COMPUTER PROGRAM FOR ANALYSIS OF ENERGY UTILIZATION IN POSTAL FACILITIES

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ABSTRACT

The accurate calculation of the energy requirements and heating and cooling equipment sizes for buildings is one of the most important, as well as one of the most difficult, problems facing the air conditioning engineer. It is important because energy cost is an essential and significant element of the building's overall owning and operating cost and very likely could be the determining factor in selection of the air conditioning system for a new structure. The problem is difficult because of its complexity. It not only requires accurate determination of the heating and cooling loads, taking into account the varying influences of weather and operating schedules, but also determination of the performance of heating and cooling systems under varying conditions of partial load.

The Computer Program For Analysis of Energy Utilization does all of the above and more. Developed for the U.S. Postal Service for use in design of postal facilities, the computer program is capable of:

1) simulating the thermal response of a building to all sources of heat gains and losses,
2) accounting for all non-thermal energy requirements in the facility or on the sites,
3) translating the building operating schedule into total energy demand and consumption costs, and identify the peak capacity requirements of heating and cooling equipment, and
4) allowing for an economic analysis that would select the most economical total owning and operating cost equipment and energy source (gas, oil, coal, steam or electricity, or combinations).

1. INTRODUCTION

The Problem

The need for rational air conditioning decision has existed since men left the trees to seek refuge in the caves. And systems have been overdesigned since the first cavemen ran out of firewood in early March.

Correct sizing of equipment and the accurate determination of energy requirements has always been difficult, not because the physics or economics is conceptually elusive, but because the task requires a huge amount of computation. For example, the correct prediction of loads on the heating and cooling equipment is important because the maximum loads determine the size, and hence the initial cost, of the system components, while the summation over time of the energy required by the system to meet the load schedule represents a large fraction of system operating costs and may therefore determine the choice of system. If the maximum loads are under-estimated, the equipment may be undersized and fail to do its job, and if the maximum loads are overestimated, the equipment will be larger, and more expensive than necessary. The calculation of heating and cooling loads requires that many factors, including the following, be accounted for.

1) Astronomy of the sun
2) Cloud cover
3) Shadows cast by complex shapes
4) Transient heat transfer in structures
5) Heating and cooling system response
6) Schedules of occupancy, equipment, and lights.

Before the advent of the computer, only a crude heating and cooling energy calculation was practical and the engineer had to rely mainly on his experience. Weather was approximated by degree days, transient heat conduction was approximated by equivalent temperature differentials, and combined radiative/convective boundary conditions were approximated using the sol-air temperature. Heating and cooling equipment was therefore oversized, as a hedge against a poor guess, and energy requirements could not be predicted with enough accuracy for the user to make a rational choice between different systems.

Such inexactness in determining energy requirements and heating and cooling equipment sizes for buildings is rapidly becoming a problem for a number of reasons. Rising construction costs and the increasing value of floor space are driving building owners to insist that equipment be no larger than absolutely necessary. Competition between energy suppliers is stiff and their claims are often conflicting, while energy utilization equipment and methods are more varied now than at any time in the past. Thus, accurate cost comparisons are necessary. Architects and building owners would like the flexibility of knowing quickly and accurately the effects of changes in such factors as design, materials, and building orientation on heating and cooling costs. Not having this information inhibits progress in building design. Last, and perhaps most important, many experts predict an energy shortage which will boost energy costs substantially. Energy requirements, which entail the greatest amount of guesswork in conventional calculations, probably will become the dominant factor in the selection of heating and cooling equipment. A better method is therefore required to accomplish purposes which, although multi-faceted, may be summarized into the following three tasks:

(1) Determine energy requirements so as to: assess operating cost; compare building designs, types of system, and choice of energy source with respect to operating cost; and guarantee adequacy of the system in the face of energy shortages.

(2) Size equipment so as to: insure adequate capacity; eliminate excessive overdesign; assess initial and upkeep cost; and compare building designs, types of system, and choice of energy source with respect to initial and upkeep cost.

(3) Assess total cost so as to: compare building designs, types of system, and choice of energy source with respect to total owning and operating cost; and aid economic planning.

The Solution

Fortunately, modern high speed digital computers make possible the detailed calculations required for rational air conditioning decisions. It is only necessary to code into computer language the well known principles of physics and economics, the implementation of which was previously impractical. This is the philosophy of the present program.

That does not imply that the program includes nothing new. Many problems posed by the load calculation are unsolvable by hand. Mathematical techniques had not been developed for solving these problems because such developments could not be rewarded with a solution. The engineers who wrote the program had to find the appropriate mathematical algorithms and then code them into computer language. For example, no method was available for computing the shapes and areas of shadows cast by objects of arbitrary shape upon surfaces of arbitrary shape. Yet such a method of shadow analysis was required for calculation of heat gain due to solar radiation. The need for parsimony also requires a degree of originality. Load calculations are tedious even by computer standards, so where algorithms for solving a problem already existed, they often had to be streamlined to save computer time and to reduce computer memory requirements. For example, a series truncation technique cut the time required to compute transient heat transfer through a thick wall by more than 50 percent.

The program presented here uses the most advanced techniques known to the modern air conditioning engineer to accomplish the three tasks of air conditioning calculation. It provides the prospective user of air conditioning equipment with a practical tool for comparing the initial and operating costs of various heating and cooling systems so that he may choose the system which in the long run costs him the least.

2. BASIC STRUCTURE OF PROGRAM

The computer program consists of four main sub-programs executed in sequence, with the output of one becoming the input to the next. The function of each sub-program is summarized below.

1) Load Calculation Sub-program. Calculates sensible and latent components of hourly heating and cooling loads, for each space* in the building, for a selected period of time. This sub-program is supported by wall and roof selection sub-sub-programs.

