these studies, one building is modeled using consistent weather data and loads, but two separate methods, MIUS and conventional, are used to provide for these loads. Yearly performance analyses were based on weather data for an average 24-hour period for each season using an in-house-developed computer analysis program called Energy System Optimization Program (ESOP). The energy analysis logic is shown in figure 3. No attempt has been made to accurately determine the cost effectiveness of particular MIUS configurations.

FACILITY APPLICATIONS

The MIUS design and performance factors applied to the six facilities studied are discussed in this section.

Garden Apartments

The garden apartment complex consists of 648 units that are occupied by 1212 people and that have a density of 28 units per 4047 square meters (1 acre). This building complex is the baseline system used to analyze the parametric effect of changing the apartment complex size or location or the insulation in the roofs and walls. Figures 4 and 5 are the site plan and the floor plans, respectively, used in this apartment study. (The layouts are typical of apartments in the Houston area.) The Houston Apartment Association gives median density for apartments in Houston in the period 1968 to 1973 as 25 units per 4047 square meters (1 acre). The construction materials are described in table I, and a typical outer wall is shown in figure 6. Figure 7 indicates the daily electrical loads for a conventional apartment and an MIUS apartment requiring maximum air-conditioning, figure 8 depicts the maximum heating and cooling loads for the apartments, and table II contains the solid- and liquid-waste design loads for each of the six facilities.

The MIUS design.- A schematic of the MIUS design is presented in figure 9. Four 75-rad/sec (720 rpm) diesel engines having a 1035-kilowatt (e) rating and a continuous-power factor of 0.8 are used. (The notation "e" indicates electrical kilowatts.) The system is designed to operate on two engines, with a third engine on standby and a fourth one scheduled for maintenance. These engines have a high electrical conversion efficiency of 36 percent at 100 percent load; heat is recovered from the exhaust and water jacket at 394 K (250° F) and from the oil cooler at 358 K (185° F). The oil cooler heat is used for domestic water heating only. The 394-K (250° F) heat is used to supply the environmental conditioning system, which has one 1470-kilowatt (420 ton) absorption chiller and two 1523-kilowatt (435 ton) compressive chillers. Two 696-kilowatt (71 horsepower) boilers are used, and the heat-rejection system consists of a 900-m^3/sec (3880 gal/min) cooling tower that uses two 30-kilowatt (40 horsepower) fans. The incinerator was selected to burn 229 kg/hr (505 lb/hr) during a 12-hr/day continuous burn cycle. The burn rate and cycle duration are selected to provide optimum heat utilization. The incinerator recovers heat from the stack in the same form as from the exhaust and water jacket and inserts it into the same heat loop. The waste-water treatment system consists of sulfur dioxide acid neutralization, cyclone separation, trimedia filtration, and third-stage disinfection with ozone. Dissolved solids are controlled by electrodialysis, and sludge is treated using progressive thermophilic digestion stabilized with unused waste heat. The cooling-tower water is also treated by this system.

Performance.- The energy analysis for the MIUS designs for the 648-unit garden apartment complex was performed with the ESOP computer program. The energy analysis logic used is shown in figure 3.

One of the main goals of the garden apartment study was to determine the relationship between annual fuel consumption and various types of air-conditioning equipment and methods of operation. The analysis was performed with the ESOP program, and the results are shown in figure 10. The floating absorption and compression air-conditioning model was used for all further analysis because it results in the lowest fuel consumption.

The amount of energy input and the energy delivered to the various services for two seasons and for the entire year are shown in figure 11. The shaded areas reflect the percentage of energy requirements met by recovered waste heat. Table III shows the seasonal and annual MIUS thermal efficiency, the degree of utilization of waste heat, and the ratio of thermal efficiency to the maximum possible thermal efficiency. (Maximum thermal efficiency is obtained when all waste heat is used for domestic hot water and then used for air-conditioning or heating.)

The MIUS system performance was compared to that of a conventional utilities system using the same building construction and loads and the same water-saving devices. A typical Houston garden apartment design was considered for the conventional utility system. Table IV contains a description of the conventional utilities system and compares it to the MIUS. The results of the comparison are shown in figure 12 and table V, which present MIUS savings or requirements and could be used to determine cost effectiveness of MIUS when fuel costs, et cetera, are given.

Also of interest in the garden apartment study was the evaluation of water-saving devices and water recycling, the results of which are shown in figure 13. The savings reflected are those for an MIUS system using water-saving devices compared to a standard conventional system, and the information could be used for evaluating the cost effectiveness of the water-saving devices.

High Rise Office Building

An existing, modern, high rise office building, the Park Tower South Building located in the Post Oak complex in Houston, Texas, was used for this MIUS study. Because the building had been recently constructed, current data were available; also, it represented an approximate mean size for a range of speculative office buildings under construction in the Houston area. The building contained examples of most of the elements of prime concern in the design and arrangement of office buildings, including high efficiency ratio, acceptable onsite parking space, and easy division into small lease areas with efficient core facilities arrangement. The office building site diagram is shown in figure 14. The office lease space of the building is 17 000 square meters (183 000 square feet) with a use efficiency of 83 percent. The building subsystem materials are described in table VI.

The MIUS design.- The power system chosen for the high rise office building application consists of four 350-kilowatt (e) gas turbines. Three of the units are intended for continuous operation during peak periods, and one is on standby. Gas turbines were incorporated to determine operational characteristics of this type of prime mover in contrast to those of a reciprocating engine. A basic block diagram of the MIUS elements involved in this design is presented in figure 15. Heat recovered from the gas turbine exhaust is collected in a manifold and provided to the absorption chilling system, which has a capacity of 2160 kilowatts (617 tons). Electrical compressive chillers are not needed in this design because the amount of heat available from the engines is large enough to meet all air-conditioning demands. Incineration heat recovery is not required because there is no need for additional waste heat. The amount of high-grade heat that would have been available is shown in figure 15. Chemical toilets were considered for minimum water use, and biological and physical/chemical treatment was considered; however, an all-inclusive trade-off study of the best systems was not attempted. Solid- and liquid-waste values are displayed in table II. Electrical and environmental load profiles for the office building are presented in figures 16 and 17, respectively. (Data in these figures are based on the average of a 10-year period of weather data for Houston, Texas.)

Performance.- The performance of the MIUS designed for the high rise office building was analyzed without the aid of a computer because the ESOP program used in the later point design was not operational. The MIUS was compared to a conventional utilities system, using metered data for conventional consumption. The MIUS savings of water and electricity in this study are shown in figure 18.

Because the gas turbine power system used in this MIUS had a lower efficiency of operation than the diesel system used in the garden apartment study, the gas turbine system was not considered in subsequent studies. A special study was performed to determine the desirability of high frequency fluorescent lighting. Two generators were driven from one gas turbine; one produced power at 60 hertz and the other at a much higher frequency for lighting. The savings percentage realized through the use of 1000-hertz lighting is also shown in figure 18. Because of increased efficiency in lighting, the cooling load was also decreased by 12 percent of the maximum design load. Negative aspects of high frequency lighting include (1) separate wiring system, (2) use of part of a turbine to generate high frequency power (reducing system reliability through fewer spares), and (3) possible unfavorable economics.

High Rise Apartments

The high rise apartment complex considered in this trade study is a 21-story building with 10 apartment units per floor. The complex is designed for an occupancy of 630 people. This size was chosen because it is considered typical of new construction in the Houston, Texas, area. A drawing of the site and floor plan for this complex is contained in figure 19. This building type includes a center-corridor concept for high structural efficiency and includes a variety of individual apartment layouts. A typical floor of the building has a volume of 3525 cubic meters (124 500 cubic feet). The study was performed by assuming a Houston location and a 50-percent occupancy ratio of young married people to people 50 years of age and older. A building materials description and a drawing of exterior construction details are shown in table VII and figure 20, respectively.

The MIUS design.- The MIUS system to supply services for this design consists of four 478-kilowatt (e), 75-rad/sec (720 rpm) engines - two for continuous maximum operation, one for ready standby, and one down for maintenance. The air-conditioning system incorporates two 1103-kilowatt (315 ton) compressive chillers and two 595-kilowatt (170 ton) absorption chillers. One 588-kilowatt (60 horsepower) boiler is used in this conceptual design. The cooling tower requires a 0.2-m^3/sec (3270 gal/min) flow on maximum demand, and the incinerator supplies heat at a rate of 125 kilowatts (425 000 Btu/hr) for 5 continuous hours per day. The high rise apartment complex with high-density plumbing offers a unique combination for domestic water use. This concept is commonly referred to as gray- and black-water plumbing. The black water from the toilet is purified separately, and the water is reused in the cooling tower. The gray water from the bath, kitchen, and laundry areas is purified and reused in many of the same areas. (Gray water is not used for drinking or cooking.) This reuse is potentially possible because of the low level of coliform bacteria and viruses in the gray water and the complete treatment given the gray water. Tests performed at the NASA Langley Research Center on purification of gray water showed that this system is feasible. With low-water-use appliances and recycled waste water, such a design concept approaches the minimum possible water use at this time without significant lifestyle changes.

The water and solid-waste requirements for this study are included in table II. The electrical load profiles for an MIUS and a conventional system are plotted together in figure 21. Air-conditioning and heating profiles are shown in figure 22 (design days).

Performance.- Performance analysis for the high rise apartment MIUS was accomplished for an MIUS using currently available hardware. A comparison was made between an MIUS and a conventional system for seasonal and annual fuel consumption. This comparison is shown in figure 23. Compared to the conventional system, the MIUS yields the following annual reductions in the required utility services: 20 percent in fuel oil, 93 percent in water, and 75 percent in solid waste.

Shopping Center

The shopping center is designed to serve a region with a market area of 100 000 population. A facility of this size can support a variety of functions and, thereby, provide a good mixture of loads for mechanical and electrical equipment. Since many shopping centers in various stages of construction are in this size range, current information is available. This study included a survey of many shopping center configurations. The design that was chosen is both esthetically pleasing and technically sound. The floor plan of the center used for this study is depicted in figure 24. The facility description, the building materials description, and construction details are presented in tables VIII and IX and figure 25, respectively.

A regional shopping center was selected for study because it contains elements of other types of shopping centers. This type of center is a collection of other centers joined by a common space usually called a mall. This collection enables the study of a wide range of building usages including department stores, commercial shops, restaurants, pharmacies, offices, and open areas or malls.

The MIUS design.- The shopping center electrical power system has a combined capacity of 5800 kilowatts. Four

53.8-rad/sec (514 rpm) diesel engines are used to drive 1450-kilowatt generators. The maximum electrical profile for this study is shown in figure 26. Heat from the engine and from incineration of solid waste are used to drive absorption air-conditioning equipment. A split of 60-percent absorption to 40-percent compression was found to be optimum at maximum cooling conditions. The cooling load profile (design day) is provided in figure 27. The total cooling capacity of the system is 6930 kilowatts (1980 tons). Because of internal electrical loads and solar input, no space heating is required. A gray- and black-water system was selected. The gray water is pumped through a reverse-osmosis system and used in a cooling tower. Black water (sewage water only) is incinerated so that no waste water is discharged under normal conditions. Enough waste heat is available for water preheating to accomplish this incineration with a minimum energy use requirement. This use is reflected in the energy-saving findings given in the next paragraph.

Performance.- To evaluate utilities performance, a comparison of the MIUS and the conventional designs was made with the same procedures used for the garden apartments comparison. Figure 28 contains the results of the comparison between the conventional system and the MIUS. The use of a nominal MIUS results in an energy saving of 35.6 percent, a water saving of 45.6 percent, a sewerage load reduction of 100 percent, and a trash load reduction of 80 percent.

High School

The high school is designed for occupancy by 2100 students. The size, construction, and facilities of the school are typical of the type being constructed in the Houston Independent School District. A description of the high school architectural and environmental features is contained in tables X and XI and figures 2, 29, and 30.

The MIUS design.- The high school design MIUS powerplant consists of three 75-rad/sec (720-rpm), 478-kilowatt (e) engines. Two engines are designed to meet the demand profiles shown in figure 31; the third engine is on standby. Power for the night load, consisting of security lights and refrigeration, is supplied by a bank of batteries rated at 80 kilowatts. A 10-kilowatt inverter supplies the air-conditioning refrigeration load. The HVAC system consists of a 700-kilowatt (200 ton) absorption unit and a 7- to 700-kilowatt (2 to 200 ton) compression unit; the percentage of use is 40 and 60, respectively. Solid waste is incinerated by a 136-kg/hr (300 lb/hr) starved-air unit and a waste-heat boiler rated at 293 kilowatts (1 x 10^6 Btu/hr). The waste-water treatment system consists of a physical/chemical waste treatment package plant and a reverse-osmosis unit for removal of dissolved solids from the cooling tower blowdown. An 18 580-square-meter (200 000 square foot) green space is irrigated from reclaimed water.

Performance.- The high school analysis was performed using the ESOP computer program to predict MIUS performance and using metered data from the Sharpstown High School facility for conventional system performance. Peak and average daily electrical consumption data were used (air-conditioning excluded) to prepare typical high school profiles. This was possible because the Sharpstown school used only absorption machinery. In figure 32, the fuel consumption of conventional and MIUS cooling options is shown and the conventional, the all-absorption, the all-compression, and the MIUS systems are compared.

The MIUS resulted in a 20-percent reduction in annual fuel consumption compared to a conventional system. The annual municipal water saving, compared to a conventional system, was approximately 76 percent. The annual waste-water reduction was 99 percent with reuse for toilet flush and 93 percent without the reuse feature. The reduction in waste-water load is very high because of reuse for cooling and for lawn watering.

Hospital

The hospital study incorporates a modern 12-story building having 32 rooms on each floor. This is a medium-large, community-sized hospital capable of providing a full range of medical services. This type of building allows for expansion with minimum perturbation of first-cost considerations. A drawing of this project is shown in figure 33. Table XII contains a general facility description; figure 34 and table XIII contain construction details.

The MIUS design.- The power for the MIUS design is generated by three 400-kilowatt (e), 125.6 rad/sec (1200 rpm) diesel engines, two for normal operation and one for standby. Two absorption chillers are used: an 875-kilowatt (250 ton) unit and a 525-kilowatt (150 ton) unit. Two incinerators supply heat at a rate of 1612 kilowatts (5.5 x 10^6 Btu/hr) to the thermal loop for a period of 16 continuous hours per day. A gray- and black-water system is used; the treated gray water is recycled, and the treated black water is used in the cooling tower. Power and environmental profiles are presented in figures 35 and 36, respectively. A schematic of the hospital design is presented in figure 37.

Performance.- The performance analysis for the hospital MIUS was accomplished with the ESOP computer program. Two MIUS designs were analyzed: a nominal MIUS using only currently available hardware and an optimistic MIUS using technically feasible hardware (some of which is not currently available) together with an improved building design. Table XIV shows the building modifications used in the optimistic case. The two designs are compared in table XV. The energy demands for both designs are shown in table XV. The two MIUS designs then were compared to the conventional design and the results are shown in figure 38. The municipal water requirements for the entire hospital are reduced by approximately 50 percent.

SIZE AND LOCATION STUDY

A separate investigation of garden apartment size and location was made to determine whether these variations would affect fuel savings significantly. Computer runs were made on three apartment complex sizes (300, 648, and 1720 units) using environmental data from five locations - Houston, Texas; Washington, D.C.; Denver, Colorado; Seattle, Washington; and Minneapolis, Minnesota.

The MIUS configuration used in this study was modeled after the design that had been defined under the conceptual design approach. Engines were selected to match power to apartment size: 275 kilowatts for 300 units, 500 kilowatts for 648 units, and 1540 kilowatts for 1720 units. The power generation efficiency compared to percent of load is shown in figure 39. During the analysis, another engine was added to the load when online engines reached a 90-percent load factor. The thermal conductance of the roof and walls used in this study was 0.246 W/(m²•K) (0.043 Btu/(hr•ft²•°F)) and 1.415 W/(m²•K) (0.247 Btu/(hr•ft²•°F)), respectively. Electrical, water, and solid-waste loads were the same as the loads used in the 648-unit garden apartments, and these loads were scaled linearly (based on dwelling unit count) for the size variations. The results of the analysis, in which the three sizes of apartments and the five locations were considered, are shown in figure 40, a bargraph of fuel savings reflected for the parameters considered in this study. The 300-unit complex shows a negative saving resulting from the inefficiency of the engine type selected and from a poor load factor. This relative size increase resulted in provision of the average load at a lower engine percentage load and, therefore, in an even lower efficiency.

Changing the location has little effect on the energy savings of the system (approximately 2 to 3 percent) (table XVI); therefore, the power generation system should be selected on the basis of the greatest electrical conversion efficiency. Heat recovered from the engine should be used first for domestic water heating and then for other uses, such as absorption, cooling, or space heating.

After this study, an investigation was made to determine the effects of various wall and roof structures on energy consumption. The total space-heating and cooling loads and their variation with ambient conditions were determined for various wall and roof conductances. Because the energy requirements for heating and cooling at the Minneapolis location were the largest percentage of total energy requirements, this site showed the largest percentage of energy used. Therefore, the Minneapolis site was chosen to determine the effect of roof and wall thermal conductance on energy consumption. In table XVII, the energy used on 1720 apartments is shown for roof conductances varying from 0.241 to 0.92 W/(m^2•K) (0.042 to 0.16 Btu/(hr•ft^2•°F)) and wall conductances varying from 0.29 to 1.415 W/(m^2•K) (0.05 to 0.247 Btu/(hr•ft^2•°F)). In this case, the study results indicated that insulation did not have a controlling effect on MIUS energy savings, because the majority of the environmental conditioning is supplied from the waste heat. However, when designing particular structures for savings in energy consumption, this effect should be considered because it is sufficiently significant for studies requiring that level of detail. If additional energy savings applications for the waste heat were found, then insulation use would become more important.

ENVIRONMENTAL EFFECTS STUDY

After the point designs were completed, a detailed environmental effects study was made on a typical MIUS design, the 648-unit apartment complex. Typically, an environmental impact study is based on a specific locale and involves the particular problems of that locale. This study consisted of a generalized assessment of the differences in environmental effects between a conventional and an MIUS configuration and does not consider the effects of a specific site. The environmental areas reviewed included water, solid waste, thermal emissions, noise, and air pollution.

Water

Sewage from the apartment complex is processed within the MIUS and recycled for MIUS plant applications and lawn watering. This procedure results in a water saving of approximately 20 percent over that for a conventional facility. The outflow of water from an MIUS is treated waste water; thus, it can be discharged into a storm sewer and will not increase loads to the available sewage plants. Some nontechnical barriers (local codes, etc.) exist and are acknowledged.

Solid Waste

Solid wastes from the garden apartments are incinerated onsite. Heat-recovery equipment is installed as part of the incineration system, and the recovered heat is used to provide air-conditioning, space heat, and domestic hot water. The residue after incineration is approximately 20 percent of the original solid waste, is sterile, and has a considerably higher density than conventional waste. Landfill can be accomplished efficiently with this waste, and fewer trips from the apartments to the solid-waste landfill would be required; thus, additional energy savings in fuel expended for solid-waste transportation can be expected. As with any incinerated-waste landfill, the contamination of potable water sources as a result of poor site location should be avoided.

Thermal Emissions

The increase in thermal emissions incident to an increase in population density has an effect on the existing air convection patterns in the area with a resulting effect on the microclimate. Suburbs have noted a 5° temperature change with rapid development, whereas city centers are now experiencing as much as 10° to 12° differences from temperatures of outlying less-developed areas. The generation of power onsite increases the amount of heat to be dissipated to the atmosphere at the apartment complex by approximately 30 percent over that for a similar garden apartment complex supplied by conventional utilities.

Noise

The principal increase in quiescent noise levels is due to the increase in traffic associated with an increase in population. The operation of generators and cooling towers is capable of producing an increase in noise; however, application of carefully designed mufflers for intake and exhaust of diesel generators and the isolation of cooling towers by increased elevation or shrubbery (or both) should alleviate any sound problems.

Air Pollution

In the operation of an MIUS, the total amount of pollutants released to the atmosphere, including trash incineration, is equivalent to that produced by combustion of 2585 cubic meters (683 000 gallons) of number 2 diesel oil per year. A conventional garden apartment providing equivalent services with a fuel-burning boiler to provide space heating and hot water uses 420 cubic meters (111 000 gallons) of number 2 diesel oil per year. Thus, the amount of pollutants released at the site is approximately six times greater for an MIUS-supported apartment than for one supported by conventional facilities. Although the local air pollution would be increased, the total environmental air pollution in the community in which the apartments are located would be reduced about twice as much because 3880 cubic meters (1 025 000 gallons) of number 2 diesel oil must be combusted at a conventional power station to supply electric service to the apartments. The effects of stack height, scrubbers, and so forth, were not considered further because of the annual regional improvement.

BUILDING TYPES

A preliminary study was performed to determine the magnitude of the building-type market potential that might influence the MIUS design. The 1975 to 1985 time frame was based on extrapolations by Abt Associates, Inc., of new-construction data from F. W. Dodge. The market was examined on a national, regional, state, and city basis. The national market was aggregated by type of construction.

All building types were considered in the study. The selected building types - hospitals, stores, public buildings, schools and libraries, offices, banks, hotels, and apartments - were determined to be candidates for an MIUS. One- and two-family houses were considered as a portion of total construction. However, the assumption was made that an MIUS unit could not economically support such dwellings unless they were combined with building types of higher density in a planned unit development or a total community.

DISTRIBUTION BY CONSTRUCTION TYPE

The estimated percentages of total national construction for the period 1975 to 1985 for selected building types are shown in table XVIII. The data show the relative magnitudes of the various types of structures predicted for the 1975 to 1985 time frame. The type with the largest percentage of total construction is one- and two-family houses, but, as stated previously, they are considered an uneconomical market when serviced individually or in a project consisting exclusively of one- and two-family dwellings. The primary market, then, is apartments (14.74 percent of dollar value). Next, in order, are stores (7.85 percent), offices (7.68 percent), and schools and libraries (7.63 percent). Thus, if a particular MIUS design is to be produced on a large-scale basis to meet a particular set of utility requirements, it should be designed to meet that required by apartments. Commonalities between apartments on the one hand and stores, offices, and schools on the other can be investigated, and modifications may possibly be defined to accommodate the secondary market types. Further studies to determine the economy of scale for an MIUS are in progress. The results should facilitate proper selection of the size range for the MIUS.

MARKET DISTRIBUTIONS

The basic data sources for building construction were the McGraw-Hill Information Systems, the F. W. Dodge Construction Reports, and the Engineering News Record (ENR). Two types of data were used from F. W. Dodge. The actual reported data contained in the Dodge reports analysis for 1970 were used for size distributions for projects valued at less than $1 million. The distributions for projects valued at more than $1 million were developed from the ENR, which is also a McGraw-Hill publication and uses the Dodge reports as a data source. The predictions for total building construction for 1975 to 1985 were developed from Dodge forecasts, which gave construction forecasts for various building types through 1977 by building type and geographical region. These construction forecasts were then linearly extrapolated through 1985.

RESULTS AND CONCLUSIONS

In the studies of the various buildings (hospitals, schools, shopping center, apartments (garden and high rise), and office buildings), results and conclusions were obtained in three categories: performance, environment, and market potential.

Performance

A modular-sized, integrated utility system configuration could be expected to save 18 to 36 percent of the annual energy requirement compared to a conventional system by providing electrical energy to the facility at 30 percent efficiency. The amount of solid waste to be removed from the facility can be reduced by 80 percent. In most cases, the heating and air-conditioning system would use waste heat recovered from solid-waste incineration and power generation; on the average, 50 percent of the air-conditioning is supplied from waste heat. Water can be saved by reusing the treated waste water in the cooling towers; this saving is expected to be 50 percent for systems without water-saving devices (depending on location). Waste water can approach zero water discharge with water-saving devices.

Savings in energy of 10 to 20 percent are available by detailed selection of building equipment such as high frequency lighting, ventilation, and building improvements for specific instances (in addition to the savings described previously).

Environment

The impact of locating utility services near the building being serviced has been assessed. It has been determined that the addition of most new building types that incorporate a modular integrated utility system will not increase substantially the liquid- or solid-waste loading and will reduce overall air pollution. (Local thermal emissions will be increased, but the total thermal pollution in the city will not be increased.) The time frame used for environmental requirements is 1975 to 1976.

Market Data Base

The study performed by Abt Associates indicates a very large market for several size ranges of modular integrated utility systems. Among the building types, apartments represent a primary market with 14.7 percent of dollar value of new construction.