2) Thermal Loads Plot Sub-program. Plots, with the support of the Punch Sub-sub-program, the load profile of any space for any period of time. Comparisons between plots permit the grouping of compatible spaces into fan system control zones**. This grouping is achieved with the help of the Editing Sub-sub-program.

3) Systems Simulation Sub-program. Computes hourly energy requirements from the heating and cooling loads computed by the load program. The System Simulation Sub-program takes into account the ventilation

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* Space is defined as a room or a group of rooms which would be treated as a single load.

** Zone is defined as group of spaces whose loads are closely correlated and which can therefore be lumped together as a single load on the equipment.

air requirements, fan system performance, and the partial load characteristics of the heating and cooling equipment.

4) Economic Analysis. Calculates the annual owning and operating costs of various combinations of heating and cooling plants.

3. LOAD CALCULATION SUB-PROGRAM

The Load Calculation Sub-program, a complex of heat transfer, environment, and geometry subroutines, computes the loads, both heating and cooling, imposed upon the building air conditioning system by each space at each hour. The input to the Load Calculation Sub-program reflects building architecture, building structure, the building surroundings, local weather, and the pertinent astronomy of the sun. The output from the Load Calculation Sub-program consists of hourly weather and psychrometric data and hourly sensible loads, latent loads, return air lighting loads and equipment and lighting power consumption for each space.

The Load Calculation Sub-program consists of a set of subroutines, small programs each of which performs an engineering calculation, and a main program which reads the required data, directs the flow of information from one subroutine to another, and writes the output on paper and magnetic tape. The logic flow chart (Figure 1) shows, schematically, the interrelationship of subroutines within the Load Calculation Sub-program. A brief description of each subroutine is given in Table 1.

Loads are computed on the basis of actual recorded weather data for a selected year, accurate evaluation of heat gain due to solar radiation, and coincident simulation of transient heat transfer in the building's structure. Weather data is taken from magnetic tape available from the U. S. Weather Bureau. Solar radiation is computed by combining hourly sun position and

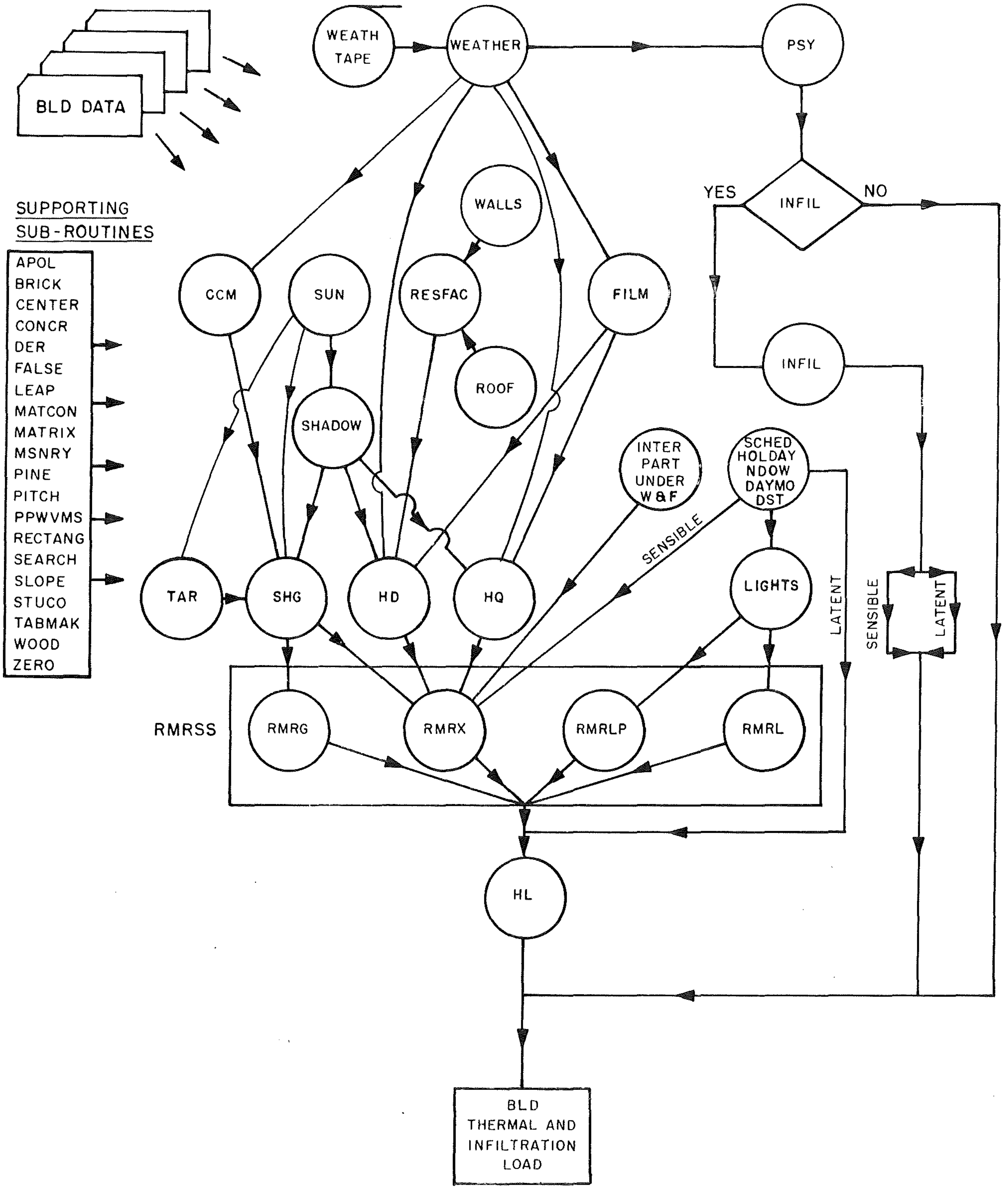


Figure 1 INTERRELATIONSHIP OF LOAD CALCULATION SUB-PROGRAM SUBROUTINES

TABLE 1

LOAD CALCULATION SUB-PROGRAM SUBROUTINES

Name of the Subroutine	Function
APOL	Calculates area and orientation of an irregular surface
CCM	Calculates cloud cover modifier
CENTER	Centers the headings of output
DAYMO	Determines day of month
DST	Determines Daylight Saving Time
FILM	Calculates outside heat transfer film coefficient
HD	Calculates heat gain through slowly responding surfaces (Delayed surfaces)
HL	Calculates sensible and plenum return air heating and cooling load due to a space
HOLDAY	Determines holiday
HQ	Calculates heat gain through quickly responding surfaces (Quick surfaces)
INF	Calculates infiltration air loads due to a space
LEEP	Determines whether the year is a leap-year
NDOW	Determines day of week
PSY and PPWVMS	Calculates psychrometric data
RECTANG	Calculates vertex coordinates of a rectangular surface
RESFAC and DER FALSE MATRIX SLOPE ZERO	Calculates response factors for walls and roofs

TABLE 1 (CONT'D)

Name of the Subroutine		Function
RMRSS	and	Calculates room hourly weighting factors
	RMRG RMRL RMRLP RMRX	
ROOFS	and	Determines thermal and physical properties of a selected roof construction
	MSNRY PITCH WOOD	
SEARCH		Limits shadow pictures to certain times and certain surfaces
SCHED		Determines lighting, people, and equipment schedules
SHADOW	and	Calculates shadow shapes and areas
	MATCON	
SHG		Calculates heat gain through windows
SUN1		Calculates daily data on solar radiation
SUN2		Calculates hourly data on solar radiation
SUN3		Calculates solar data which depends on orientation of a surface
TABMAK		Tabulates output
TAR		Calculates glass absorption and transmission factors
WALLS	and	Determines thermal and physical properties of a selected wall construction
	BRICK CONCR PINE STUCO	
WEATHER		Decodes weather tape

cloud cover with a new procedure for predicting shadows. Transient heat transfer is computed using the Convolution Principle.

Hourly Weather Data

The program uses hourly weather data, obtained on magnetic tape from the U. S. Weather Bureau, to calculate heating and cooling loads. Weather tapes of past years are available for enough weather stations throughout the United States so that a tape is most likely available for a station within 100 miles of the site of any building being considered. The load sub-program (see Section 7) reads the weather tape, as it runs, to realistically simulate the changing meteorological conditions to which the building is continuously exposed. The data read from the weather tape and a brief summary of the uses to which they are put are listed below.

- Dry-bulb temperature (used in computing heat transfer and sensible loads)
- Wet-bulb temperature (used in computing humidity ratio and latent loads)
- Wind velocity (used in computing outside surface heat transfer film coefficient)
- Barometric pressure (used in computing density of air)
- Cloud type and amount (used in computing heat gain and heat loss by radiation between the building and the sky)

Hourly Solar Radiation Data

The amount of heat gained by the building through an exterior surface (roof, exterior walls, or window) depends upon the radiant environment to which the surface is exposed. This radiant environment may be simulated more accurately by a computer than by hand calculations because the computer can evaluate the components of radiant environment on an hourly basis. The program makes hourly calculations of the following components of the radiant environment for each exterior surface:

- angle of incidence of the sun's rays
- direct normal intensity
- brightness of sky and ground
- re-radiation to sky
- shadows cast upon the surface.

By combining these data with such constants of the surface as emissivity, shape factor between surface and sky, and shape factor between surface and ground, the program arrives at hourly radiation fluxes in Btu/hr.

The Convolution Principle

The program takes account of heat storage in the building's structure by a mathematical device called the convolution principle. The example of heat gain through a thick wall will illustrate how the convolution principle works.

The value of heat gain (Q) into the building through a thick wall, for a constant inside air temperature, depends on the present value, and the past history, of the temperature difference (ΔT) between the inside air and the outside surface of the wall. In other words, the graph of the schedule of Q versus time (t) depends on the graph of the schedule of ΔT versus t (see Figure 2).