Lyndon B. Johnson Space Center
National Aeronautics and Space Administration
Houston, Texas, April 19, 1976
386-01-00-00-72

TABLE I.- GARDEN APARTMENTS BUILDING SUBSYSTEM

MATERIALS DESCRIPTION

Building subsystem	Materials
Structure	Conventional wood framing Concrete foundation on grade
Exterior wall	10.2-cm (4 in.) thick brick 1.3-cm (1/2 in.) thick sheathing 8.9-cm (3-1/2 in.) thick wood studs 1.3-cm (1/2 in.) thick gypsum board
Roof/ceiling	3-ply built-up roof Rigid insulation board 1.3-cm (1/2 in.) thick wood deck 5.1-cm (2 in.) thick airspace 15.2-cm (6 in.) thick insulation 1.60-cm (5/8 in.) thick gypsum board ceiling
Floor/ceiling	4.1-cm (1-5/8 in.) thick lightweight concrete 2.5-cm (1 in.) thick plywood deck 1.3-cm (1/2 in.) thick gypsum board
Interior partitions	1.3-cm (1/2 in.) thick gypsum board on each side of wood studs

TABLE II.- DAILY SOLID-WASTE GENERATION, HEAT VALUE, AND WATER USE FOR ALL FACILITIES

Project	Solid waste, kg (lb)	Heat value, mJ/kg (Btu/lb)	Water, m^3 (gal)
Garden apartments	2 751 (6 060)	11 723 (5040)	246 (65 000)
Office building	1 362 (3 000)	13 956 (6000)	133 (35 050)
Shopping center	21 792 (48 000)	14 886 (6400)	409 (108 000)
Hospital	6 274 (13 820)	17 447 (7501)	288 (76 000)
High rise apartments	1 430 (3 150)	11 816 (5080)	151 (39 950)
High school	703 (1 550)	13 491 (5800)	273 (72 000)

TABLE III.- GARDEN APARTMENTS ANNUAL ENERGY UTILIZATION

Season	Thermal efficiency, percent	Thermal efficiency/max. thermal efficiency, percent	Utilization of recovered heat, percent
Summer	67	93	87
Winter	57	79	63
Spring	65	90	82
Fall	66	92	82
Annual average	63.8	88.5	78.5

TABLE IV.- GARDEN APARTMENTS CONVENTIONAL AND MIUS UTILITIES DESCRIPTION

Service	Conventional	MIUS
Electrical power	Typical natural-gas-fired steam boiler-turbine facility with area transmission and distribution facilities; 33 percent generation efficiency, peak operation at 68 percent of capacity; transmission, distribution losses per 1970 Federal Power Commission survey	Onsite power generation, reciprocating internal combustion diesel, 36 percent generation efficiency at peak load
Summer and winter air-conditioning	All-compression; central system: fuel-fired space heating, circulating hot and chilled water	Combination absorption/compression cycles; space heating supplied with recovered heat, supplemented with fuel-fired boiler when necessary; circulating hot and chilled water
Waste water	Collection, primary and secondary treatment based on Clear Lake City data; currently, raw sewage typically goes into outfall during periods of heavy rainfall	Sewage processed "onsite" with outfall designed to meet future EPA standards; water reused in cooling tower and lawn watering
Solid waste	Baseline 725 600-kg/day (800 ton/day) collection, transport to landfill, and incineration of waste	Waste incinerated onsite, heat recovered, ash residue hauled to landfill
HVAC loads	Same as MIUS	Same as conventional
Domestic electric loads	Same as MIUS	Same as conventional
Water supply	Municipal treated water supply (water-saving devices considered for conventional and MIUS)	Municipal treated water supply; however, onsite treatment and storage available
Domestic hot water	Fuel-fired hot water heaters, 80 percent efficiency, 12-year life, distribution to individual dwelling units	Heated with recovered heat, supplemented with fuel-fired boiler when necessary, circulated to individual units

TABLE V.- GARDEN APARTMENTS CONVENTIONAL SYSTEM WATER-SAVINGS COMPARISON

Parameter	Without water savings, percent	With water savings, percent
Energy savings	33	33
Water savings	46	9
Sewage load reduction	75	48
Trash load reduction	74	74

TABLE VI.- HIGH RISE OFFICE BUILDING SUBSYSTEM MATERIALS DESCRIPTION

Building subsystem	Materials
Outer walls	Masonry wall (61.5 percent) - 9321 m^2 (100 332 ft^2) 10.2-cm (4 in.) thick facing brick Airspace Dampproofing (single-layer permeable felt) 10.2-cm (4 in.) thick concrete block Airspace 1.3-cm (1/2 in.) thick gypsum board Spandrel glass (20.4 percent) - 1901 m^2 (20 462 ft^2) 0.6-cm (1/4 in.) thick spandrel glass, polished, tinted, and tempered Airspace 2.5- to 3.8-cm (1 to 1-1/2 in.) thick rigid insulation Airspace 1.3-cm (1/2 in.) thick gypsum board 0.6-cm (1/4 in.) thick polished plate glass (18.1 percent) - 1692 m^2 (18 212 ft^2)
Roof	Built-up roof with hot asphalt Roof felts 6.4-cm (2-1/2 in.) thick rigid insulation 7.6-cm (3 in.) thick concrete beam Sprayed fireproofing
Structure	Reinforced concrete
Floor/ceiling	12.7-cm (5 in.) thick concrete slab 1.3-cm (1/2 in.) thick spray-on fireproofing Airspace 1.6-cm (5/8 in.) thick acoustical tile
Interior partition	1.6-cm (5/8 in.) thick gypsum board on 6.4-cm (2-1/2 in.) thick metal studs

TABLE VII.- HIGH RISE APARTMENT BUILDING SUBSYSTEM MATERIALS DESCRIPTION

Building subsystem	Materials
Structure	Reinforced concrete frame with concrete slab Concrete footing and foundation
Exterior wall	10.2-cm (4 in.) thick anodized aluminum window wall with 0.6-cm (1/4 in.) thick polished plate glass 15.3-cm (6 in.) thick concrete with 1.3-cm (1/2 in.) thick gypsum board furring and batt insulation
Roof/ceiling	3-ply built-up roof 3.8-cm (1-1/2 in.) thick rigid insulation board 15.3-cm (6 in.) thick structural concrete slab 1.6-cm (5/8 in.) thick acoustic board ceiling
Floor/ceiling	15.3-cm (6 in.) thick structural slab 1.6-cm (5/8 in.) thick acoustic board ceiling
Interior partitions	6.4-cm (2-1/2 in.) thick metal studs with 1.6-cm (5/8 in.) thick gypsum board both sides

TABLE VIII.- REGIONAL SHOPPING CENTER

GENERAL FACILITY DESCRIPTION

(a) Land usage

Land	Area, m² (ft²)
Building ground coverage	35 861 (386 000)
Parking for 3575 cars[1]	117 058 (1 260 000)
Landscaping/setback, 10 percent	15 292 (164 600)

(b) Building usage[2]

Building	Area, m² (ft²)
Major department store	15 794 (170 000)
Major department store	16 723 (180 000)
Commercial shops	18 581 (200 000)
Restaurants	3 716 (40 000)
Pharmacies	2 787 (30 000)
Offices	2 787 (30 000)
Total area	60 388 (650 000)

(c) Facility occupancy

Facility	Number of persons
2 floors, wholesale and retail stores, offices, drinking and dining establishments	
Ground floor - 2.8 m² (30 ft²) per person	11 260
Second floor - 4.7 m² (50 ft²) per person	5 630
Total code occupancy	16 890
Design occupancy	8 000

[1] 5.9 cars per 100.0 square meters (1076 square feet) leasable; 32.5 square meters (350 square feet) per car.

[2] Floor-to-floor height, 4.88 meters (16 feet); total height, 9.75 meters (32 feet); total volume of building usage, 234 464 cubic meters (8 280 000 cubic feet).

TABLE IX.- REGIONAL SHOPPING CENTER BUILDING SUBSYSTEM MATERIALS DESCRIPTION

Building subsystem	Materials
Structure	9- by 9-m (30 by 30 ft) bay Structural steel framing Steel bar joists Concrete footings and grade beams
Exterior wall	10.2-cm (4 in.) thick tilt-up exposed aggregate concrete fiberglass 9.2-cm (3-5/8 in.) thick metal studs with batt insulation and gypsum board 10.2-cm (4 in.) thick aluminum window wall with 0.6-cm (1/4 in.) thick bronze-tinted glass
Roof/ceiling	3-ply built-up roofing 5.1-cm (2 in.) thick board insulation 8.9-cm (3-1/2 in.) thick insulating concrete fill on steel deck 1.6-cm (5/8 in.) thick acoustic board ceiling
Floor/ceiling	8.9-cm (3-1/2 in.) thick lightweight concrete on steel bar joists with 1.6-cm (5/8 in.) thick acoustic board ceiling 10.2-cm (4 in.) thick concrete slab on grade
Interior partition	10.2-cm (4 in.) thick concrete block with 1.2-cm (1/2 in.) thick gypsum board both sides - area separation wall 6.4-cm (2-1/2 in.) thick metal stud with 1.2-cm (1/2 in.) thick gypsum board both sides

TABLE X.- HIGH SCHOOL GENERAL FACILITY DESCRIPTION

(a) Land usage

Land	Area, m² (ft²)
Building ground coverage	11 297 (121 600)
Parking drives	9 513 (102 400)
Practice fields and open space	18 181 (195 700)
Total	38 991 (419 700)

TABLE X.- HIGH SCHOOL GENERAL FACILITY DESCRIPTION - Continued

(b) Building usage

Section (number in facility) (1)	Dimensions, m (ft)	Area, m^2 (ft^2)
First floor		
Central wing (1)		
Administrative/offices/lounges	38.1 by 18.3 (125 by 60)	696.8 (7 500)
Library	18.3 by 18.3 (60 by 60)	334.5 (3 600)
Lobby	7.6 by 16.8 (25 by 55)	127.7 (1 375)
Circulation	64.0 by 6.1 (210 by 20)	438.5 (4 720)
Toilets	7.6 by 4.6 (25 by 15)	34.8 (375)
Science wing (2)		
Classrooms	15.2 by 64.0 (50 by 210)	975.5 (10 500)
Corridors	4.6 by 64.0 (15 by 210)	316.8 (3 410)
Toilets	6.1 by 6.1 (20 by 20)	37.2 (400)
Classroom wing (3)		
Classrooms	15.2 by 64.0 (50 by 210)	975.5 (10 500)
Corridors	4.6 by 64.0 (15 by 210)	316.8 (3 410)
Toilets	6.1 by 6.1 (20 by 20)	37.2 (400)
Cafeteria	18.3 by 51.8 (60 by 170)	947.6 (10 200)
Kitchen	18.3 by 21.3 (60 by 70)	390.2 (4 200)
Corridors	--	195.1 (2 100)
Gym facilities		
Boys' gymnasium	36.6 by 27.4 (120 by 90)	1 003.4 (10 800)
Boys' dressing/showers	16.8 by 27.4 (55 by 90)	459.9 (4 950)
Girls' gymnasium	36.6 by 19.8 (120 by 65)	724.6 (7 800)
Girls' dressing/showers	16.8 by 19.8 (55 by 65)	332.1 (3 575)
Corridors	--	300.5 (3 235)
Shops		
Wood shop	9.1 by 18.3 (30 by 60)	167.2 (1 800)
Metal shop	9.1 by 18.3 (30 by 60)	167.2 (1 800)
Corridors	4.6 by 18.3 (15 by 60)	83.6 (900)
Band/choral	25.9 by 18.3 (85 by 60)	473.8 (5 100)
Corridors	4.6 by 25.9 (15 by 85)	118.5 (1 275)

[1] Corridor dimensions include adjacent stairwells for building coverage.

TABLE X.- HIGH SCHOOL GENERAL FACILITY DESCRIPTION- Continued

(b) Building usage - Concluded

Section (number in facility) (1)	Dimensions, m (ft)	Area, m^2 (ft^2)
First floor - Concluded		
Auditorium	(2)	1 156.6 (12 450)
Corridors/foyer	(2)	488.7 (5 260)
Second floor		
Domestic arts and sciences wing (4)		
Classroom/laboratories	15.2 by 64.0 (50 by 210)	975.5 (10 500)
Corridors	4.6 by 64.0 (15 by 210)	316.8 (3 410)
Toilets	6.1 by 6.1 (20 by 20)	37.2 (400)
Classroom wing (5)		
Classrooms	15.2 by 64.0 (50 by 210)	975.5 (10 500)
Corridors	6.1 by 64.0 (20 by 210)	390.2 (4 200)
Toilets	7.6 by 4.6 (25 by 15)	34.8 (375)
Classroom wing (6)		
Classrooms	15.2 by 64.0 (50 by 210)	975.5 (10 500)
Corridors	4.6 by 64.0 (15 by 210)	316.8 (3 410)
Toilets	6.1 by 6.1 (20 by 20)	37.2 (400)
Art/drama wing	7.6 by 36.6 (25 by 120) + [3]68.6 (+ [4]225)	299.6 (3 225)
Corridors	4.6 by 36.6 (15 by 120)	191.4 (2 060)
Mechanical	18.3 by 27.4 (60 by 90)	501.7 (5 400)
Corridors	4.6 by 33.5 (15 by 110)	153.3 (1 650)

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[1] Corridor dimensions include adjacent stairwells for building coverage.
[2] See figure 2.
[3] Square meters.
[4] Square feet.

(c) Building area totals

Level	Area, m^2 (ft^2)
First floor	11 300.0 (121 635)
Second floor	5 205.4 (56 030)
Total floor area	16 505.4 (177 665)
Roof	11 300.0 (121 635)

TABLE XI.- HIGH SCHOOL BUILDING SUBSYSTEM MATERIALS DESCRIPTION

Building subsystem	Materials
Structure	Steel columns, steel bar joist Metal deck with lightweight concrete fill Concrete foundation and footings
Exterior wall	Masonry with 9.2-cm (3-5/8 in.) thick 18-gage metal studs Batt insulation and 1.6-cm (5/8 in.) thick gypsum board
Roof/ceiling	3-ply built-up roofing 3.8-cm (1-1/2 in.) thick rigid insulation 6.4-cm (2-1/2 in.) thick lightweight concrete fill Metal deck 1.6-cm (5/8 in.) thick acoustic board ceiling
Floor/ceiling	10.2-cm (4 in.) thick concrete slab 1.6-cm (5/8 in.) thick acoustic board ceiling
Interior partition	6.4-cm (2-1/2 in.) thick 24-gage metal studs with 1.6-cm (5/8 in.) thick gypsum board each side

TABLE XII.- COMMUNITY HOSPITAL GENERAL FACILITY DESCRIPTION

(a) Land usage

Land	Area, m^2 (ft^2)
Building ground coverage	1 631 (17 550)
Parking/drives	10 684 (115 000)
Landscaping	657 (7 075)
Total	12 972 (139 625)

(b) Building usage

Floor	Value
Area	
Service (ground) floor, m^2 (ft^2)	1 394 (15 000)
Social (main) floor, m^2 (ft^2)	929 (10 000)
Typical floor (651 m^2 (7000 ft^2)) for 12 floors, m^2 (ft^2)	7 812 (84 000)
Total, m^2 (ft^2)	10 135 (109 000)
Floor-to-floor height	
Service and social floor, m (ft)	4.9 (16)
Typical floor, m (ft)	3.6 (12)
Volume	
Service floor, m^3 (ft^3)	6 792 (240 000)
Social floor, m^3 (ft^3)	4 528 (160 000)
Typical floor (7812 m^2 (84 000 ft^2) by 3.6 m (12 ft)), m^3 (ft^3)	28 526 (1 008 000)
Total, m^3 (ft^3)	39 846 (1 408 000)

(c) Building occupancy

Type of occupancy	Quantity
Beds	384
Persons (design occupancy, maximum)	850
Total occupancy by code, 7.4 m^2 (80 ft^2) per person	1362

TABLE XIII.- COMMUNITY HOSPITAL BUILDING SUBSYSTEM MATERIALS DESCRIPTION

Building subsystem	Materials
Structure	Reinforced concrete post and beam framing One-way ribbed reinforced concrete slab Concrete footings and foundation
Exterior wall	Masonry with 9.2-cm (3-5/8 in.) thick 18-gage metal studs with batt insulation and 1.6-cm (5/8 in.) thick gypsum board 10.2-cm (4 in.) thick anodized aluminum window wall with 0.6-cm (1/4 in.) thick solar gray-tinted glass
Roof/ceiling	3-ply built-up roofing 5.1-cm (2 in.) thick board insulation 8.9-cm (3-1/2 in.) thick insulating concrete fill 15.2-cm (6 in.) thick structural concrete slab 1.6-cm (5/8 in.) thick acoustic board ceiling
Floor/ceiling	10.2-cm (4 in.) thick reinforced concrete slab 1.6-cm (5/8 in.) thick acoustic board ceiling
Interior partition	10.2-cm (4 in.) thick concrete block with 1.6-cm (5/8 in.) thick gypsum board on both sides 6.4-cm (2-1/2 in.) thick 24-gage metal studs with 1.3-cm (1/2 in.) thick gypsum board on both sides

TABLE XIV.- HOSPITAL PROJECT OPTIMIZED HVAC LOADS AND ENERGY CRITERIA

[Assumed improved absorption chiller coefficient of performance = 1.0]

Parameter	Nominal	Optimistic[1]	Comments
Conductance			
Windows:			
Summer, W/(m² • K) (Btu/(hr • ft² • °F)) .	6.07 (1.06)	2.9 (9.5)	Double-pane glass, optimistic
Winter, W/(m² • K) (Btu/(hr • ft² • °F)) .	6.47 (1.13)	--	Double-pane glass, optimistic
Walls, W/(m² • K) (Btu/(hr • ft² • °F)) . .	.401 (.070)	.183 (.032)	Replace standard insulation with polyurethane foam, optimistic
Roof, W/(m² • K) (Btu/(hr • ft² • °F)) . . .	.458 (.080)	.258 (.045)	Replace built-up portion of roof with 5.08-cm (2 in.) thick polyurethane foam
Ventilation rate			
Operating room, air changes/hr	25	15	20-percent recovery of rejected heat, optimistic

[1] Reduced the domestic electrical load by 10 percent; assumed boiler efficiency of 90 percent.

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TABLE XV.- HOSPITAL PROJECT HVAC PERFORMANCE CHARACTERISTICS

HVAC subsystem	Value
Nominal MIUS	
Absorption chillers (single-effect), nominal, kW (ton)	525 (150) 875 (250)
82 737 N/m^2 (12 psig) steam, kg/hr (lb/hr)	3574 (7880)
kW (Btu/hr)	2685 (9 160 000)
Condenser water, m^3/min at 305 to 314 K (gal/min at 90° to 105° F)	6 (1685)
Makeup water, m^3/min (gal/min)	0.114 (30)
1-cell cooling tower (6.1 by 6.1 by 3.7 m (20 by 20 by 12 ft)), fan, W (hp)	29 840 (40)
Chiller water, m^3/min at 280 K (gal/min at 45° F)	4 (970)
2 blowers - operating room, nominal, m^3/min (ft^3/min)	170 (6000)
all other rooms, nominal, m^3/min (ft^3/min)	71 (2500)
Fan coils (384 patient rooms), m^3/min/room	7 (230)
Optimistic MIUS	
Absorption chillers (dual-effect), nominal, kW (ton)	2065 (590)
861 845 N/m^2 (125 psig) steam, kg/hr (lb/hr)	2699 (5950)
kW (Btu/hr)	1641 (5 600 000)
Condenser water, m^3/min at 305 to 311 K (gal/min at 90° to 100° F)	8 (2120)
Makeup water, m^3/min (gal/min)	0.14 (37)
1-cell cooling tower (6.1 by 6.1 by 3.7 m (20 by 20 by 12 ft), fan, W (hp)	29 840 (40)
Chiller water, m^3/min at 280 K (gal/min at 45° F)	4 (970)
Blowers - operating room, nominal, m^3/min (ft^3/min)	113 (4000)
all other rooms, nominal, m^3/min (ft^3/min)	71 (2500)
Fan coils (384 patient rooms), m^3/min/room	7 (230)

TABLE XVI.- 648-UNIT GARDEN APARTMENT COMPLEX ENVIRONMENTAL LOADS ANALYSIS

Environment	Percentage of total building loads[1]	Percentage of energy consumed[1]
Houston	21.3	22.7
Minneapolis	40.0	27.5
Denver	31.5	21.8
Seattle	27.3	17.9
Washington, D.C.	26.8	20.8

[1] Based on ambient conditions.

TABLE XVII.- ENERGY CONSUMPTION IN MINNEAPOLIS 1720-UNIT GARDEN APARTMENT COMPLEX ROOF AND WALL CONDUCTANCE STUDY

Type of construction	Wall conductance, $W/(m^2 \cdot K)$ $(Btu/(hr \cdot ft^2 \cdot °F))$	Energy consumed, TJ/yr (Btu/yr), at a roof conductance of -		
		0.241 $W/(m^2 \cdot K)$ $(0.042\ Btu/(hr \cdot ft^2 \cdot °F))$	0.46 $W/(m^2 \cdot K)$ $(0.08\ Btu/(hr \cdot ft^2 \cdot °F))$	0.92 $W/(m^2 \cdot K)$ $(0.16\ Btu/(hr \cdot ft^2 \cdot °F))$
MIUS	0.29 (0.05)	294.1 (0.28×10^{12})	299.8 (0.28×10^{12})	311.9 (0.30×10^{12})
Conventional		400.0 $(.38 \times 10^{12})$	406.0 $(.39 \times 10^{12})$	418.8 $(.40 \times 10^{12})$
MIUS	0.86 (0.15)	308.7 (0.29×10^{12})	314.6 (0.30×10^{12})	327.2 (0.31×10^{12})
Conventional		414.9 $(.39 \times 10^{12})$	421.0 $(.40 \times 10^{12})$	434.3 $(.41 \times 10^{12})$
MIUS	1.415 (0.247)	323.8 (0.31×10^{12})	329.8 (0.32×10^{12})	342.7 (0.32×10^{12})
Conventional		430.3 $(.41 \times 10^{12})$	432.3 $(.41 \times 10^{12})$	450.5 $(.43 \times 10^{12})$

TABLE XVIII.- ESTIMATED TOTAL CONSTRUCTION FOR SELECTED BUILDING TYPES FOR 1975 TO 1985

Building type	Construction area, m^2 (ft^2)	Percent of total floor area of construction	Value, dollars	Dollar value of construction, percent
Nonresidential				
Hospitals	127 x 10^6 (1 375 x 10^6)	2.91	73 008 x 10^6	6.90
Stores	465 (5 005)	10.58	83 008	7.85
Public building	62 (663)	1.40	32 838	3.10
Schools and libraries	200 (2 148)	4.54	80 734	7.63
Offices	232 (2 500)	5.28	80 468	7.68
Banks	13 (140)	.30	6 239	.59
Residential				
Hotels	72 (770)	1.63	18 598	1.76
Apartment	836 (9 000)	19.03	156 033	14.74
1- and 2-family houses	1 597 (17 190)	36.34	284 559	26.89
Total	3 604 (38 791)	82.01	871 636	77.14