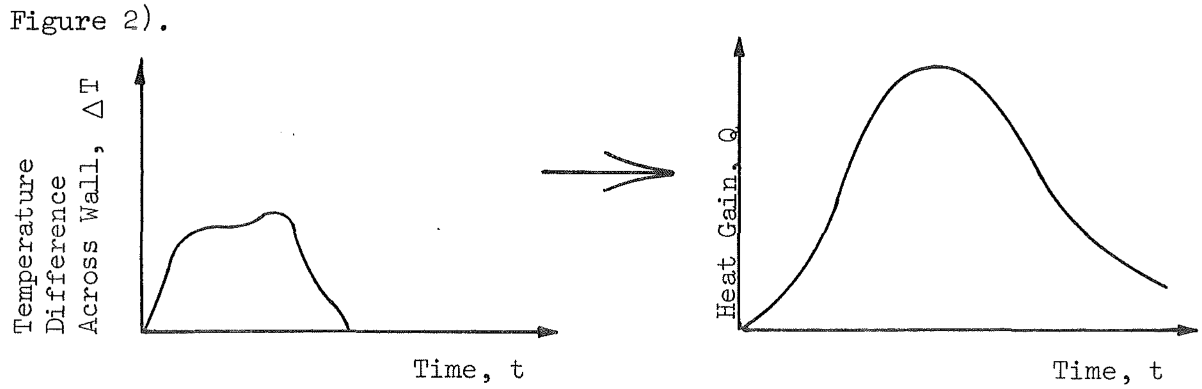
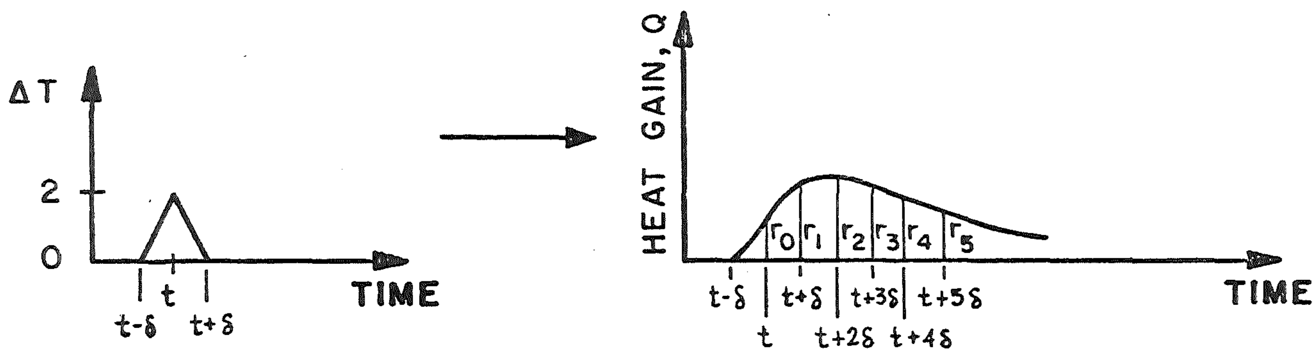


Figure 2 DEPENDENCE OF HEAT GAIN SCHEDULE ON TEMPERATURE DIFFERENCE SCHEDULE

Were it necessary to compute Q for each hour, on the basis of the hourly history of ΔT, the differential equation of heat conduction would have to be repeatedly solved by numerical methods, and the computation time would be prohibitive even with a fast computer. Fortunately, the problem can be simplified so that Q need be determined as a function of t for only one temperature difference schedule. The one temperature difference schedule for which the program must compute a heat gain schedule is called the triangular pulse, and the values of Q which the triangular pulse elicits, at successive equal time intervals after the peak of the pulse, are called the response factors (r_0, r_1, r_2, ...) of the wall (see Figure 3).

Any arbitrary schedule of ΔT (Figure 4a) may be squared off to give a schedule (Figure 4b) of approximate temperature differences, $\Delta T'$, whose values agree with those of ΔT at integral multiples of the time interval, δ. This schedule of approximate temperature differences, $\Delta T'$, may be resolved into a series of triangular pulses (ΔT_1, ΔT_2, ΔT_3, ΔT_4, and ΔT_5 of Figure 4c) which, when added together, give exactly $\Delta T'$. Each of these component pulses has a base width, or duration, of 2δ, a peak occurring at each integral multiple of δ, and a height equal to the value of $\Delta T'$ at the time of the pulse's peak. Each such pulse alone would elicit its own schedule of heat gains as shown in Figures 4d, 4e, 4f, 4g, and 4h. The pulse ΔT_1, for example, would elicit the heat gain schedule Q_1 (see Figure 4d), the pulse ΔT_2 would elicit Q_2 (see Figure 4e) and so on. The heat gain schedules elicited by the individual pulses are all the same except for two differences. Their heights are proportional to the heights of the pulses which elicit them, and each is moved to the right, on the time axis, as far as the pulse which produced it.

The values of the individual responses, Q_1 ... Q_5, may be added, at each value of time, to give the curve of sums (Figure 4i). A mathematical principle



T = OUTSIDE SURFACE TEMPERATURE

T_o = INSIDE AIR TEMPERATURE

$\Delta T = T - T_o$

Figure 3 HEAT GAIN SCHEDULE FOR A TRIANGULAR TEMPERATURE PULSE SHOWING RESPONSE FACTORS

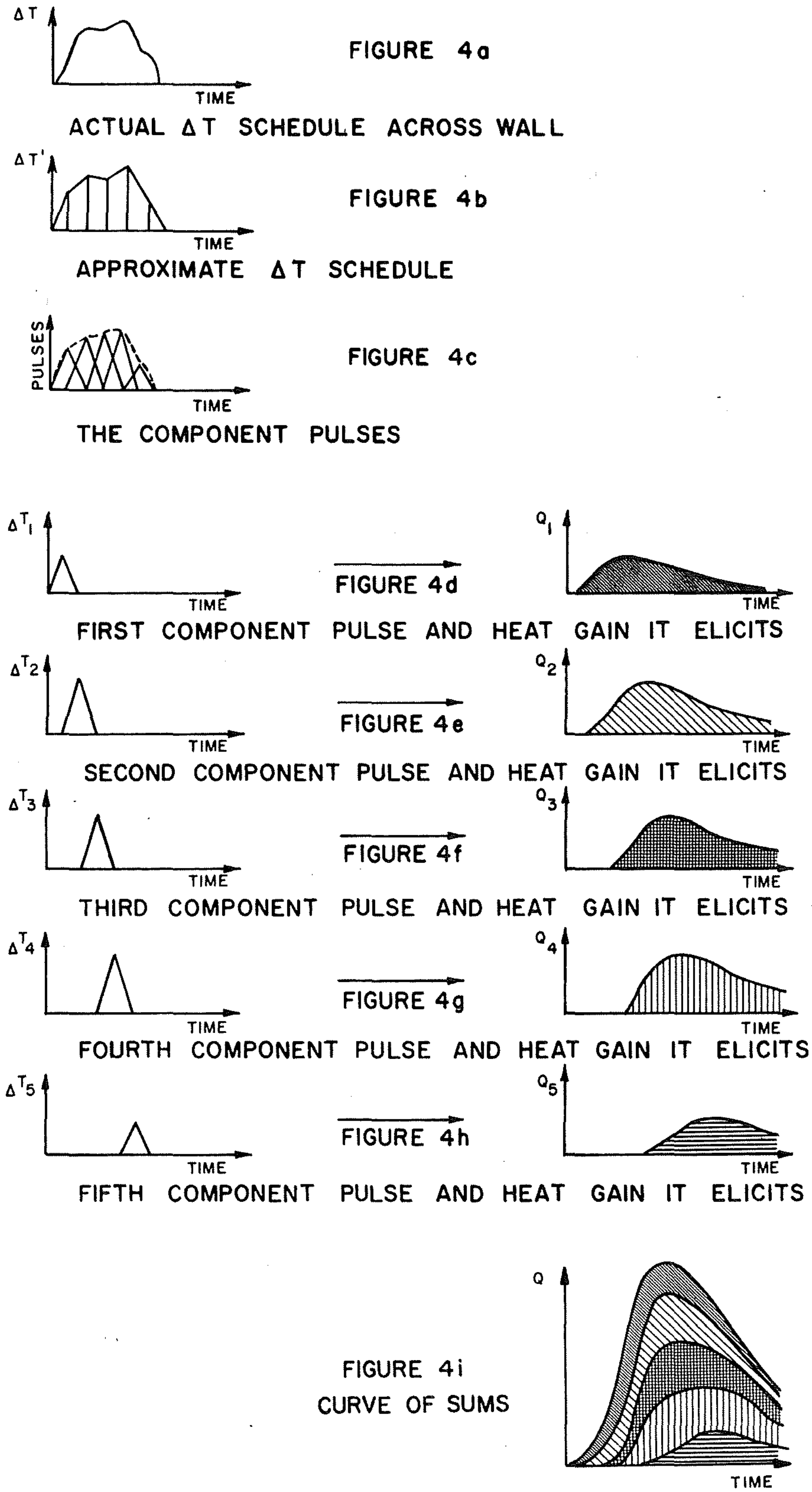


Figure 4 THE CONVOLUTION PRINCIPLE

known as the superpositon theorem asserts that the curve of sums is exactly the heat gain schedule which would be elicited by the approximate temperature difference schedule, $\Delta T'$. Due to the smoothing effect of the heat transfer process, ΔT and $\Delta T'$ give nearly the same heat gain schedule. Therefore the curve of sums is very nearly the heat gain schedule elicited by the original temperature difference schedule, ΔT. This method of resolution and recombination is called the convolution principle.

To the air conditioning engineer, the convolution principle means that the difficult problems of transient heat transfer can be solved, for each simulated hour, by adding and multiplying very few numbers. The convolution principle, as applied to heat gain through a thick wall, is expressed mathematically by the equation

$$Q_j = \sum_{i=0}^{n} r_i \Delta T_{j-i} \tag{1}$$

where: Q_j equals the heat gain at the hour j; ΔT_{j-i} equals the temperature difference i hours previous to hour j; r_i equals the i^{th} response factor for the wall; and n equals the number of hours of the temperature difference history which significantly effect Q_j. Notice that the response factors are the only information about the wall which appears in equation 1 . Thus, the response factors characterize completely the thermal properties of the structure of the wall and, alone describe how the structure absorbs and releases heat over a prolonged period of time.

The program allows the user to specify either actual thermal data - that is, layer by layer thicknesses, conductivities, and specific heats - which the program will convert to response factors, or the response factors themselves. Tables of response factors are now available for a variety of structures.

Where neither the layer by layer thermal data nor the response factors of a wall or roof are known, a feature is available to generate approximate response factors from these simplified data: U-factor; conditions (summer or winter) to which the U-factor applies; material of outside layer, and thickness of insulation, if present. The wall and roof construction subroutine works by selecting a wall or roof construction from a stored library of constructions standardized by ASHRAE, to fit the simplified data. The load program uses the response factors of the selected construction.

A cost saving feature of the load sub-program is the use of a subtle modification of equation 1 which allows n to equal infinity while saving a good deal of computer time. That is, all previous hours of the temperature difference schedule are taken into account - very inexpensively.

The load sub-program uses the convolution principle for the following three purposes.

1) To compute the exterior surface temperature of a thick wall at each simulated hour on the basis of past temperatures and present radiation and convection data.

2) To compute heat gain as already described.

3) To compute the time delay between heat gain to a space and the resulting loads on the air conditioning system. In this last case, the series of numbers which characterizes the structures (room furnishings, floors, partitions) are called room weighting factors, rather than response factors.

To summarize, the convolution principle is used by the load sub-program to simulate, with great accuracy, the transient heat conduction taking place within the structures of the building. Various experiments with the program indicate that the convolution principle, when used in heating and cooling load calculations, gives more realistic values of the maximum loads and more accurate estimates of the times of their occurrence. For example, the program shows that maximum cooling loads occur several hours after the hottest time of the day, at which time some buildings are unoccupied. For practical purposes, this means that the equipment specified with the help of the program will be smaller than equipment specified as a result of hand computation, and that the elusive demand figures for utility services can be determined accurately, allowing a realistic estimation of energy costs.

4. THERMAL LOADS PLOT SUB-PROGRAM

One of the initial tasks performed by the engineer in preparing his input for the Load Calculation Sub-program is the breaking of the building into spaces*. One engineer might carry the task to extremes and call every room a space, while another engineer might combine several rooms into a space because he knows from past experience that these rooms will have similar load profiles.