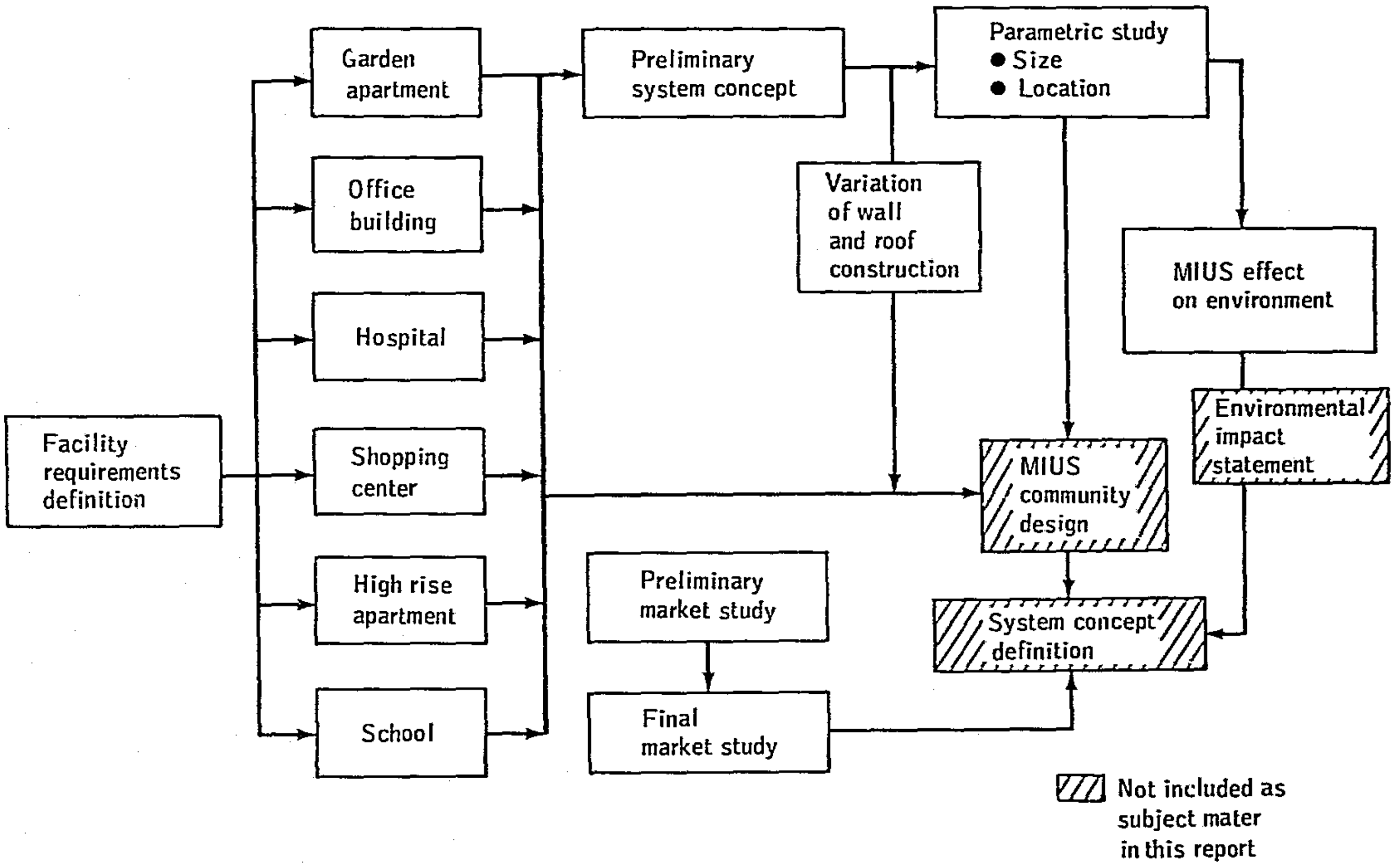
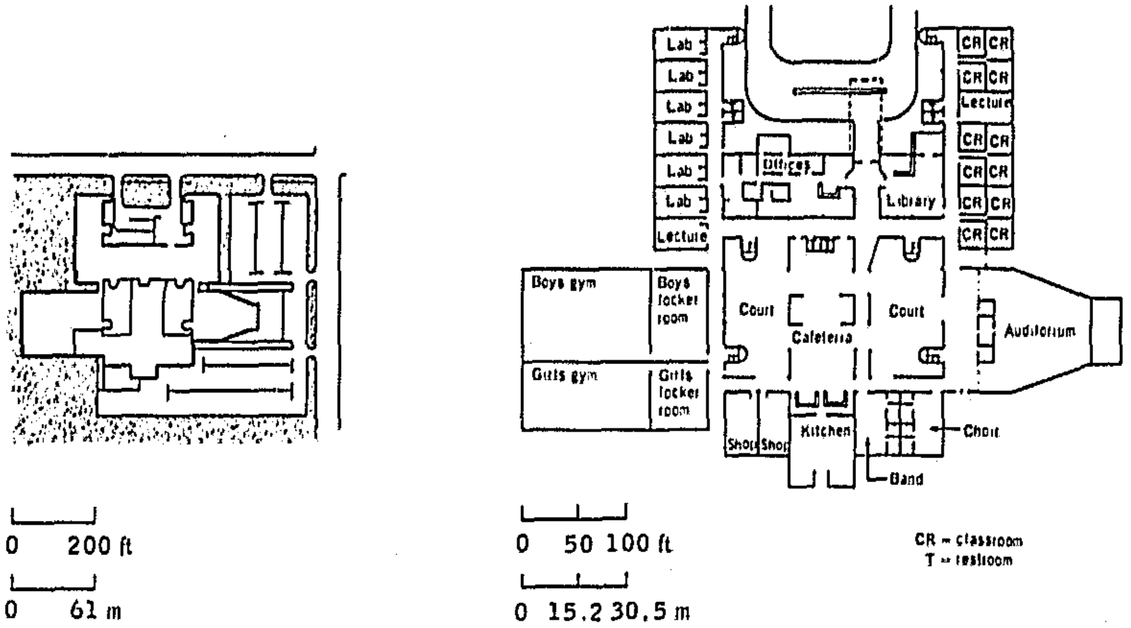
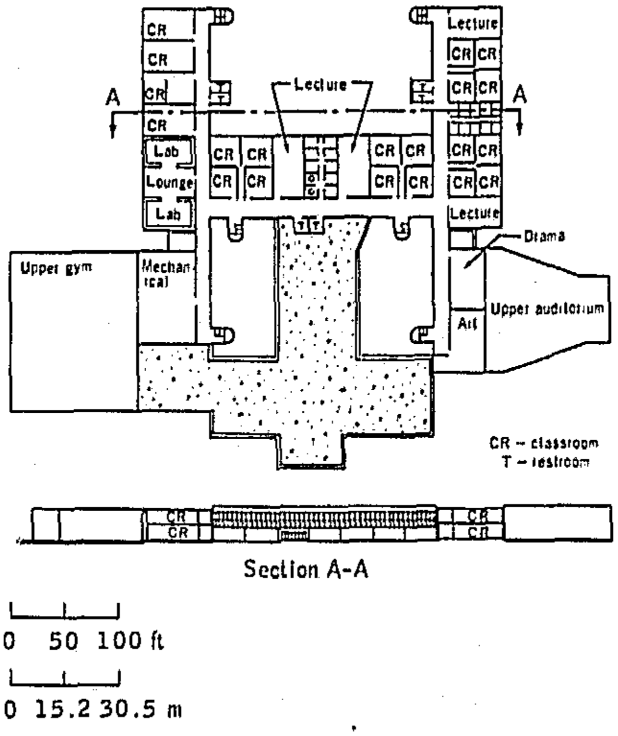


Figure 1.- The MIUS study logic.



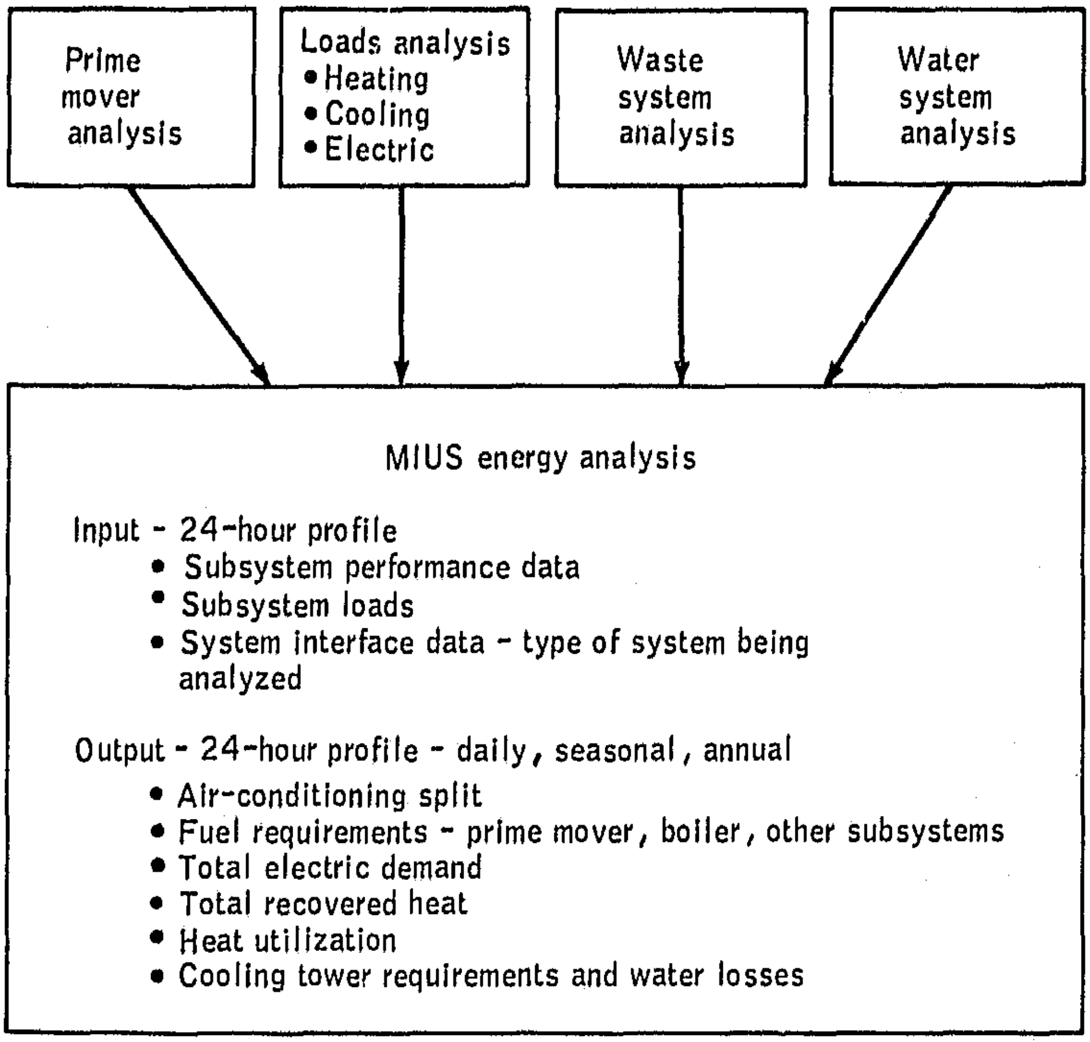
(a) Site plan.

(b) First floor plan.



(c) Second floor plan.

Figure 2.- High school plan.



Input - 24-hour profile
- Subsystem performance data
- Subsystem loads
- System interface data - type of system being analyzed

Output - 24-hour profile - daily, seasonal, annual
- Air-conditioning split
- Fuel requirements - prime mover, boiler, other subsystems
- Total electric demand
- Total recovered heat
- Heat utilization
- Cooling tower requirements and water losses

Figure 3.- The MIUS energy analysis logic.

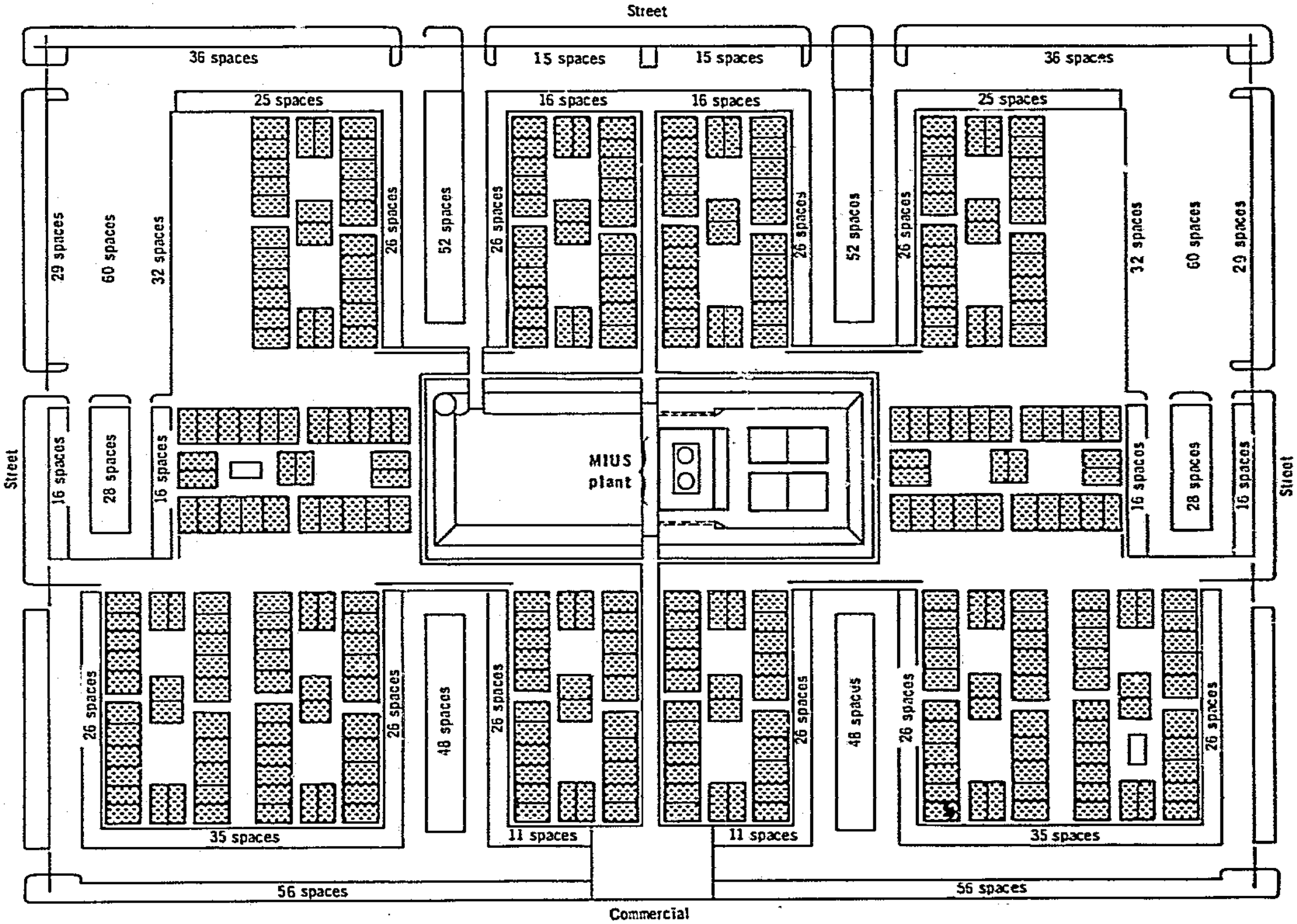


Figure 4.- The 648-unit garden apartment complex site plan, typical of apartment layouts in the Houston area.

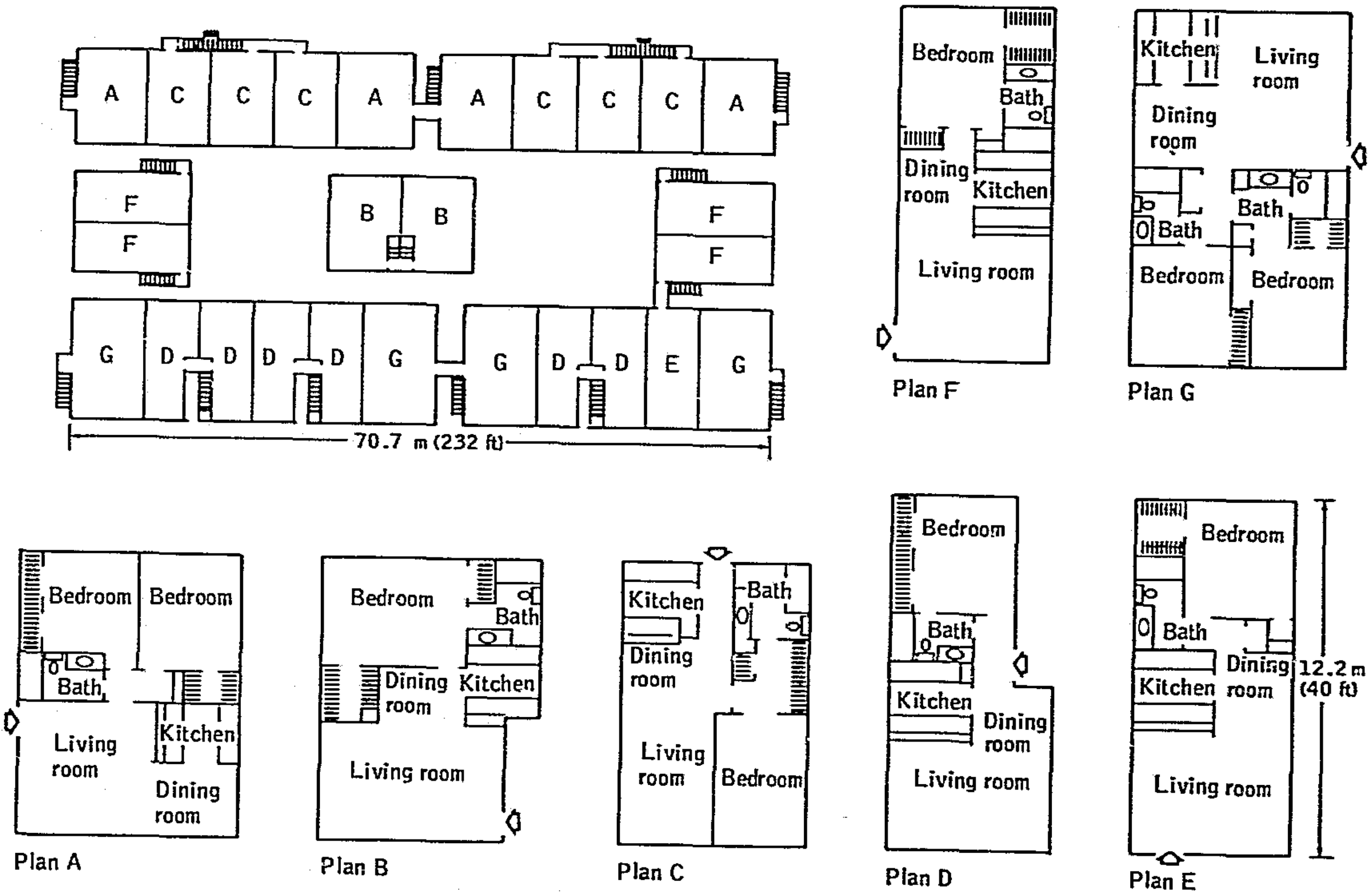


Figure 5.- The 648-unit garden apartment module and floor plans, typical of apartment layouts in the Houston area.

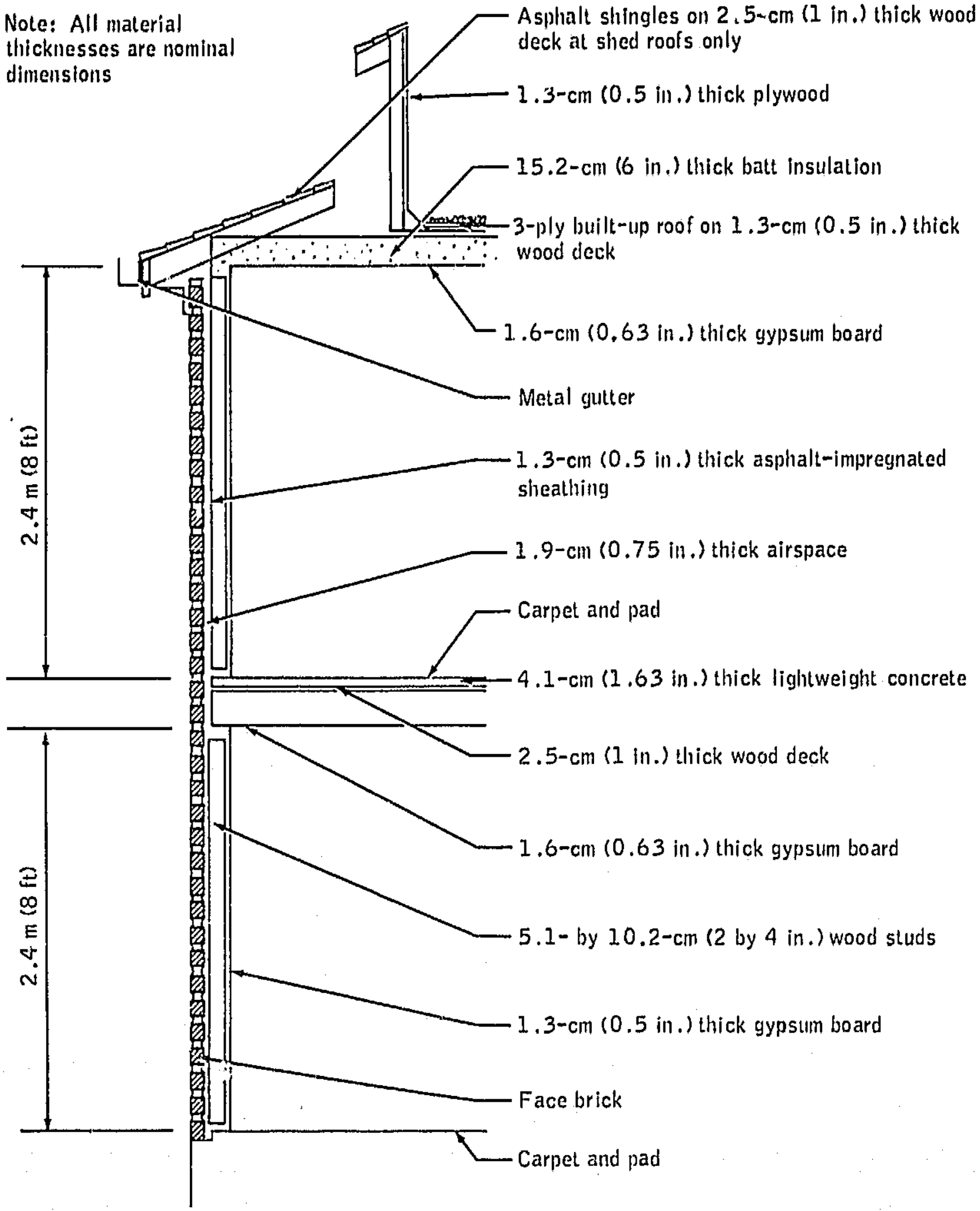


Figure 6.- The 648-unit garden apartment complex typical outer wall construction.

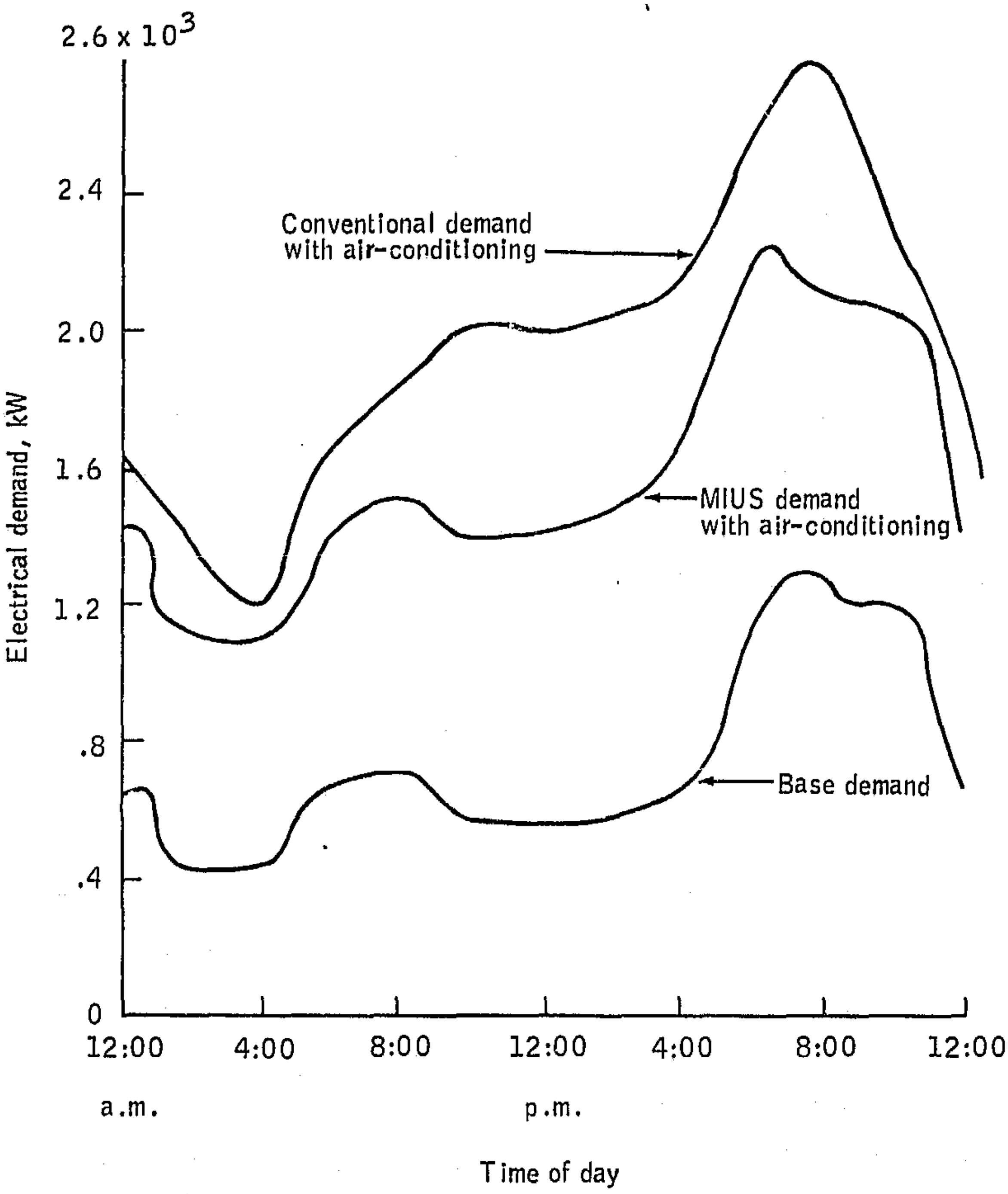


Figure 7.- Electrical load profiles for a conventionally serviced and an MIUS apartment complex.

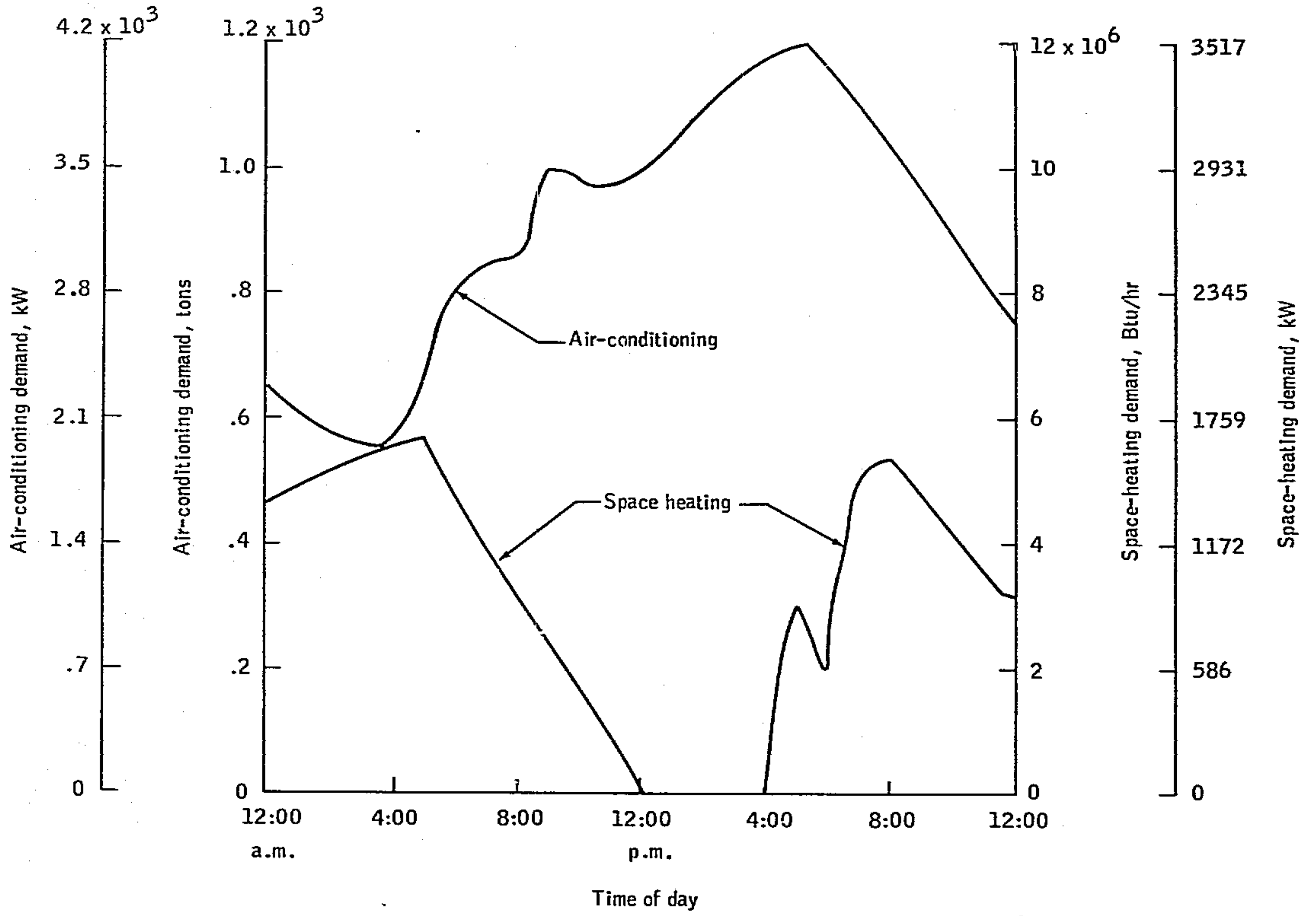


Figure 8.- Environmental conditioning load profiles for a 648-unit garden apartment complex (design days).

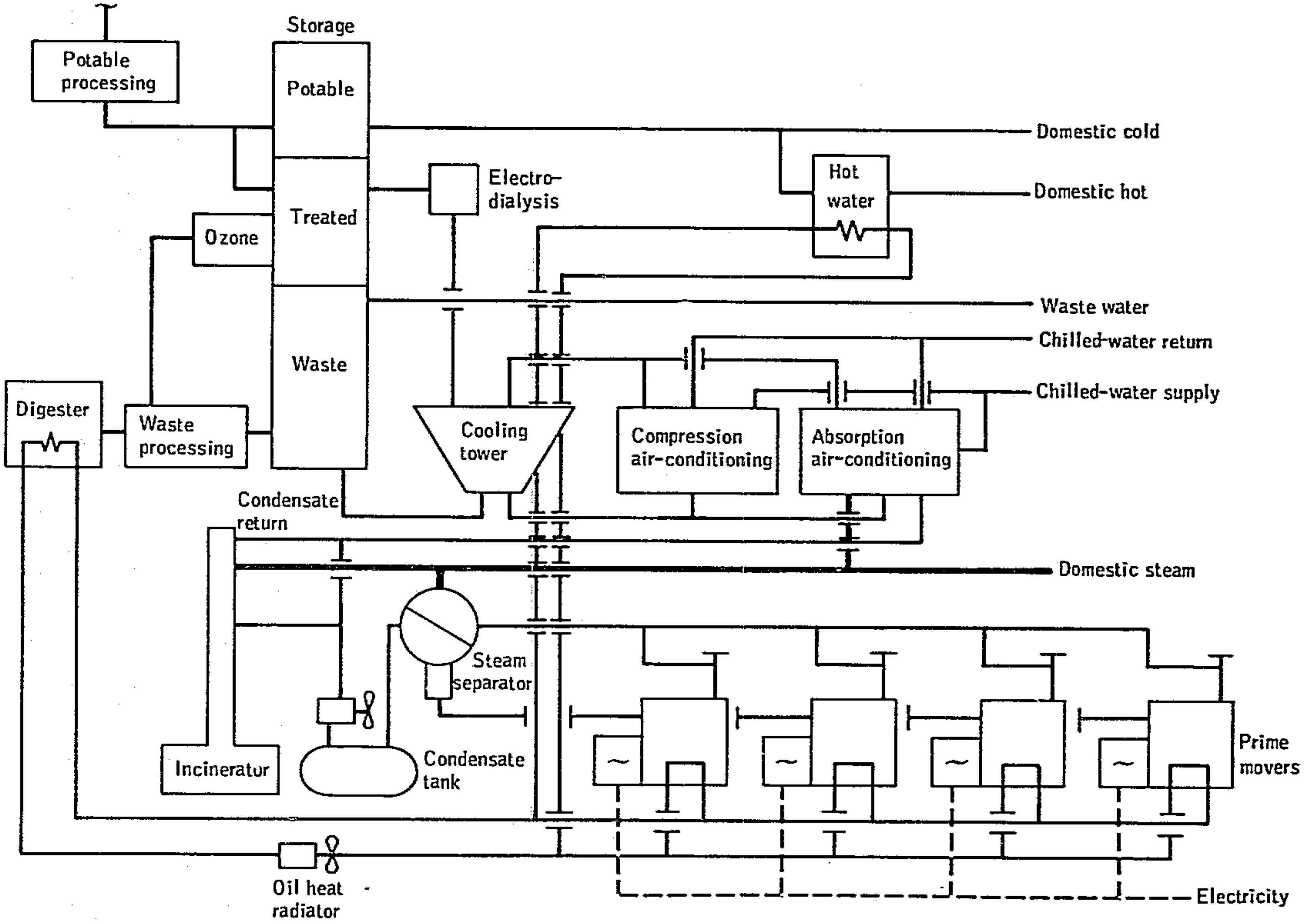


Figure 9.- Utilities schematic for a 648-unit garden apartment complex.

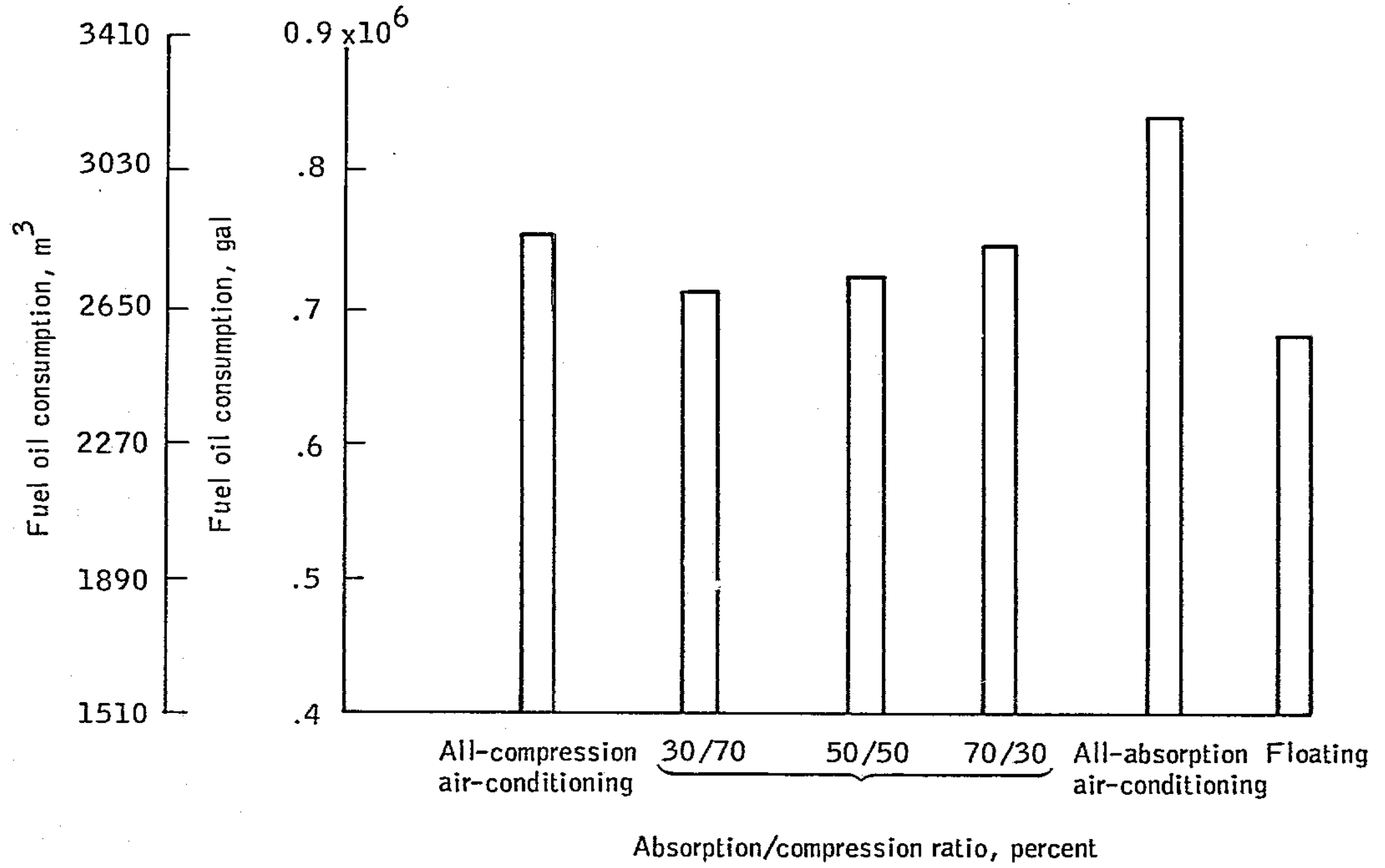
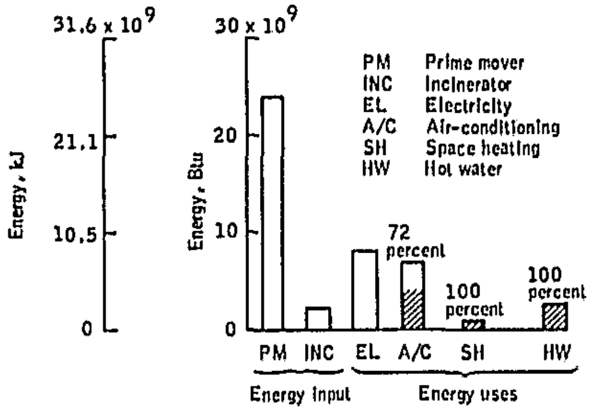
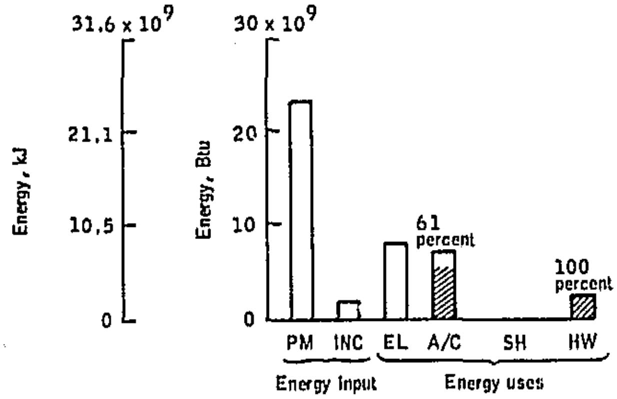


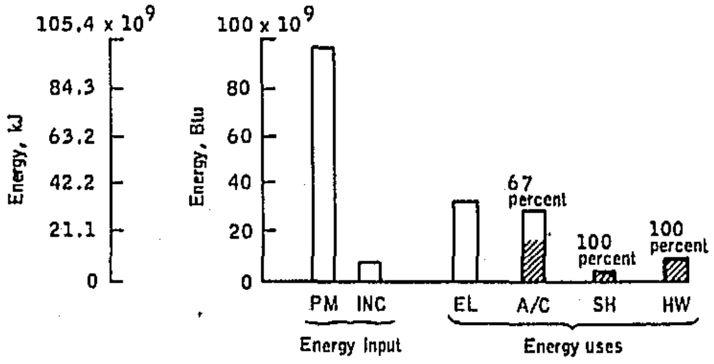
Figure 10.- Annual fuel consumption for a Houston-area 648-unit garden apartment complex with an incinerator.



(a) Spring.

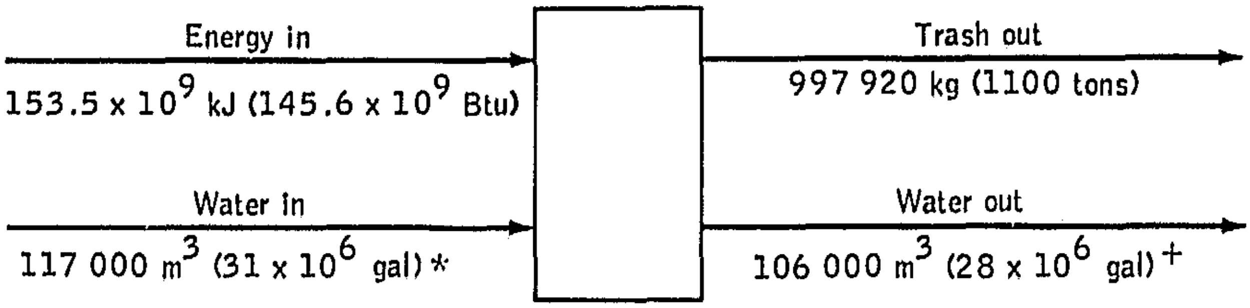


(b) Fall.



(c) Entire year.

Figure 11.- Garden apartment complex energy utilization for spring, for fall, and for the entire year. Shading indicates portion of services met by using recovered waste heat.

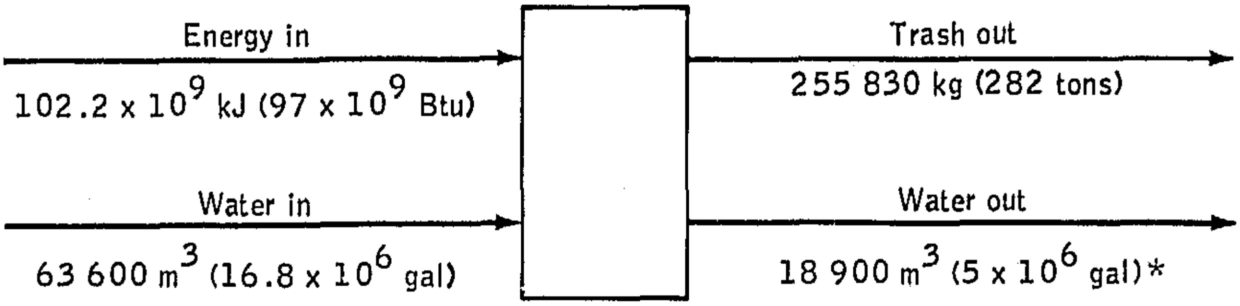


* With water-saving devices - 70 300 m^3 (18.5 x 10^6 gal)

\+ With water-saving devices - 37 100 m^3 (9.8 x 10^6 gal)

(See figure 13 for a description of the water-saving device.)

(a) Conventional.



* Waste-water use in heat rejection system increases water consumption.

(b) MIUS.

Figure 12.- Comparison of conventional and MIUS utilities systems for garden apartments.

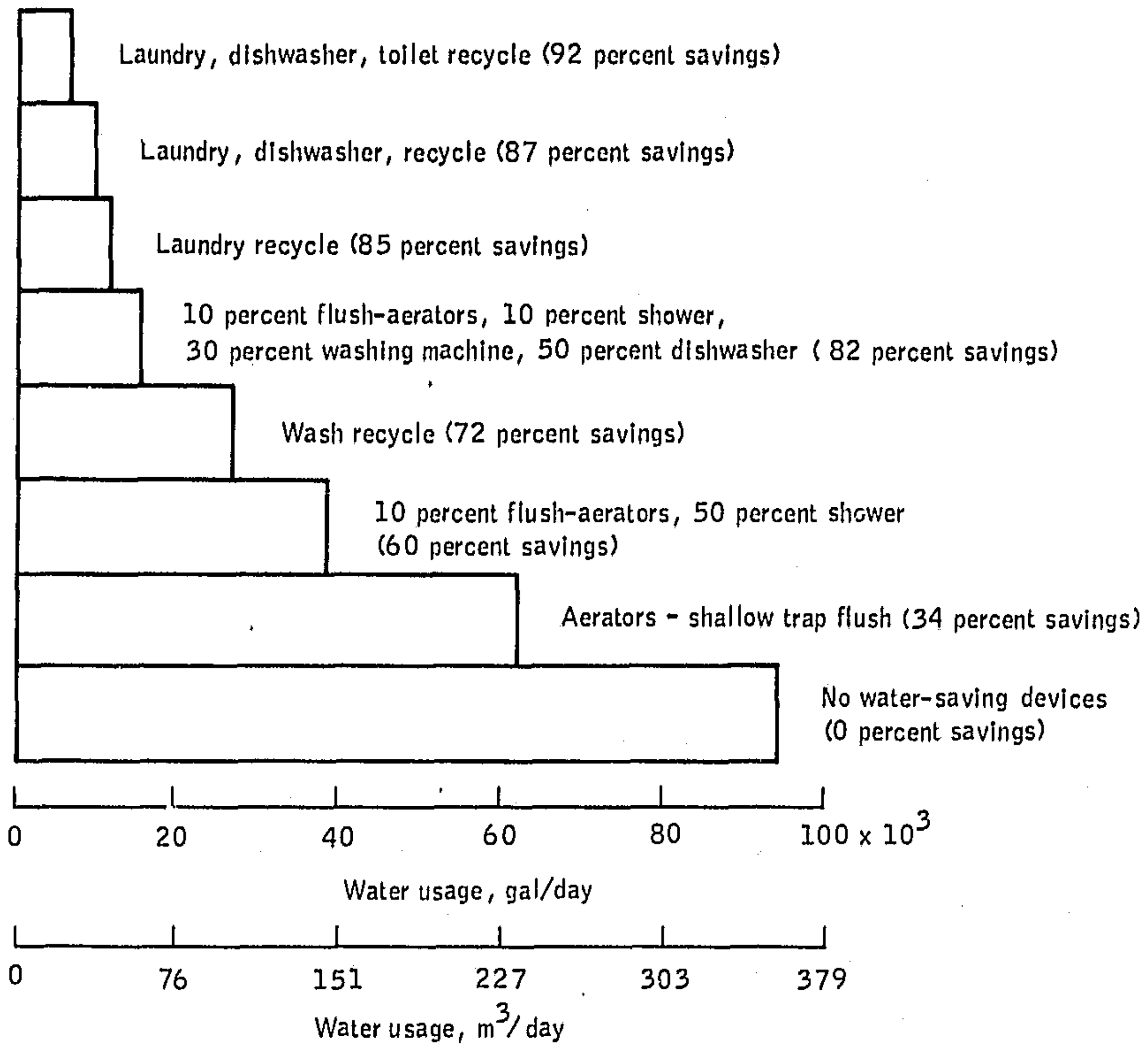


Figure 13.- Garden apartment complex water-savings evaluation. The bars represent water used per day in an MIUS system. The percent savings reflect the comparison to a conventional system.

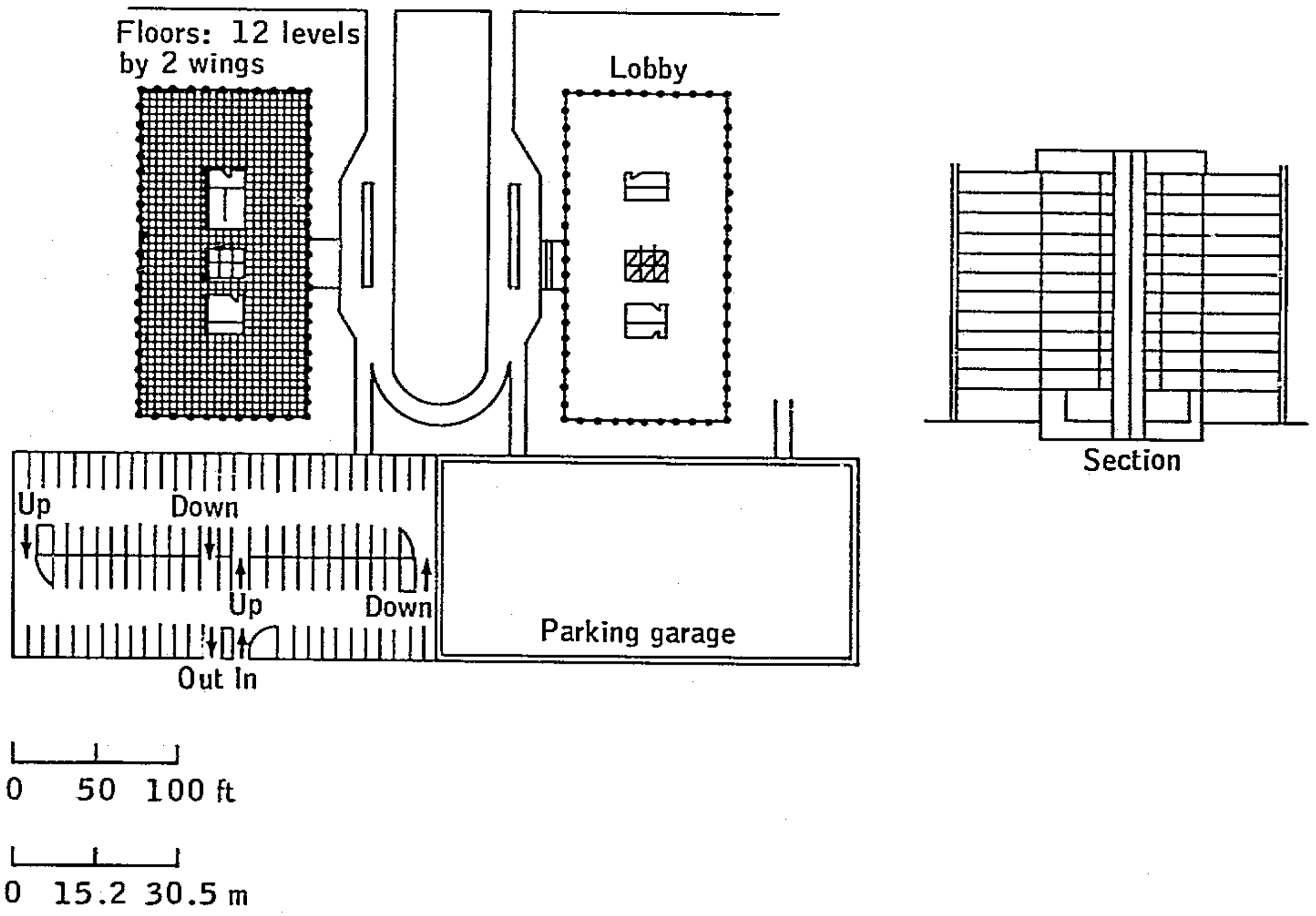


Figure 14.- Office building site diagram.