Before running the Systems Simulation Sub-program (Section 7), again, the engineer must give consideration to the definition of areas within the building but this time in terms of fan zones rather than spaces. More often than not, especially in large buildings, several spaces will be grouped and controlled off of one thermostat. We speak of the area being controlled by a thermostat as a fan zone. Economic considerations tell us to use as few thermostats and fan systems as possible, but comfort considerations tell us otherwise. Through the use of the Thermal Loads Plot Sub-program, the engineer can call for load profile plots for any or all spaces and thereby graphically compare the profiles to determine compatible grouping of spaces into zones.

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* See page 4 for definition.

If, initially, care was taken to break the building directly into fan zones, use of the Thermal Loads Plot Sub-program would probably not be required. If, however, it is decided to define fan zones differently from spaces, then use can be made of the Editing Sub-sub-program to combine and reorder the output tape from the Load Calculation Sub-program and create a new tape of format compatible for use by the Systems Simulation Sub-program.

In summary, use of the Thermal Loads Plot Sub-program gives the engineer a tool whereby he can more rationally set up fan zones within a building.

5. SYSTEMS SIMULATION SUB-PROGRAM

The Systems Simulation Sub-program performs three important tasks:

(1) Sizes energy-consuming heating and cooling equipment (chillers, boilers, pumps, cooling towers, etc.) and fan systems using peak zone and peak building heating and cooling loads determined by the Load Calculation Sub-program.

(2) For each hour of the analysis, sums together zone thermal loads and ventilation air loads through use of the characteristics of each fan system to obtain the hourly output requirements that must be provided by the heating and cooling plants.

(3) Through the use of part load performance data from typical systems, converts the thermal requirements into energy requirements.

Since the types of buildings constructed by the Postal Service range in size from 10,000 square feet all the way up to several million square feet, the System Simulation Sub-program has been broken into two parts: the Central System Simulation Sub-program, for large buildings (usually with floor areas 35,000 square feet and larger), and the Packaged System Simulation Sub-program, for small buildings (usually with floor areas less than 35,000 square feet) where the Postal Service generally uses packaged or unitary equipment. The Central System Simulation Sub-program is capable of simulating the following thermal distribution systems (earlier referred to as fan systems).

- Single Zone System
- Multi-Zone System
- Dual-Duct System
- Unit Ventilator
- Unit Heater
- Single Zone Reheat System
- Radiant Floor Panel Heating

To simulate these systems is meant to imitate the action of the control system in order to realistically determine the heating and/or cooling requirement that the distribution system is demanding from the heating and cooling plant for the hour under consideration. The distribution system control schedules used in the program are particularly suited to Postal Service specifications.

The heating and cooling plant combinations within the range of the Central System Simulation Sub-program include the following:

(1) Conventional Systems

- Hermetic Reciprocating Chiller with Gas, Oil, or Steam Heat
- Hermetic Centrifugal Chiller with Gas, Oil, or Steam Heat
- Open Centrifugal Chiller with Gas, Oil, or Steam Heat
- Steam Absorption Chiller with Electric or Steam Heat

(2) Total Electric System

- Hermetic Reciprocating Chillers with Electric Heat
- Hermetic Centrifugal Chiller with Electric Heat

- Open Centrifugal Chiller with Electric Heat

(3) Total Gas Systems

- Steam Absorption Chiller with Gas Heat
- Steam Turbine-Driven Open Centrifugal Chiller with Gas Heat

(4) Total Oil Systems

- Steam Absorption Chiller with Oil Heat
- Steam Turbine-Driven Open Centrifugal Chiller with Oil Heat

(5) On-Site Generation Systems

- Total Gas with Steam Absorption Chiller, Gas Heat and Gas Engine-Generation Sets
- Total Oil with Steam Absorption Chiller, Gas Heat and Diesel Fuel Engine-Generation Sets

The Packaged Systems Simulation Sub-program is capable of analyzing the following systems:

(1) Electric Air Conditioning (DX Coil) with Gas Heating

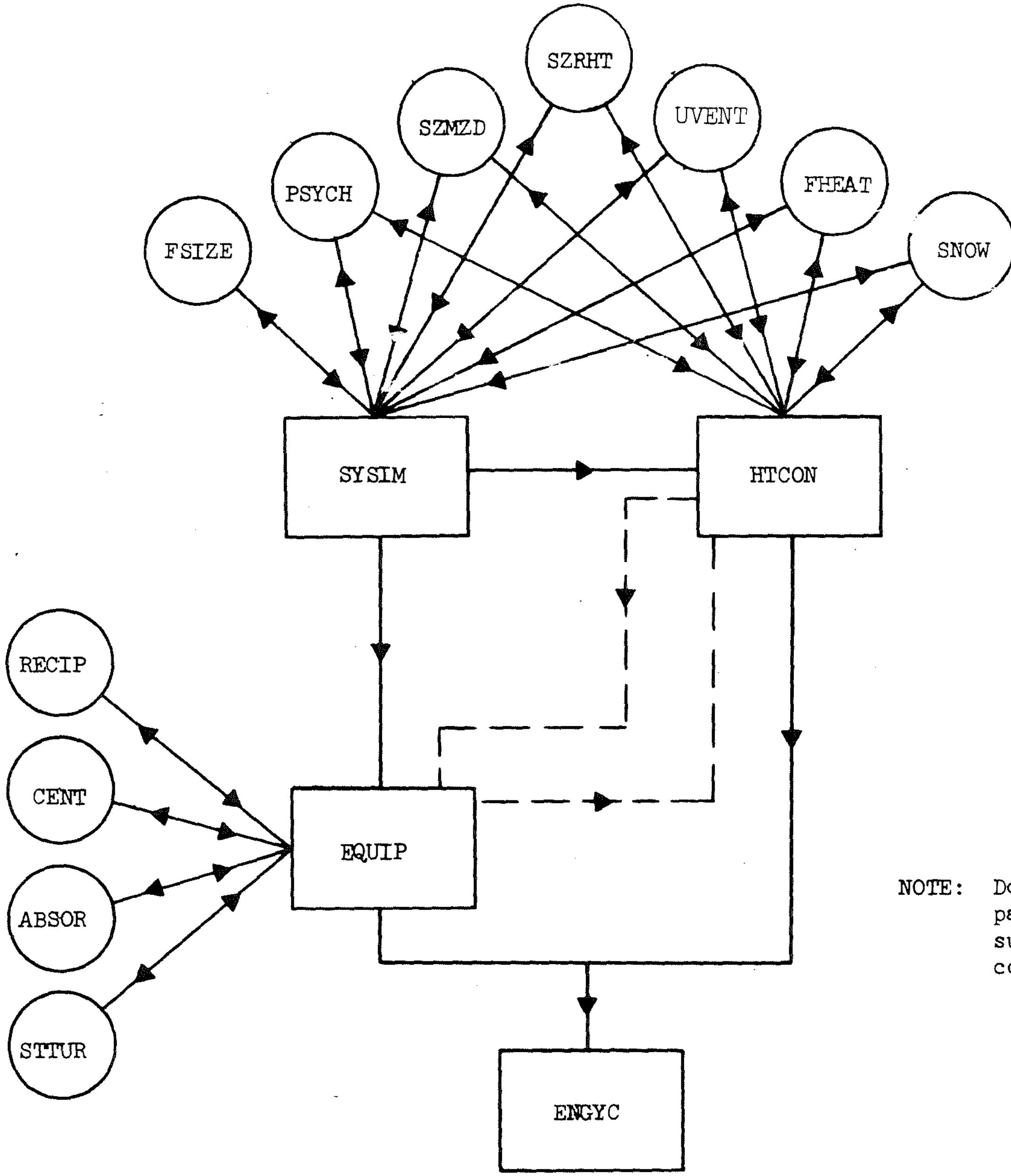
(2) Electric Air Conditioning (DX Coil) with Oil Heating

(3) Reversible Cycle Heat Pump with Electric Resistance Heating

(4) Gas Air Conditioning with Gas Heating

For the above-mentioned heating and cooling systems, simulation here not only entails imitating the action of the overall control systems, but also the simulating of the part load performance characteristics so that an accurate estimate of the unit's energy consumption can be made.

Taking a closer look at the structure of the Systems Simulation Sub-program reveals that it is actually made up of 15 smaller programs or subroutines. Table 2 gives a short description of each subroutine and Figure 5 illustrates their logical interrelationship. Subroutine SYSIM directs the flow of logic through the sub-program and controls the order in which calculations are to be performed. The sequence of calculations is generally as follows.



NOTE: Dotted line indicates path of logic taken for summer operation of heat conservation machines.

Figure 5 INTERRELATIONSHIP OF SYSTEM SIMULATION SUB-PROGRAM SUBROUTINES

TABLE 2

SYSTEM SIMULATION SUB-PROGRAM SUBROUTINES
AND THEIR FUNCTION

NAME OF THE SUBROUTINE	FUNCTION
SYSIM	Controls the operation of the entire Systems Simulation Sub-program by executing the subroutines in their proper order.
FSIZE	Sizes the air flow quantities for each fan zone.
HTCON	Simulates the operation of the heat conservation system.
SZRHT	Simulates the operation of single zone/reheat fan system.
SZMZD	Simulates the operation of single zone, multi-zone and dual-duct fan systems.
UVENT	Simulates the operation of unit ventilator and unit heater systems.
FHEAT	Simulates the operation of floor panel heating systems.
PSYCH	Calculates the psychrometric properties of moist air.
EQUIP	Simulates the operation of heating and cooling central systems and on-site generation systems.
RECIP	Simulates the operation of reciprocating water chillers.
CENT	Simulates the operation of hermetic centrifugal water chillers.
ABSOR	Simulates the operation of steam absorption water chillers.
STTUR	Simulates the operation of steam turbines.
SNOW	Simulates the operation of snow-melting systems.
ENGYC	Prints out annual energy consumption summary in a form similar to POD Form No. 2215.

1) The zone air flows are sized using the peak hourly heating and cooling zone loads.

2) The central heating and cooling plant components (chillers, boilers, pumps, etc.) are sized based upon the peak building heating and cooling loads.

3) An hour-by-hour analysis of the building's thermal distribution systems is performed. Each distribution system is examined individually and the hourly heating and/or cooling requirements calculated and summed to give the total demand that is being placed on the central plant.

4) At the end of an hour's calculation, after the last distribution system has been examined, the EQUIP subroutine is called upon to convert the total thermal requirements into hourly energy requirements based upon the type of equipment under investigation.

5) At the end of the analysis period, a monthly summary of the building's energy consumption is printed.

A more detailed explanation of this output, as well as others extracted from the Systems Simulation Sub-program, is given in Section 8.

6. ECONOMIC ANALYSIS SUB-PROGRAM

The Economic Analysis Sub-program determines the annual owning and operating cost by taking into account all life cycle costs for each heating/cooling combination analyzed by the Systems Simulation Sub-program. Life cycle costs are those expenditures which occur either singularly or periodically over the life of the building and include cost of energy, cost of equipment in terms of first costs and replacement costs which occur if the expected life of the equipment is less than that of the building, cost of maintenance (material and labor), cost of periodic overhaul (material and labor), salvage value of equipment at the end of building life, and costs of floor space which might result due to the unavailability of space occupied by equipment for other purposes.