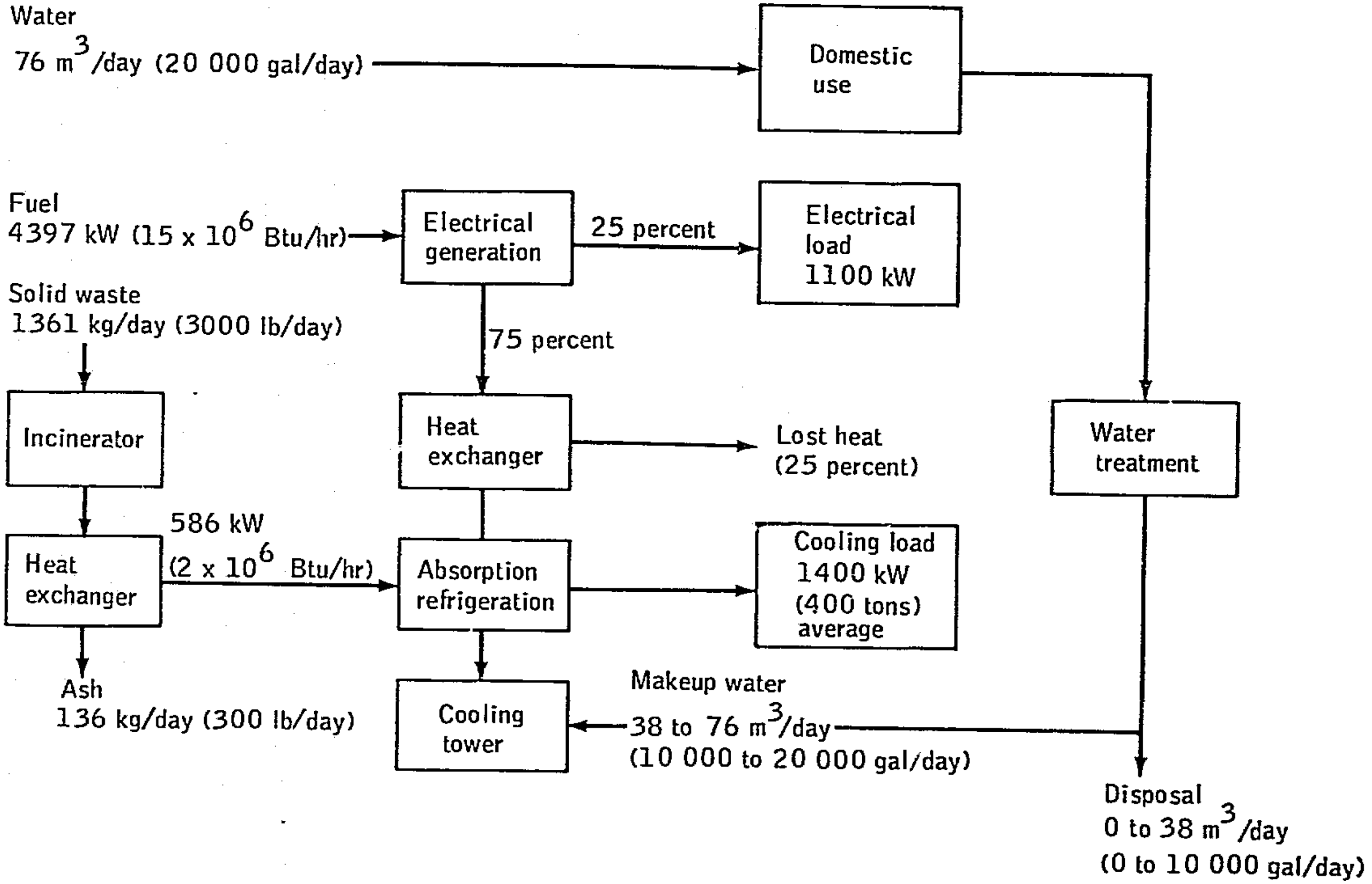


Figure 15.- Block diagram of the MIUS elements in office building design.

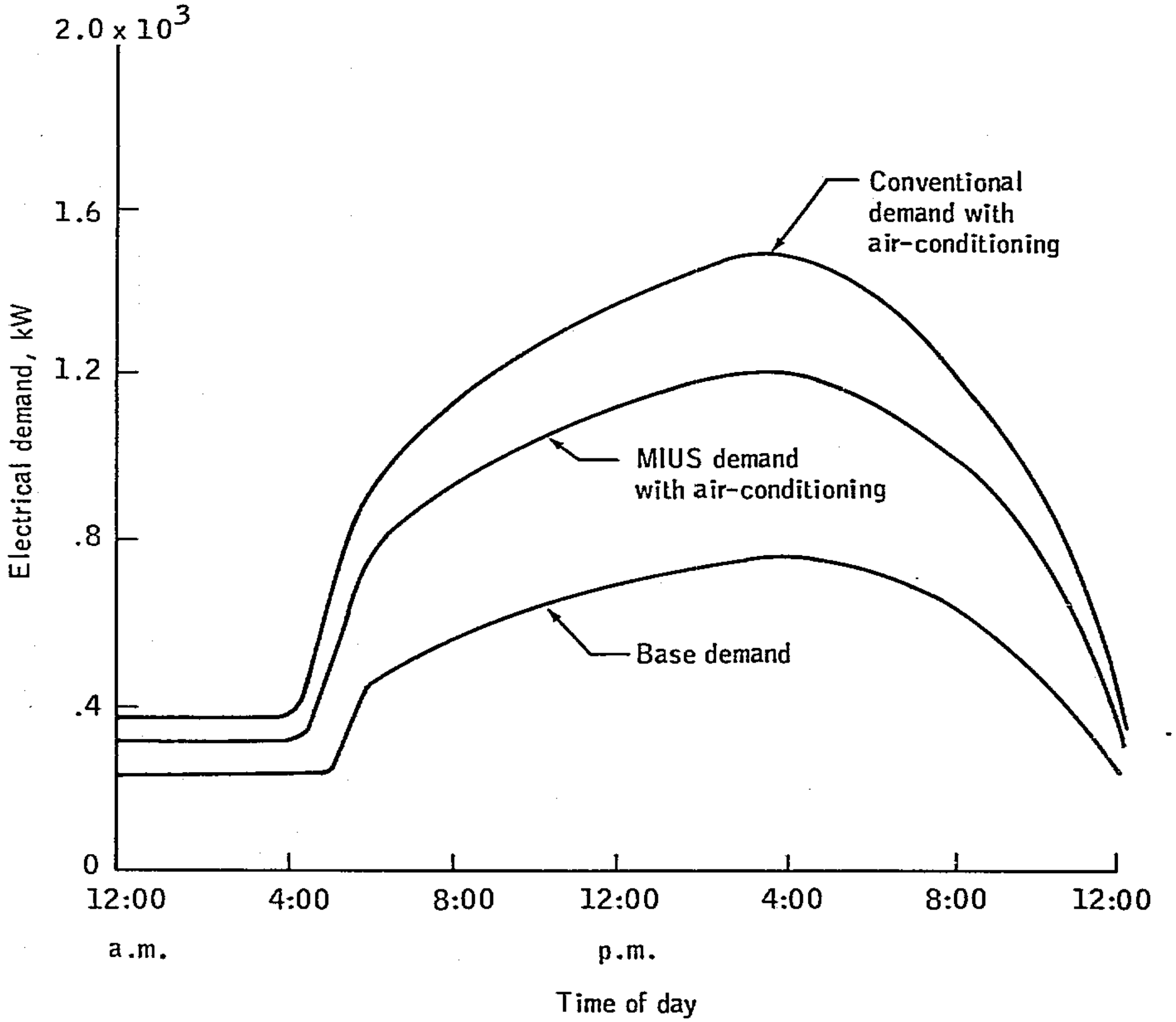


Figure 16.- Office building electrical load profiles.

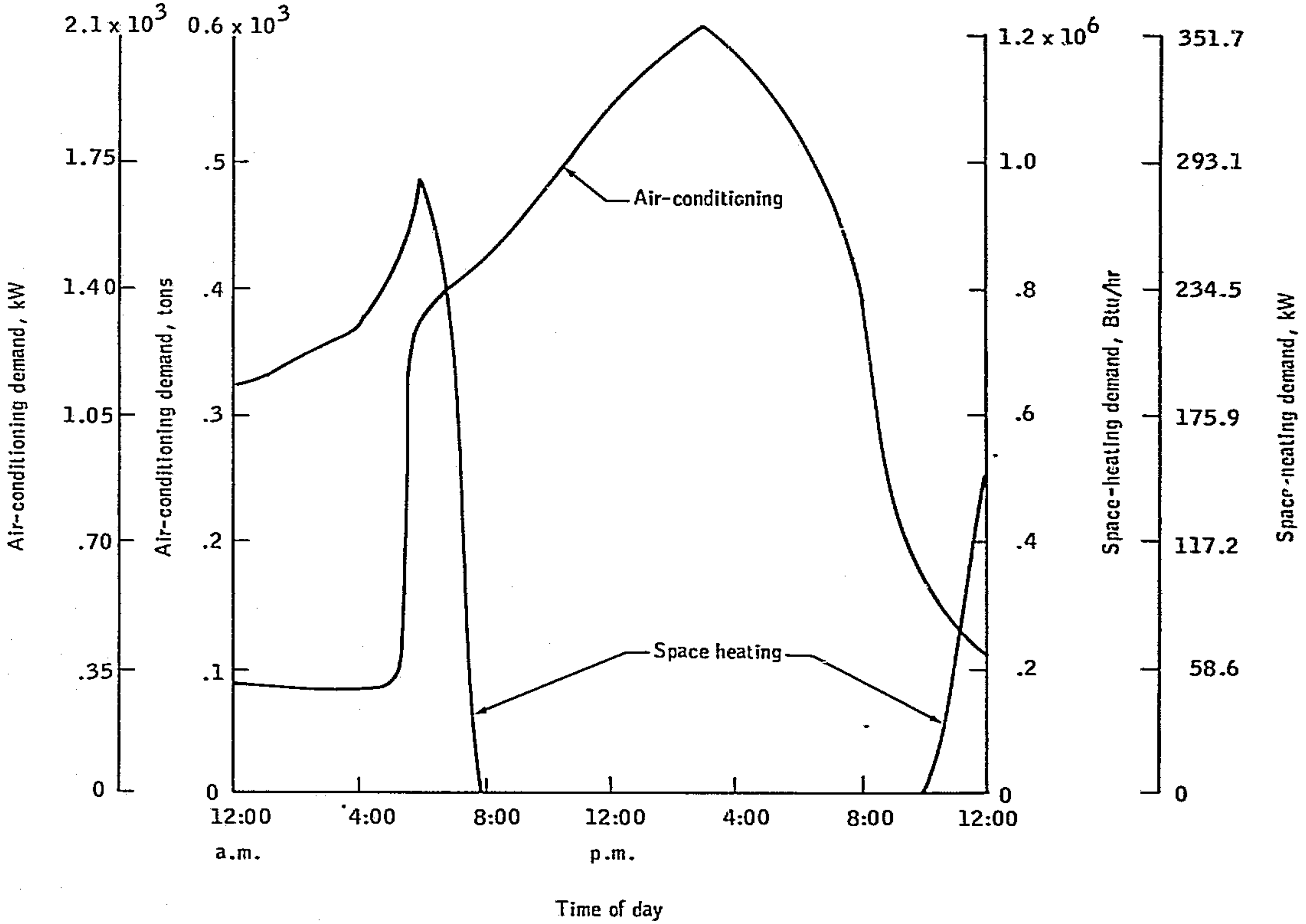


Figure 17.- Office building environmental conditioning load profiles.

Overall fuel savings, 18 percent

Water consumption savings, 50 percent

Reduction in sewage volume, 50 to 100 percent

Reduction in solid waste, 90 percent

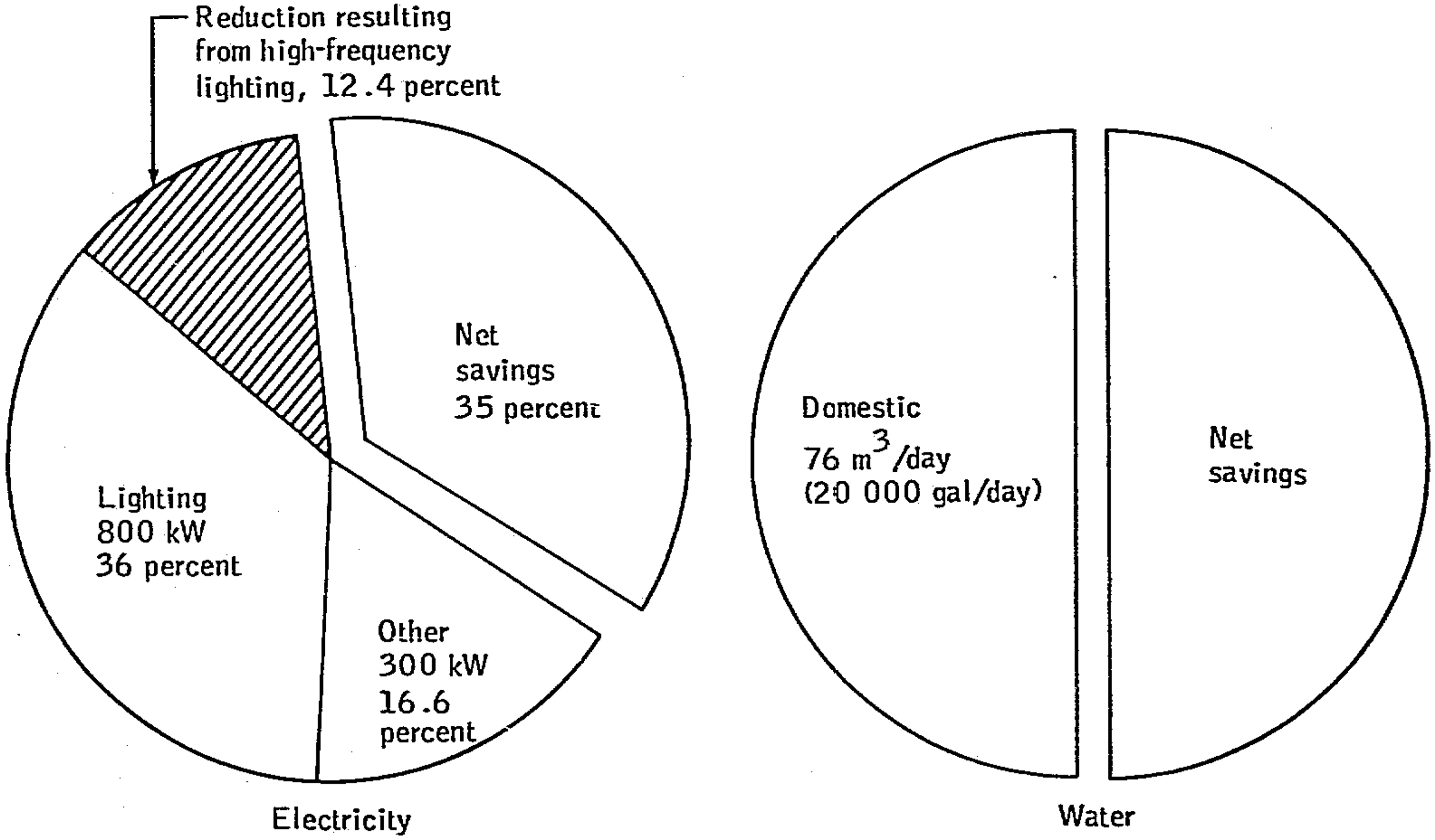
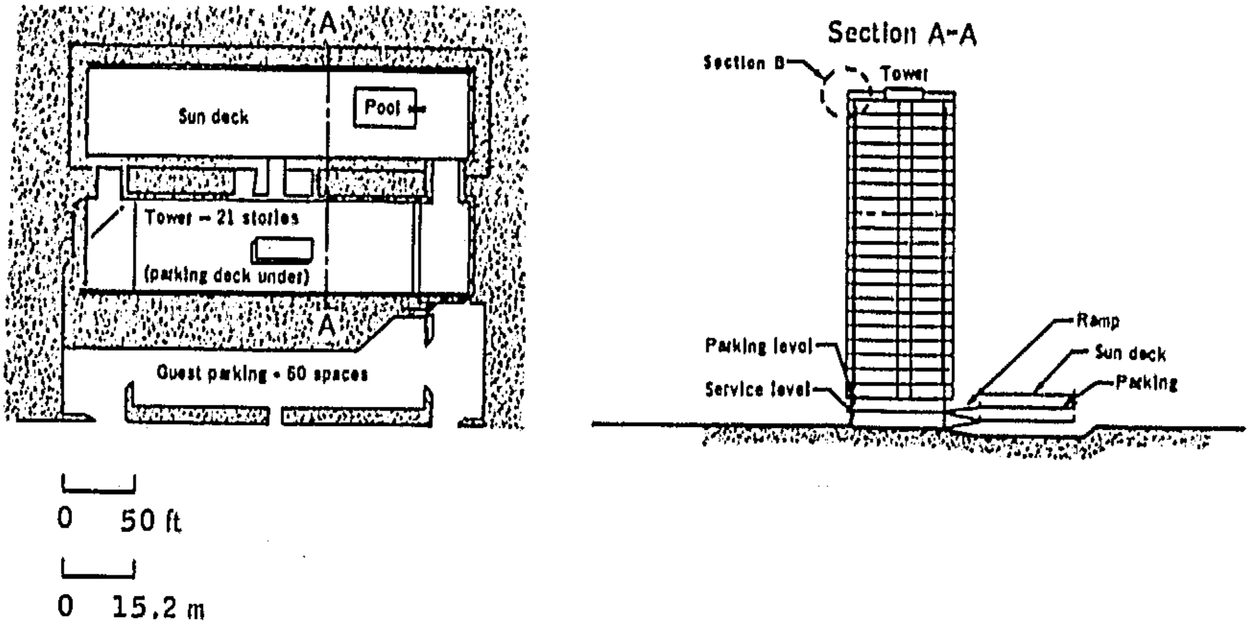
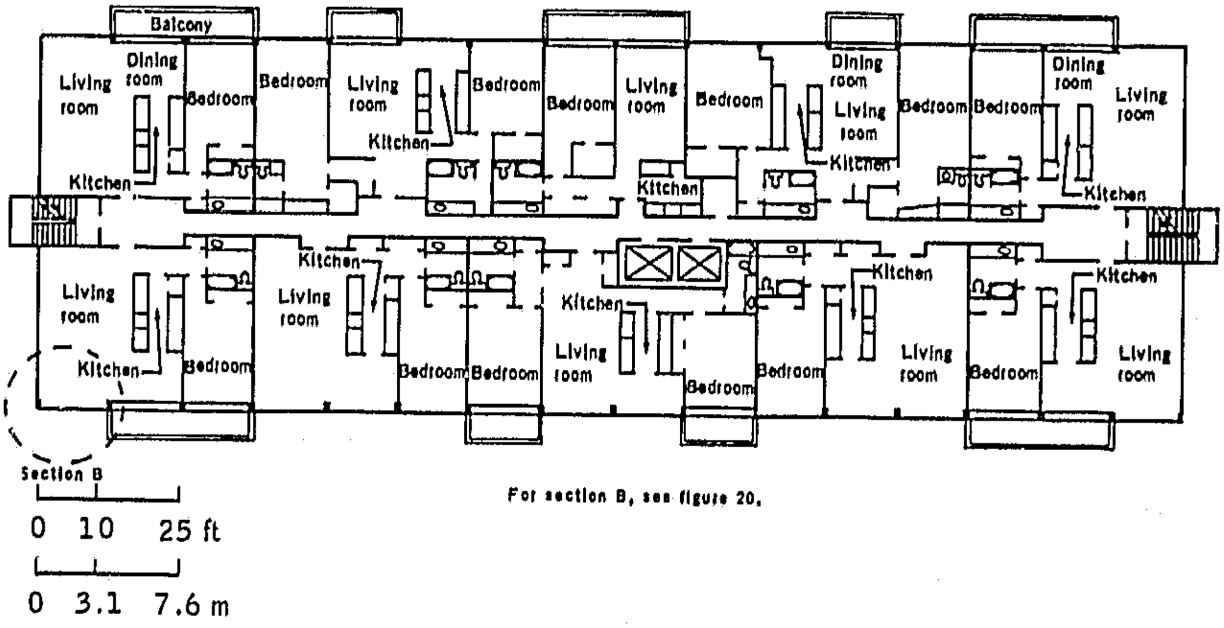


Figure 18.- Advantages of MIUS approach to high rise office building utilities.



(a) Site plan.



For section B, see figure 20.

(b) Floor plan.

Figure 19.- High rise apartment building plan.

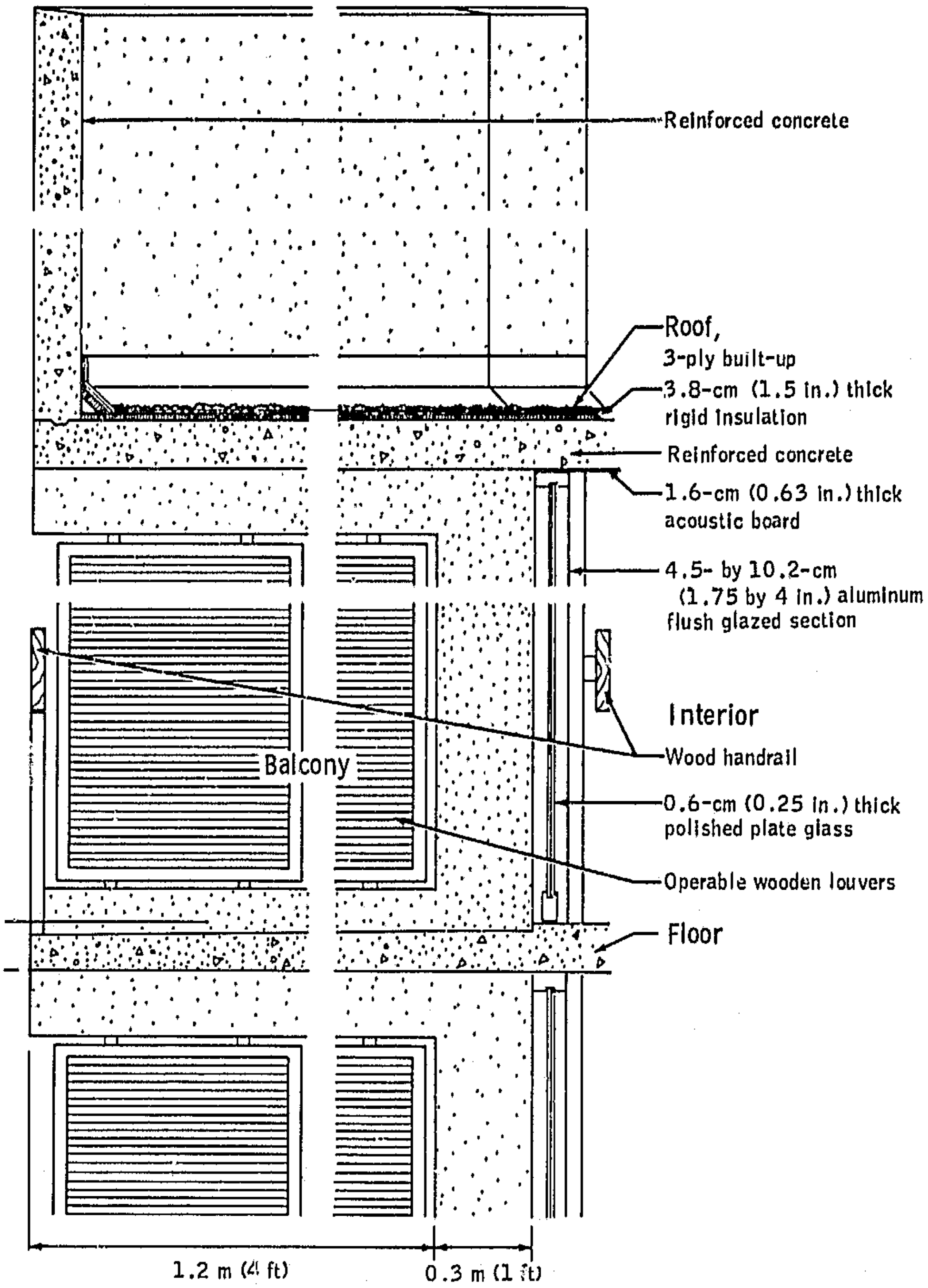


Figure 20.- High rise apartment building exterior construction details (section B).

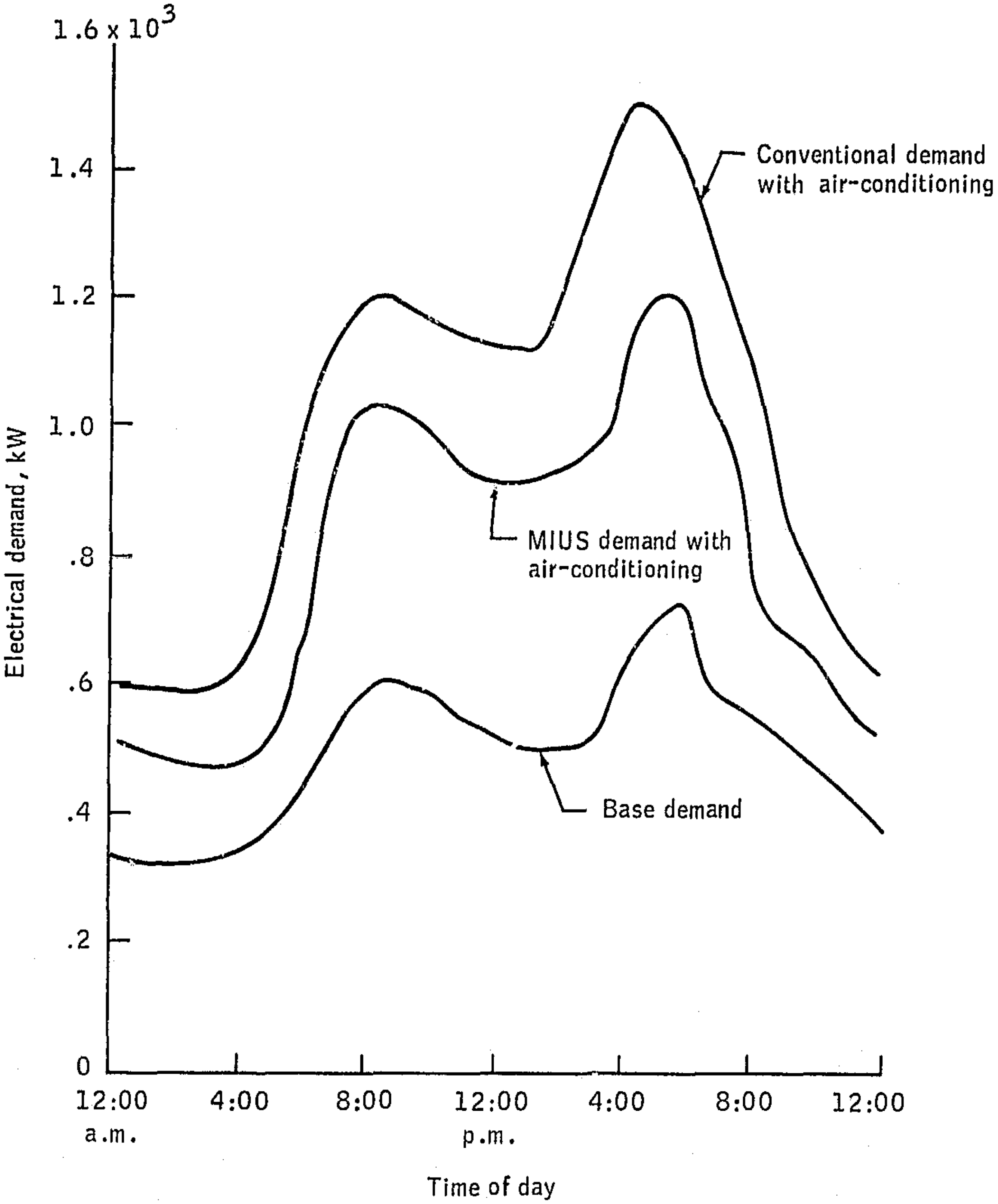


Figure 21.- High rise apartment building electrical load profiles.

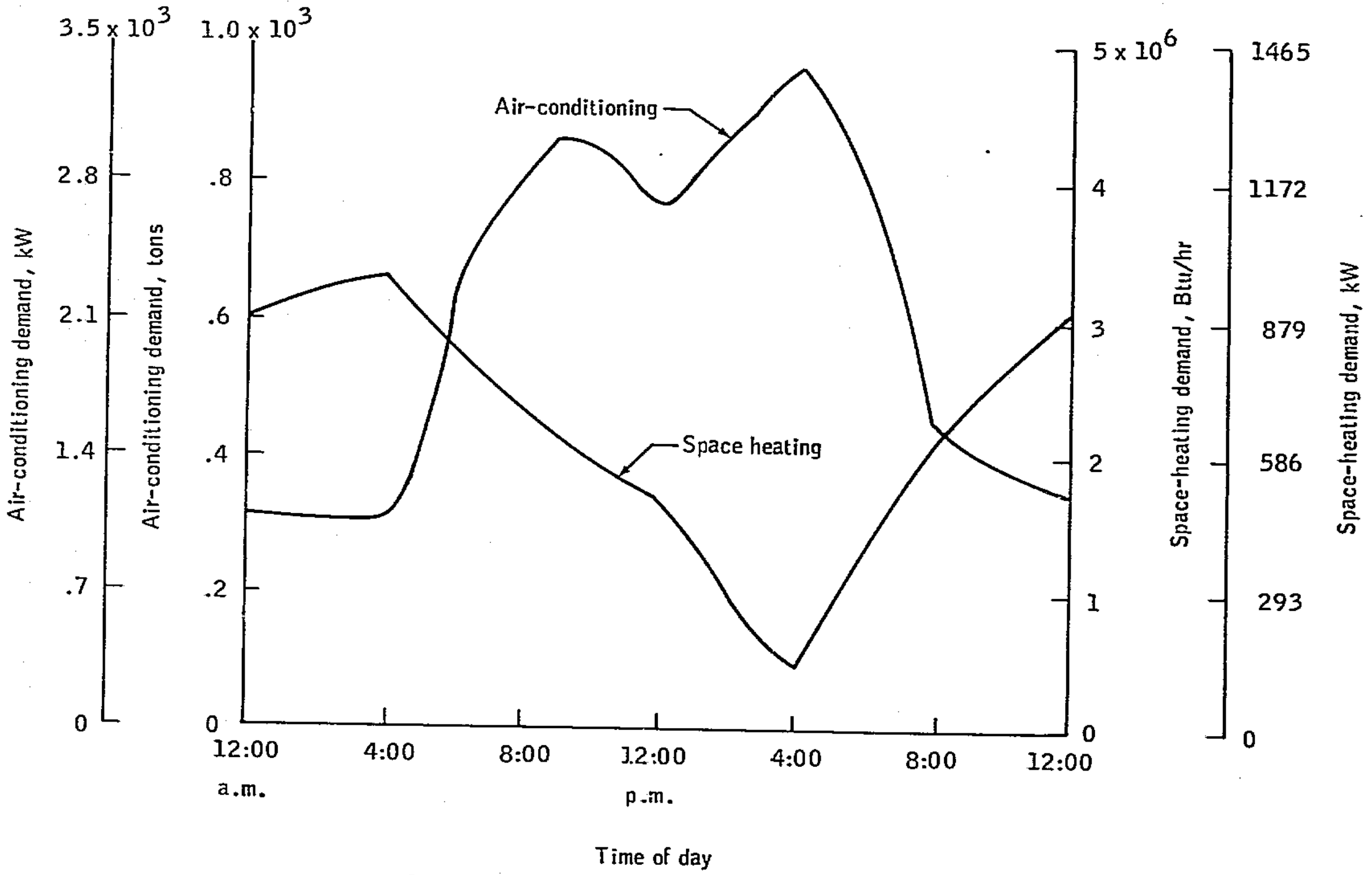


Figure 22.- High rise apartment building environmental conditioning load profiles (design days).

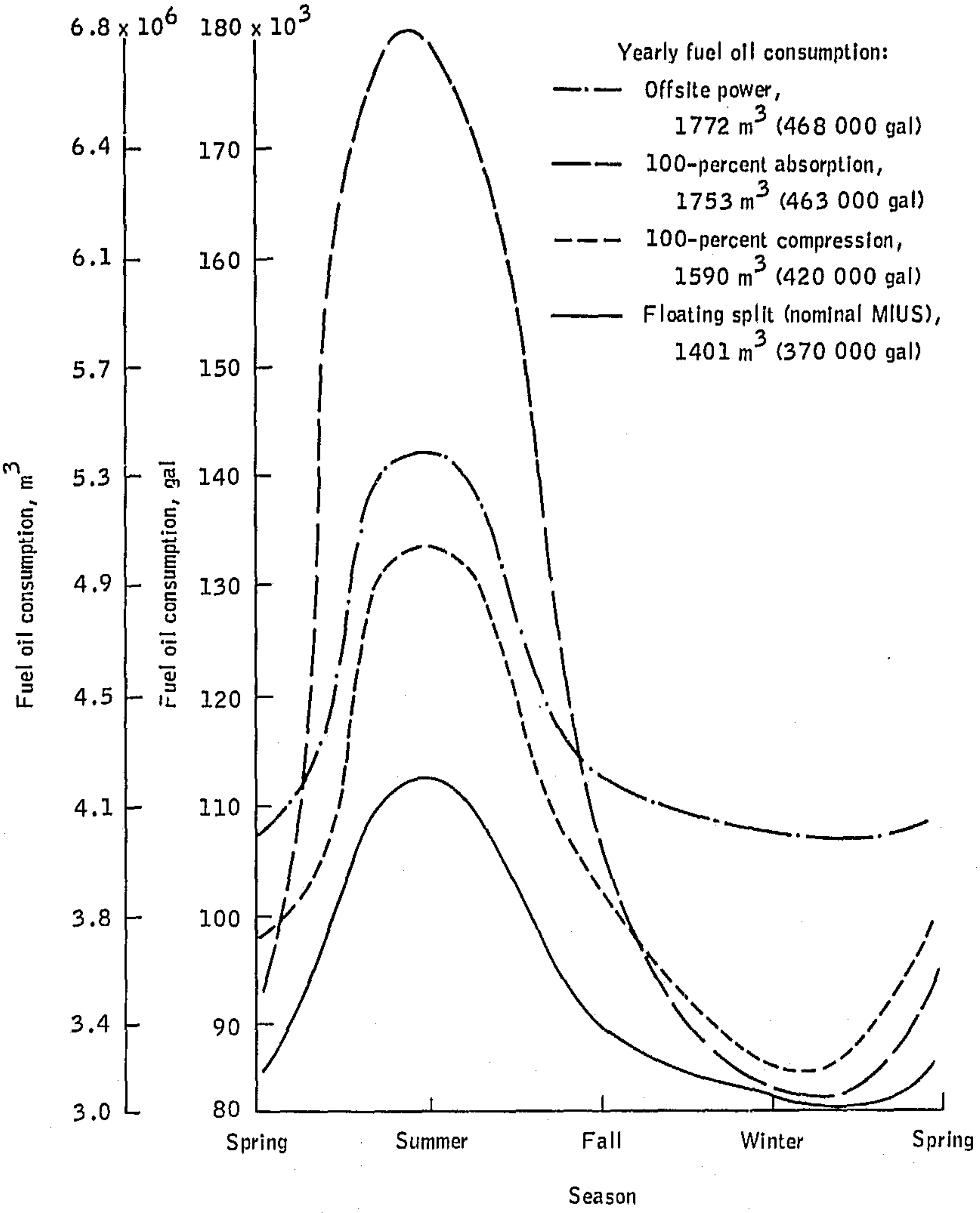
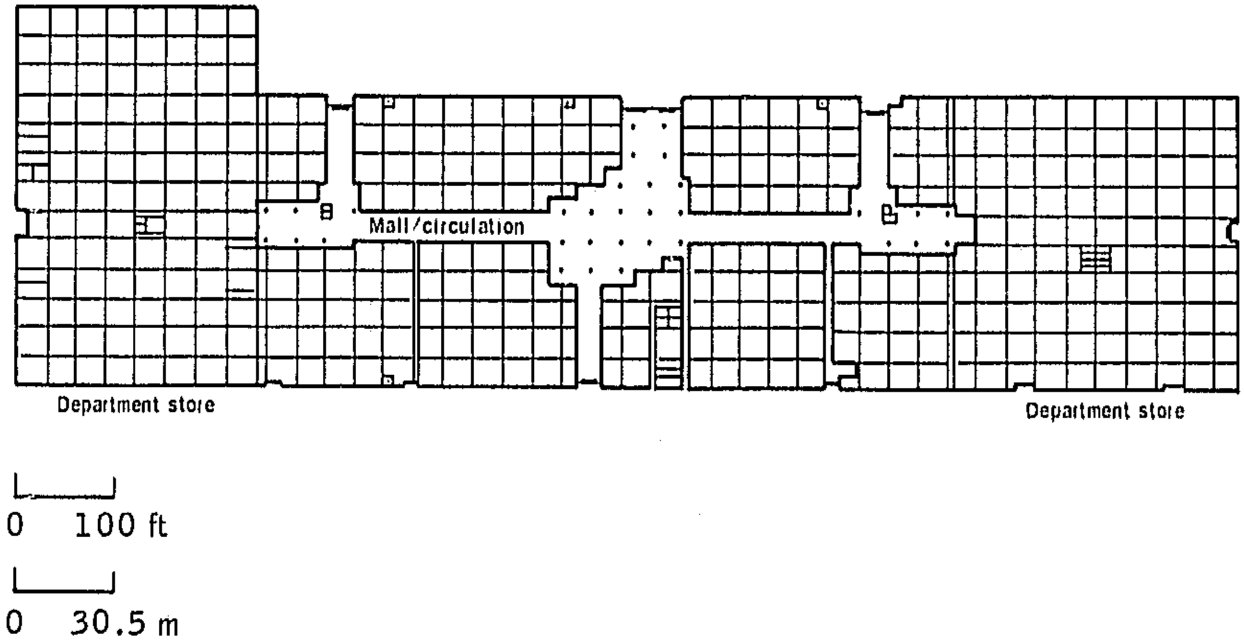
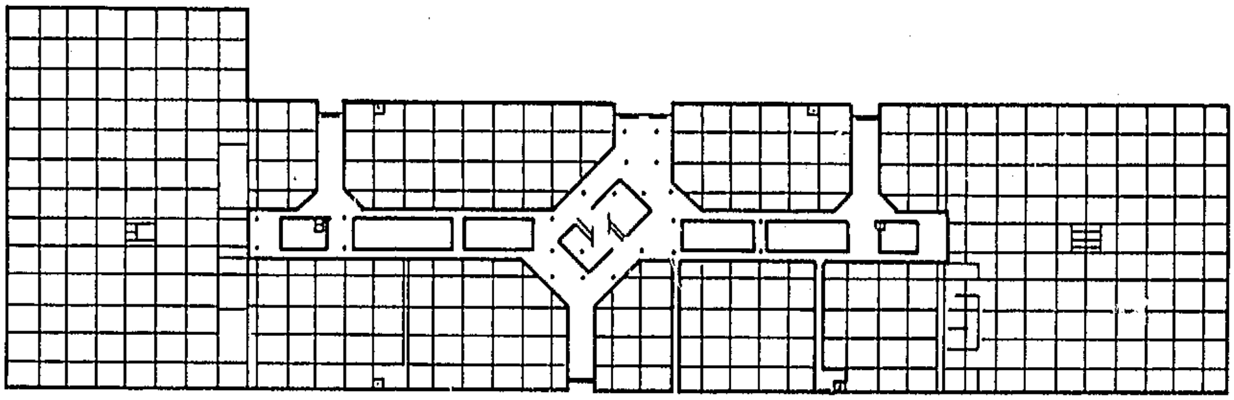


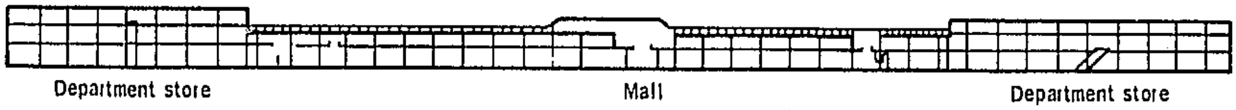
Figure 23.- High rise apartment building fuel oil consumption for various cooling options.



(a) Ground floor plan.

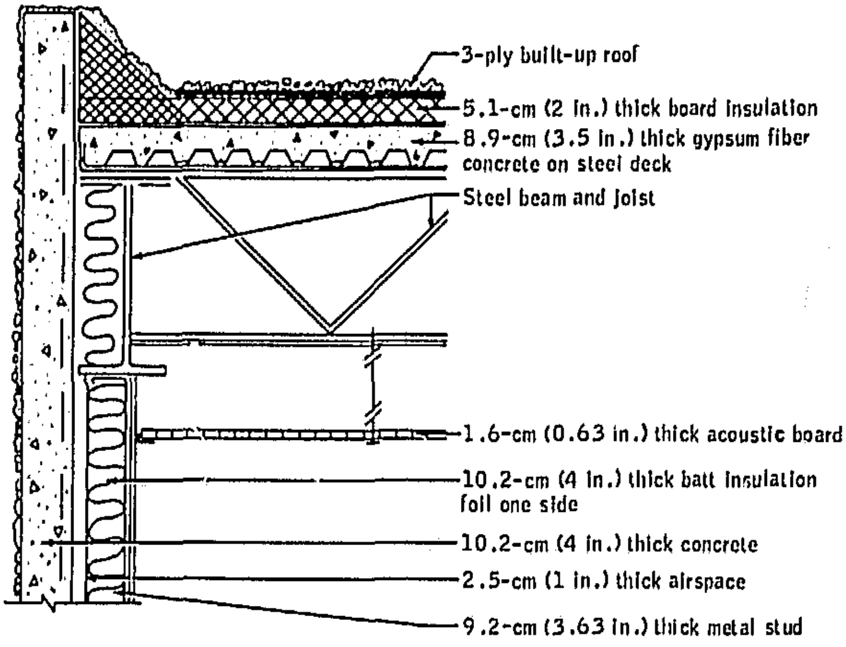


(b) Second floor plan.

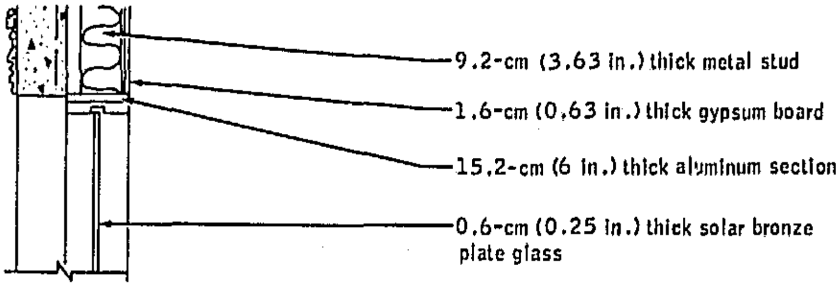


(c) Section through main mall.

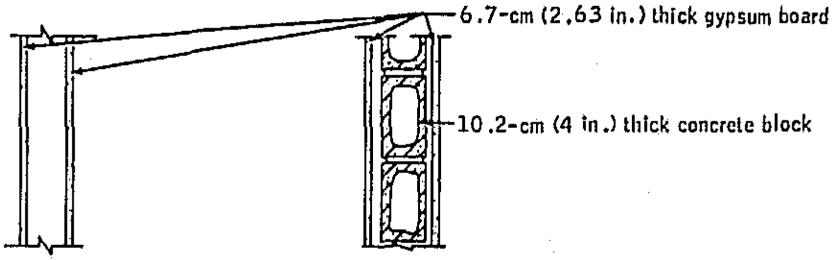
Figure 24.- Regional shopping center plan.



(a) Wall/roof construction cutaway.



(b) Glass curtainwall cutaway.



(c) Interior partition and area separation.

Figure 25.- Regional shopping center structure.

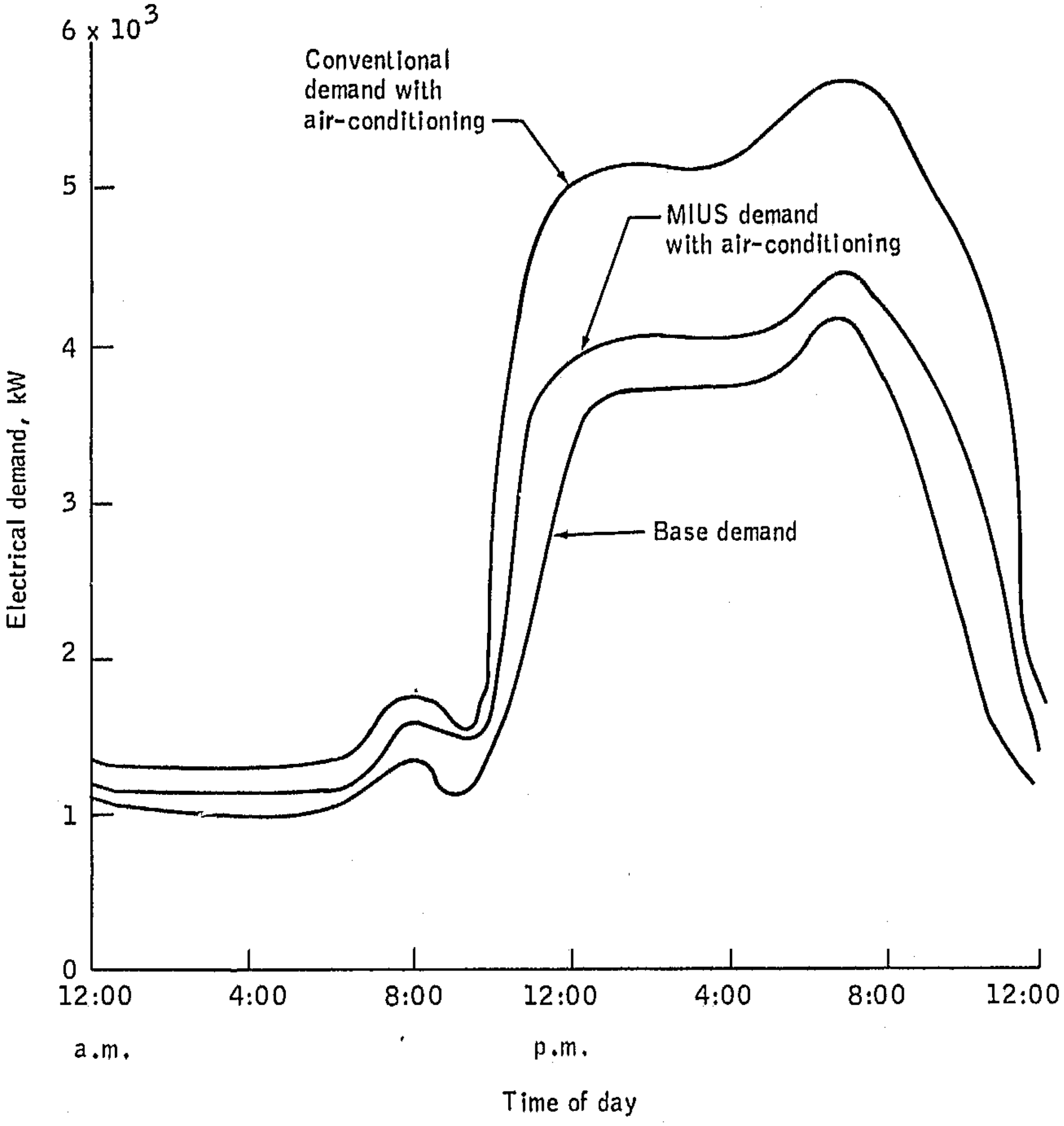


Figure 26.- Shopping center electrical load profiles.

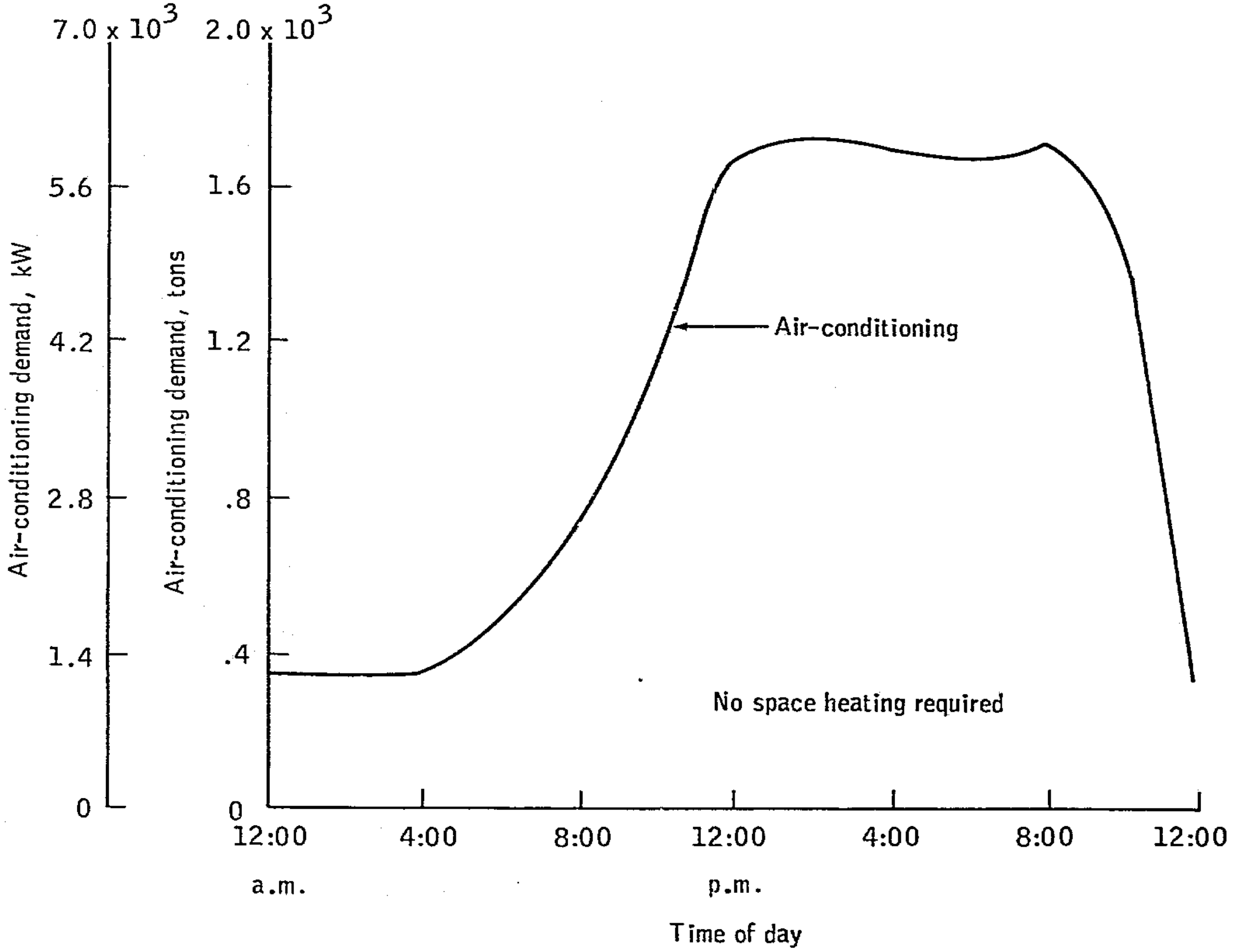
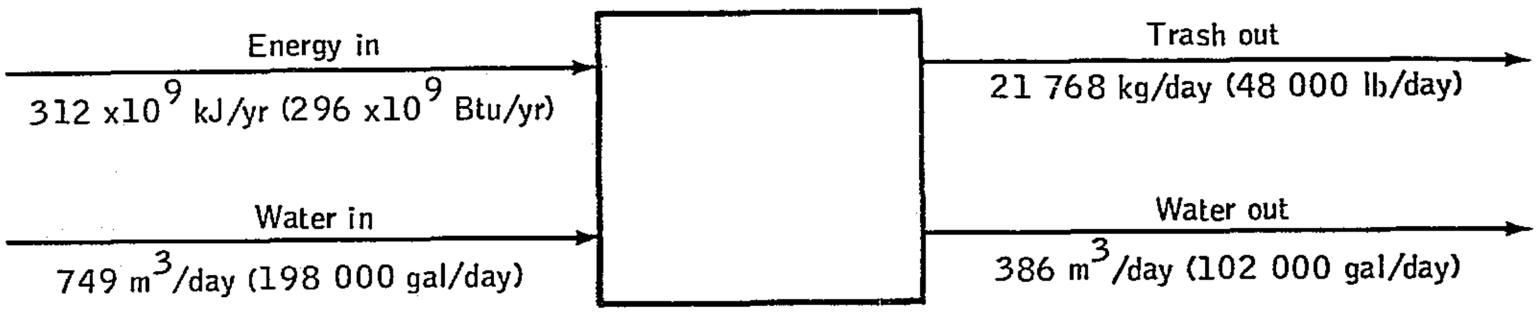
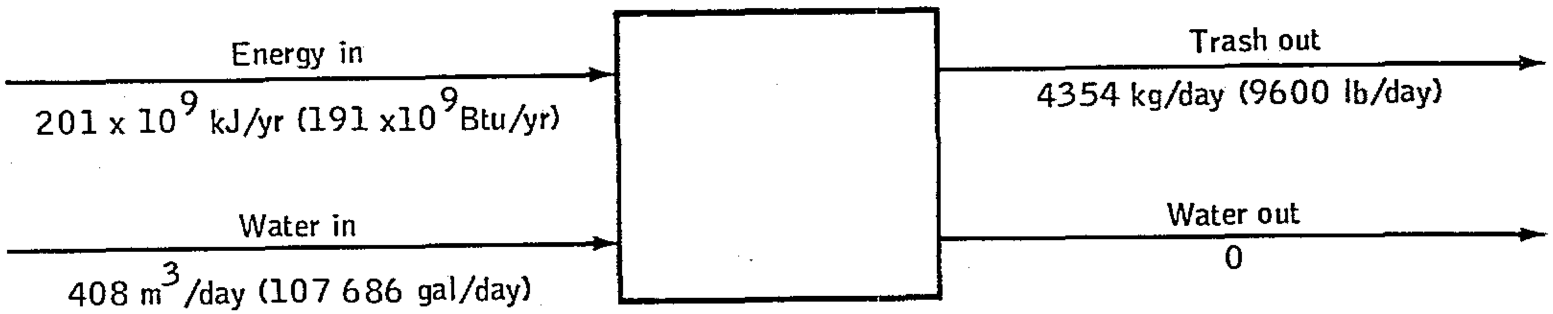


Figure 27.- Shopping center environmental conditioning load profile.



(a) Conventional.



(b) Nominal MIUS.

Figure 28.- Shopping center utilities performance comparison.

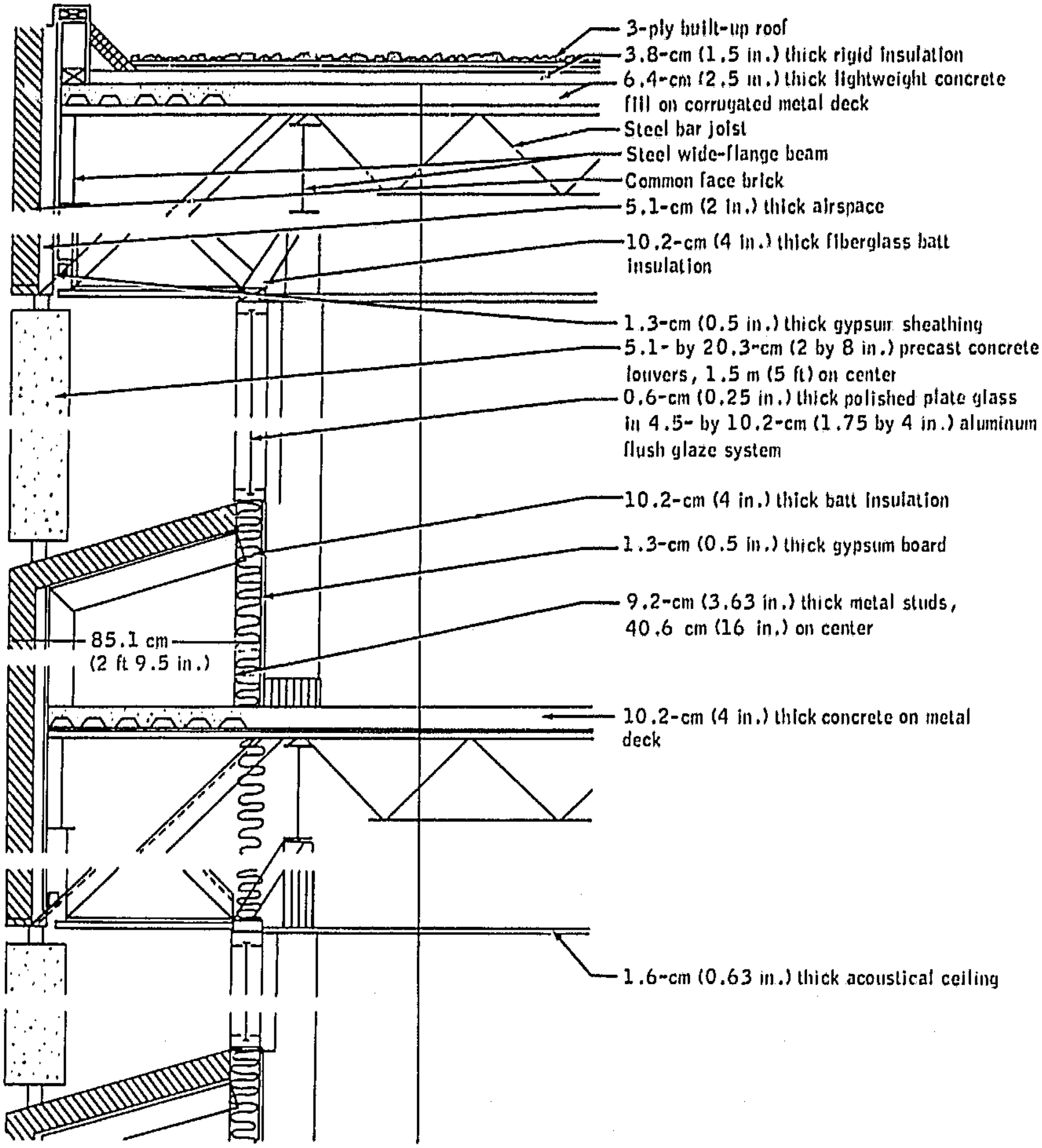


Figure 29.- High school typical wall section cutaway.

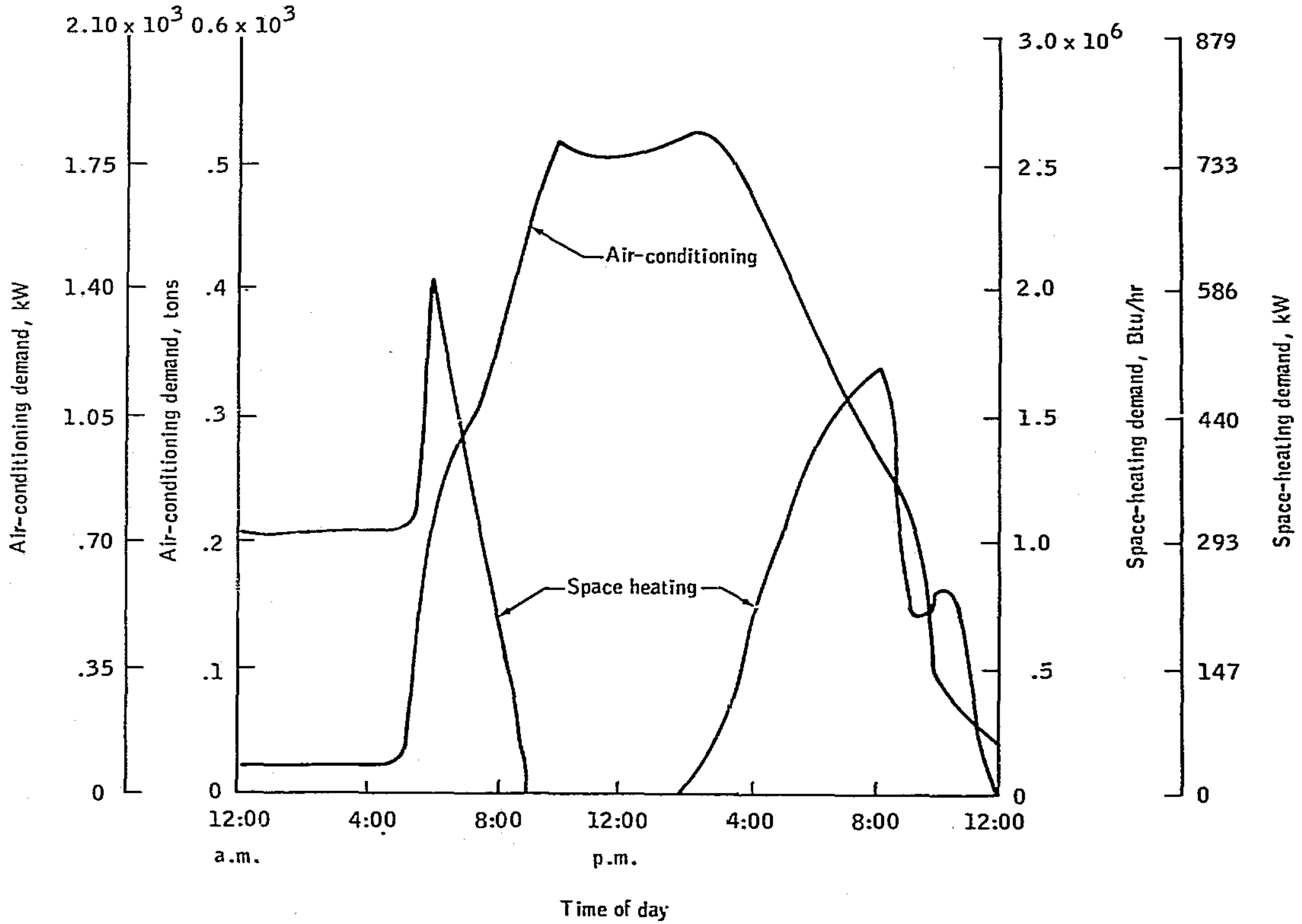


Figure 30.- High school environmental conditioning load profiles.

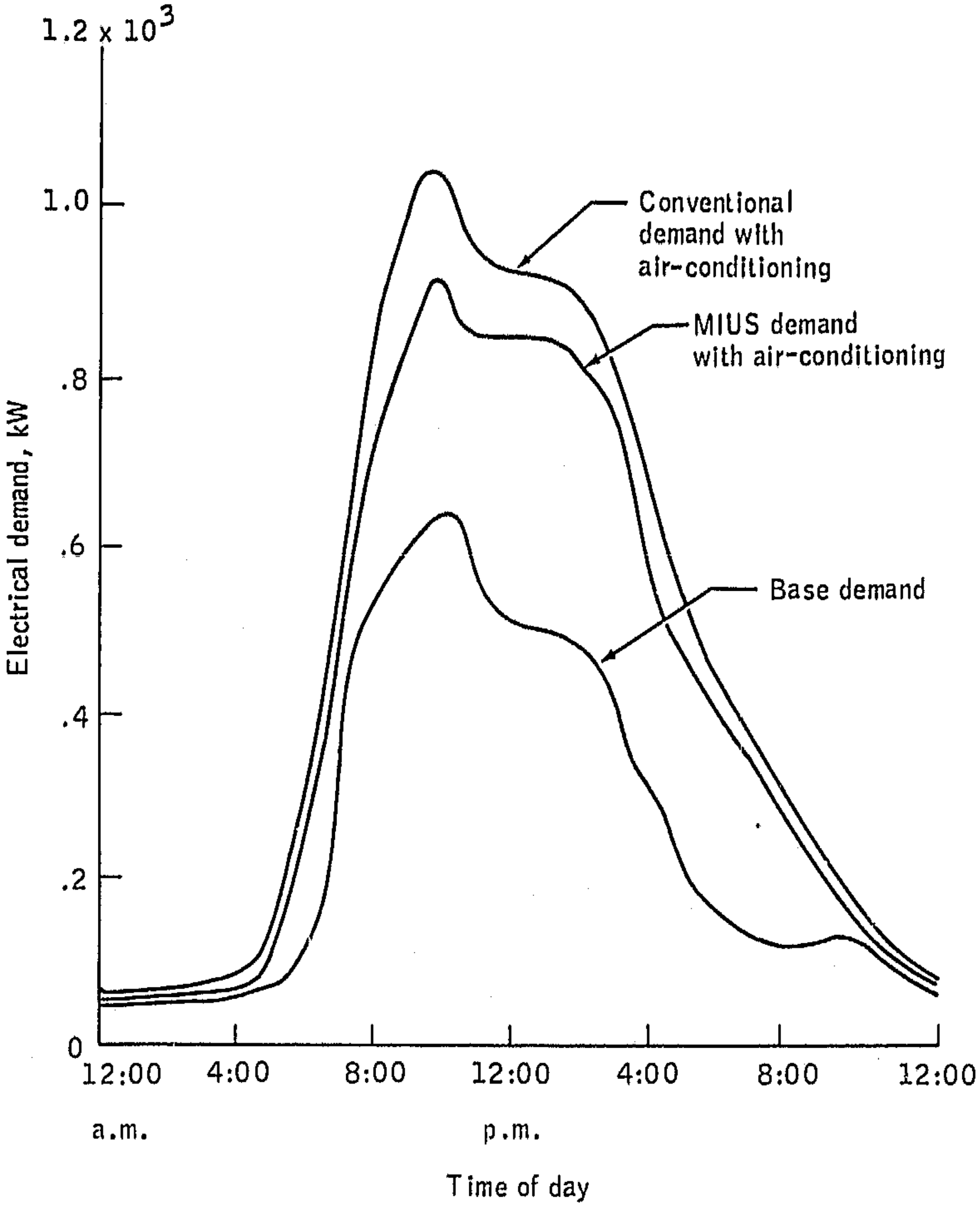


Figure 31.- High school electrical load profiles.

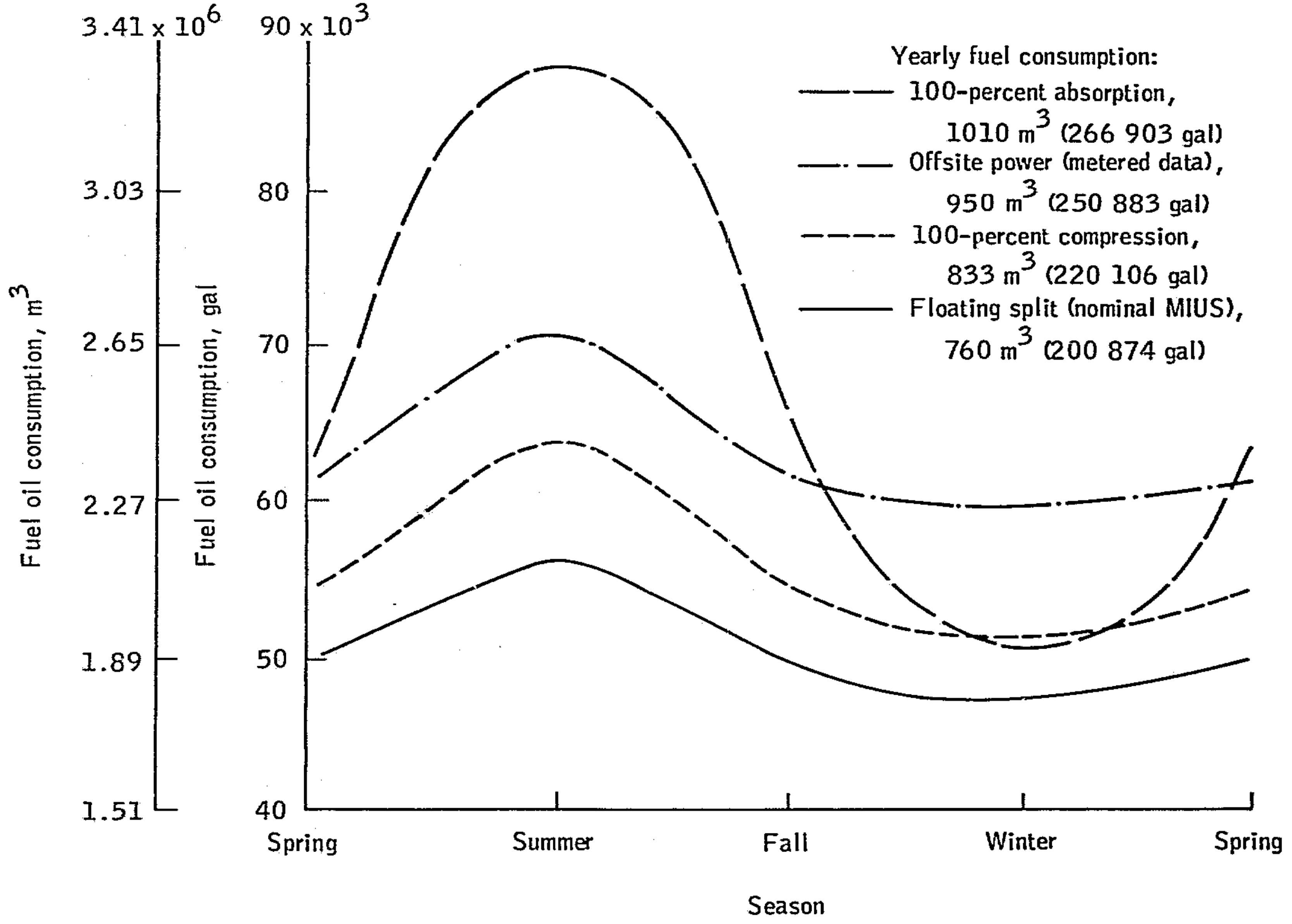
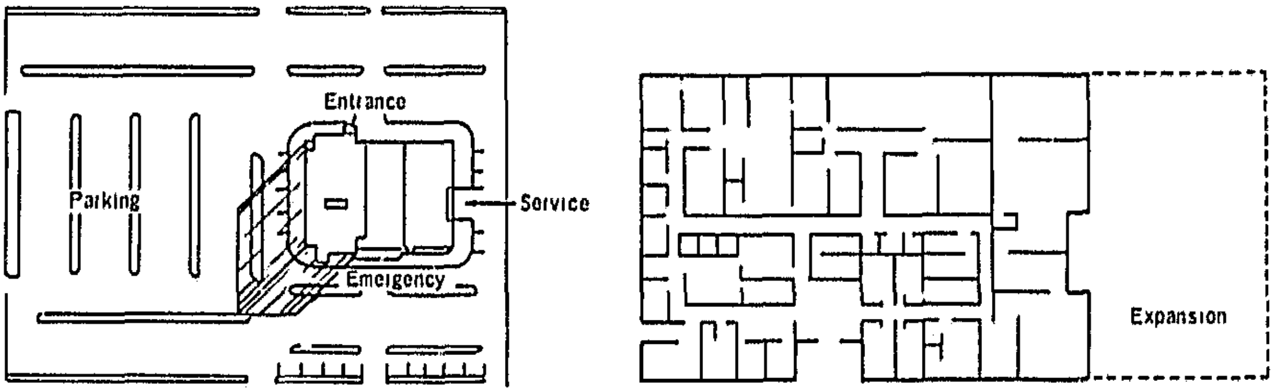
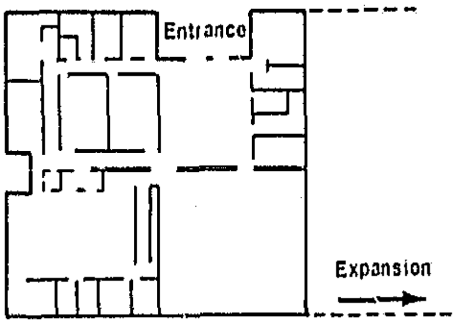


Figure 32.- High school fuel oil consumption for various cooling options.

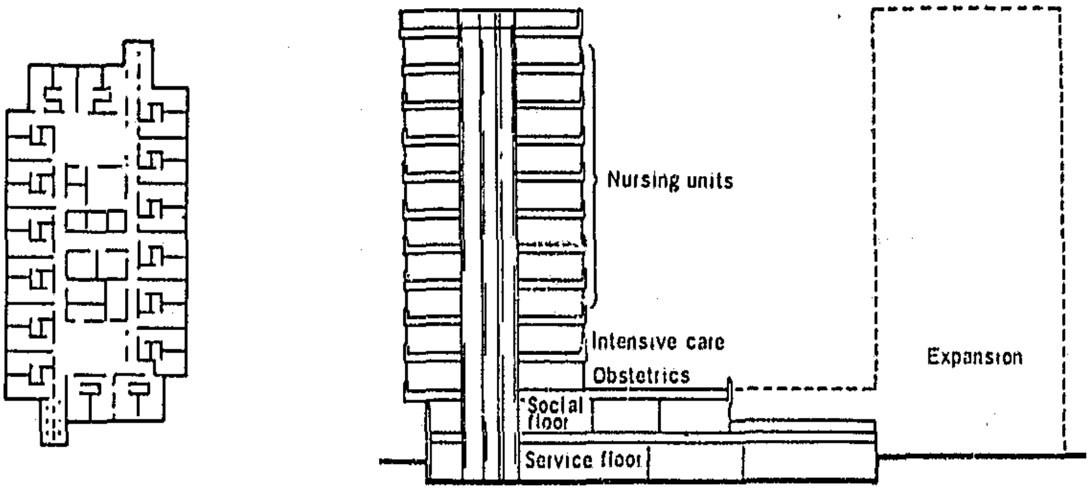


(a) Site plan, showing land use.

(b) Ground floor plan, for service functions.



(c) Main floor plan, for social functions.



(d) Third to tenth floor plan, for nursing functions.

(e) Section through elevator shaft.

Figure 33.- Hospital plan.

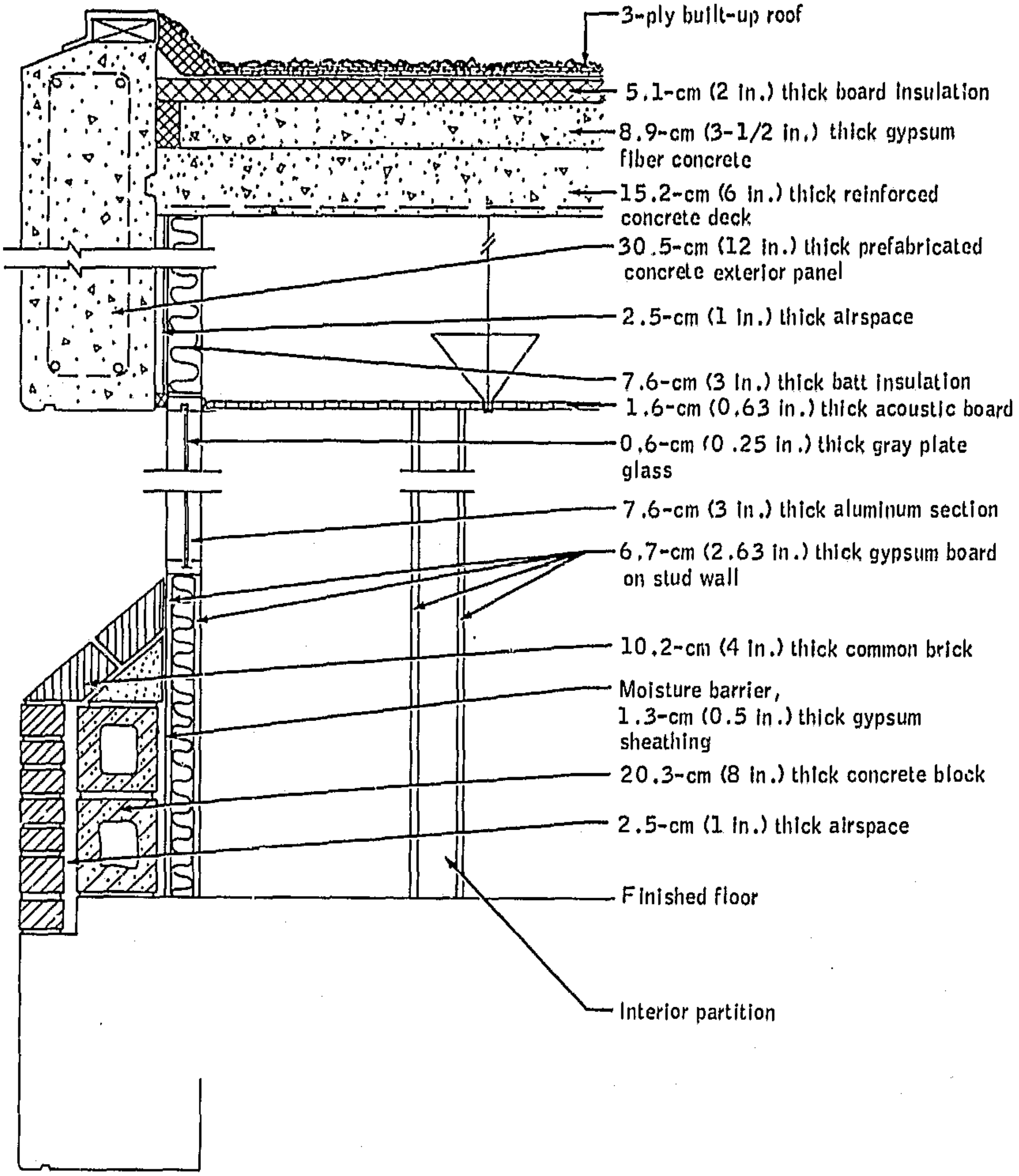


Figure 34.- Hospital project building construction details.

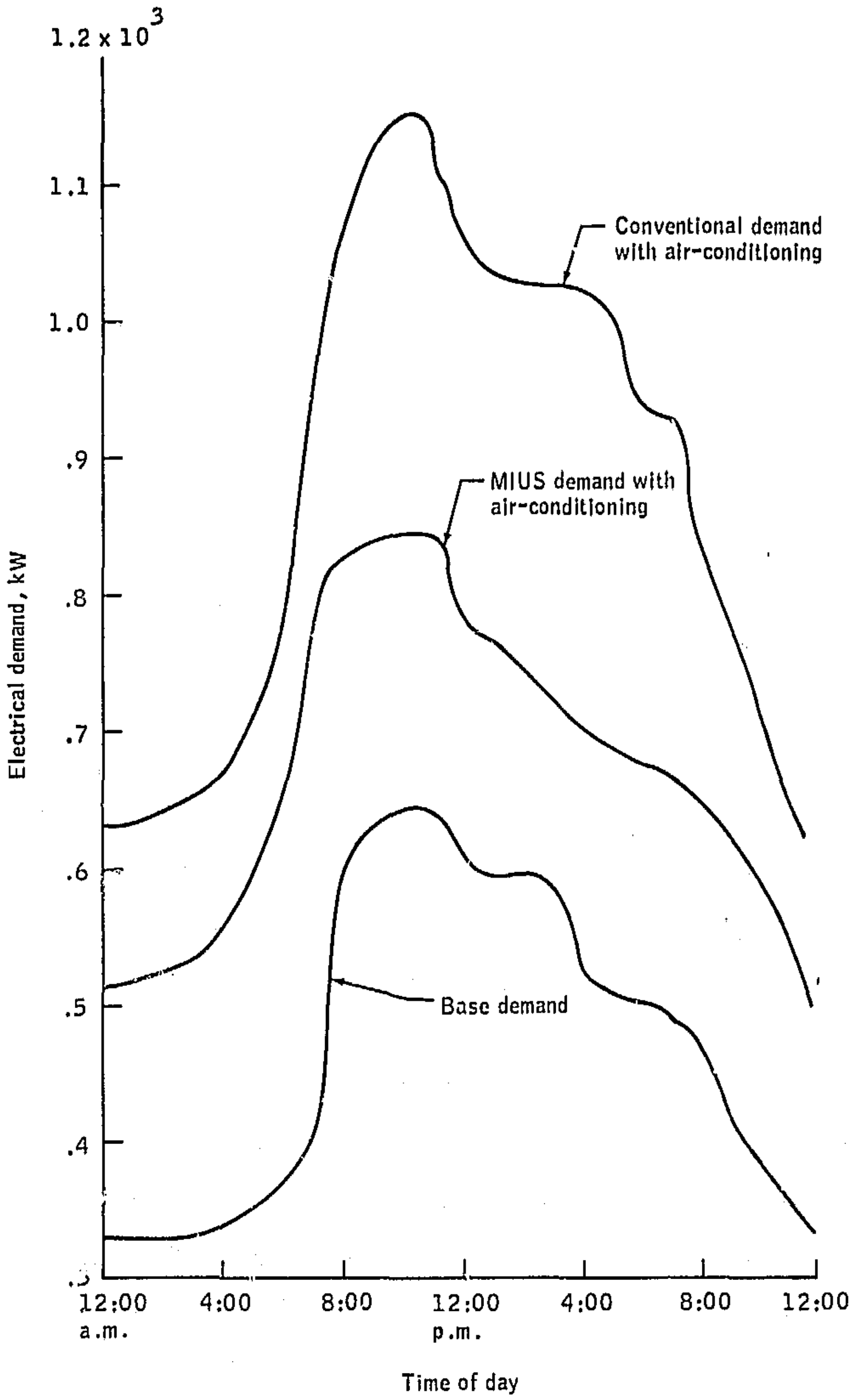


Figure 35.- Hospital project electrical load profiles.

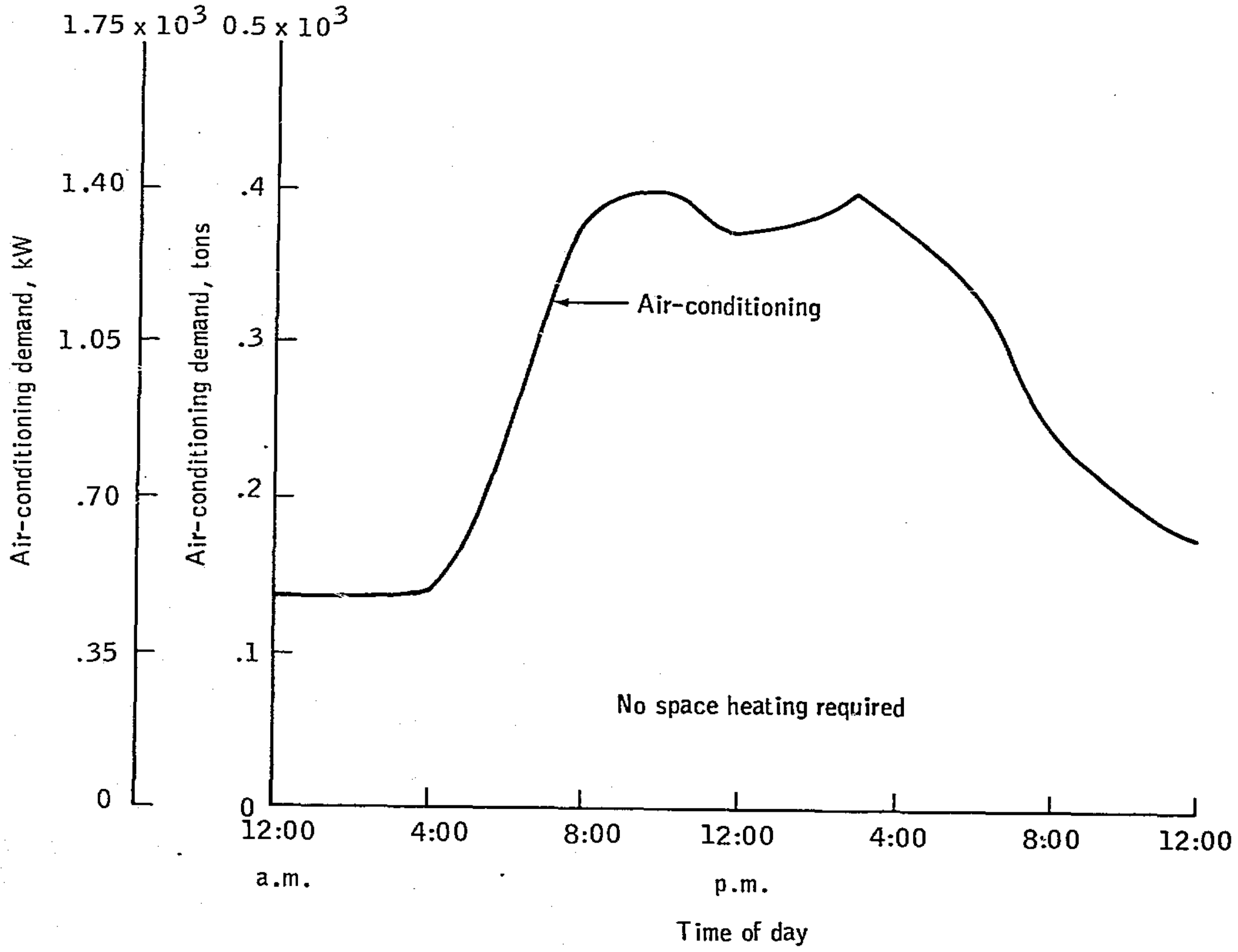


Figure 36.- Hospital project environmental conditioning load profile.

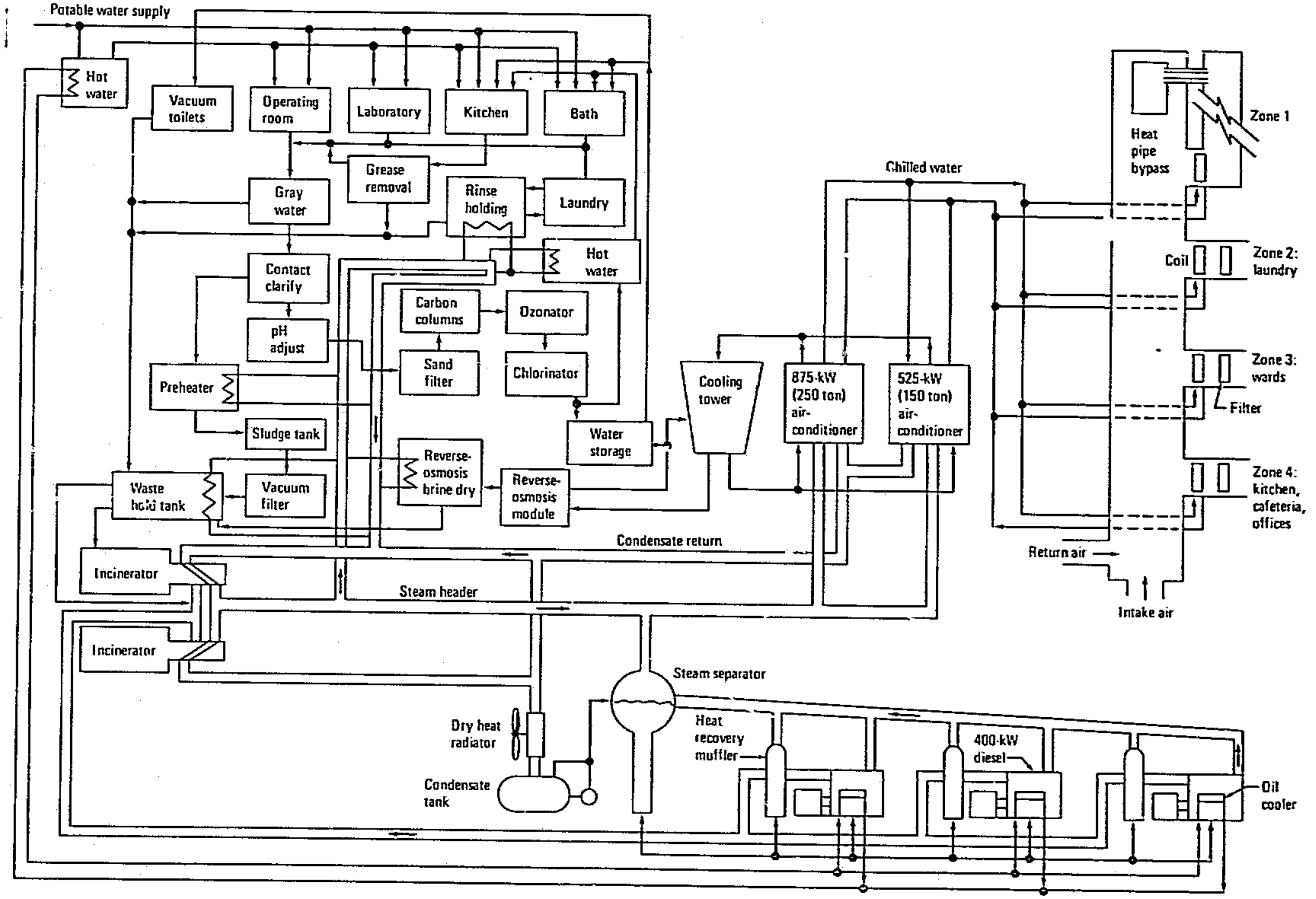
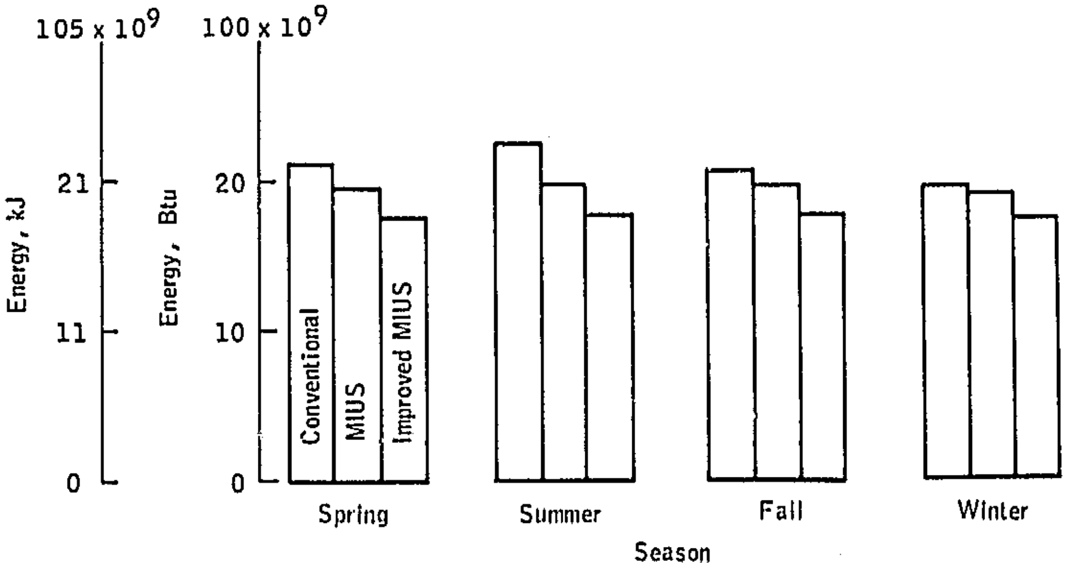
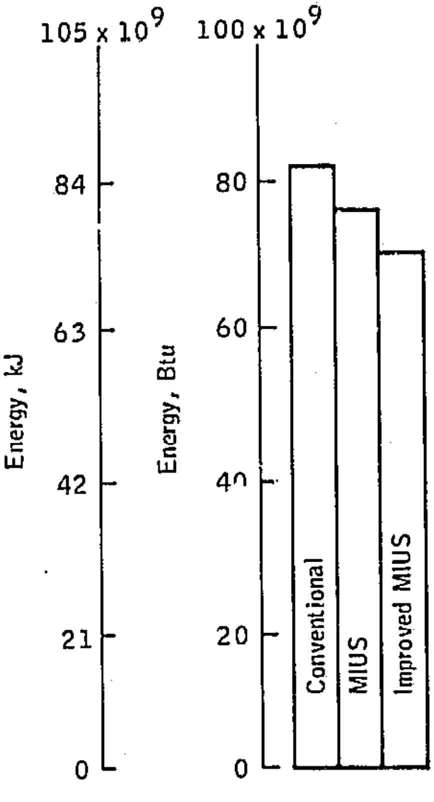


Figure 37.- The 384-bed hospital utilities design schematic.



(a) Seasonal.



(b) Annual.

Figure 38.- Hospital conventional, MIUS, and improved MIUS system energy demand.

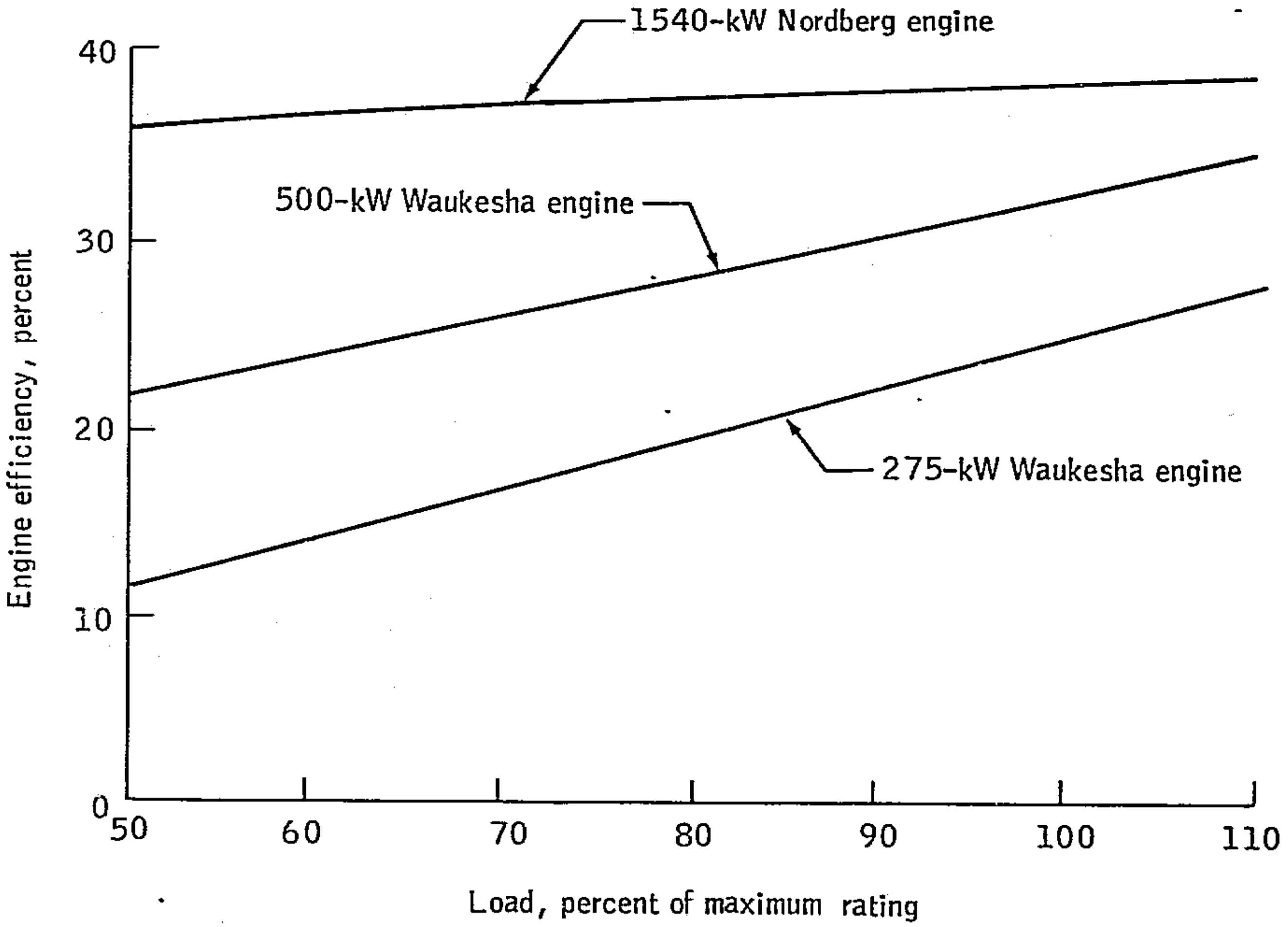


Figure 39.- Power generation efficiency compared to percent of load.

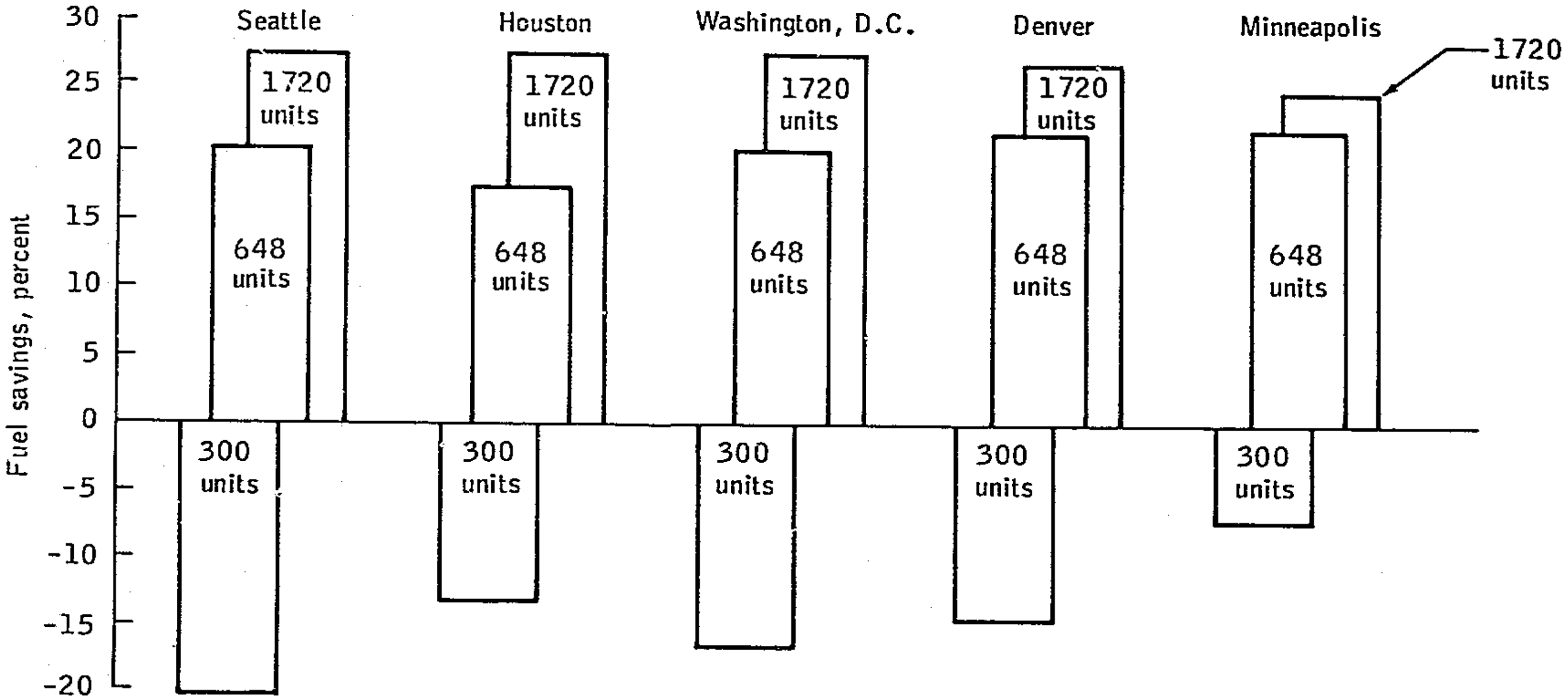


Figure 40.- Percent fuel savings as a function of size and location, based on an average year and best nominal MIUS.

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