The only aid that the program gives the engineer in estimating these life cycle costs for input to the Economic Analysis Sub-program is in the area of energy cost and equipment cost. Energy costs can be determined using the monthly energy consumption summary from the Systems Simulation Sub-program and utility rate schedules for the locale in which the building is to be situated. Equipment costs can be obtained from equipment supplier based upon the equipment quantities and capacities supplied by the Systems Simulation Sub-program. All other life cycle costs must be estimated by the engineer based upon operating practices and procedures of the agency for which the building is being constructed. Once the life cycle costs have been accumulated and entered into the Economic Analysis Sub-program, the sub-program then proceeds to determine the present value of all life cycle costs over the expected life of the building and calculate the total owning and operating annuity which is construed to mean the uniform annual cost, considering all life cycle costs, to the owner during the life-time of the building.

7. SEQUENCE OF SUB-PROGRAM USE

The sequence of using sub-programs depends upon the information the engineer wishes to obtain and if he can initially break the buildings into fan system control zones rather than just spaces. Figure 6 illustrates the paths of sub-program sequencing that can be taken as a function of the engineer's decisions. As the engineer becomes more adept at breaking a building directly into control zones, the need for space load plots and/or re-grouping of spaces will diminish.

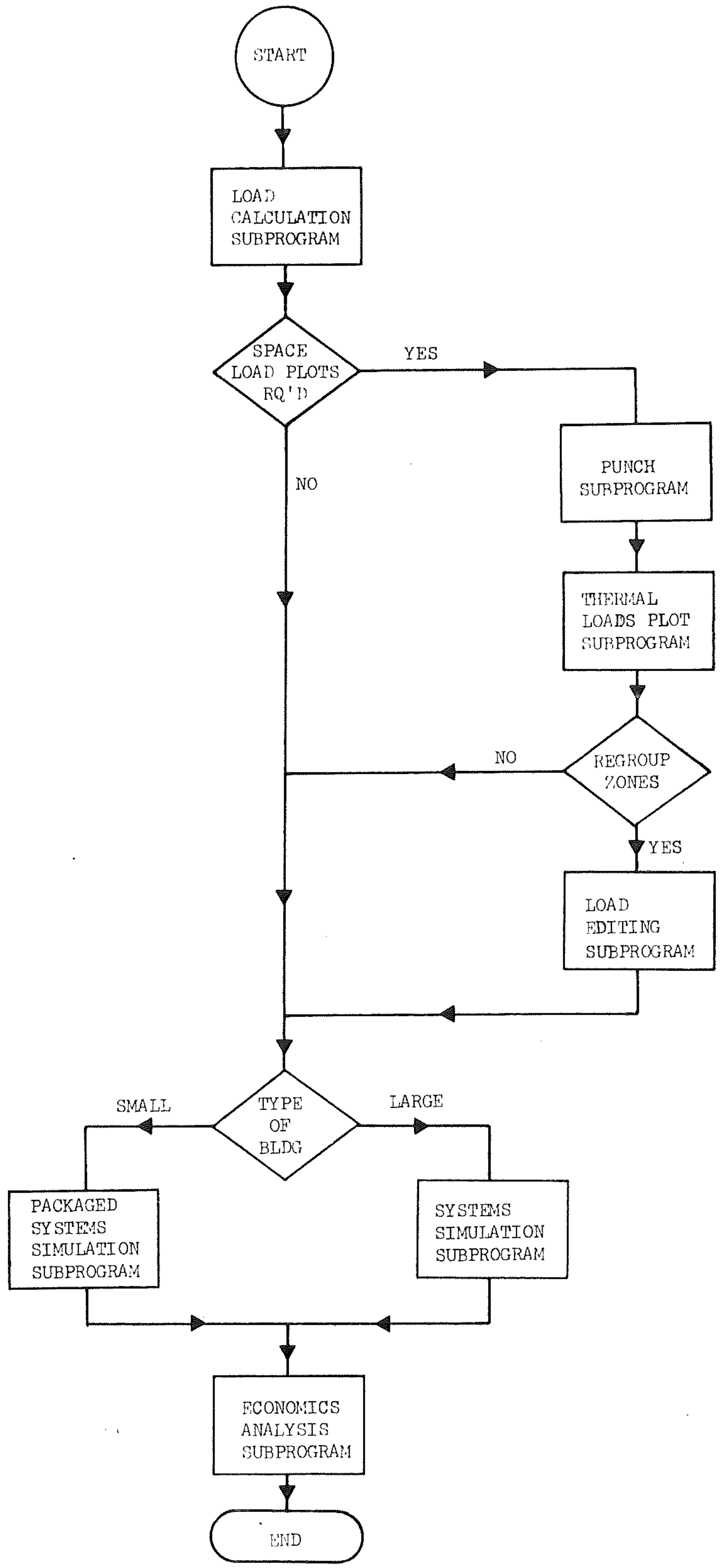


Figure 6 THE PATHS OF SUB-PROGRAM SEQUENCING

The card input data required by some of the sub-programs cannot be prepared until the output of another sub-program has been examined. For example, the proper grouping of spaces into control zones, and then control zones into fan systems required for the Systems Simulation Sub-program, probably cannot be done until the results of the Thermal Load Plot Sub-program are reviewed to establish which spaces have similar load profiles. Neither can monthly energy costs be calculated and inputted to the Economics Analysis Sub-program until the monthly energy consumption summary has been received from the Systems Simulation Sub-program. Nor can the engineer collect the necessary equipment cost data required by the Economics Analysis Sub-program until the Systems Simulation Sub-program tells him the quantity and capacity of the chillers, boilers, cooling towers, etc.. Figures 7 and 8 illustrate the dependence of input upon output for small and large buildings, respectively. For small buildings, where use of all sub-programs is probably not required, the engineer can elect to use only the Load Calculation Sub-program, the Packaged Systems Simulation Sub-program, and the Economics Analysis Sub-program. If experience indicates no need for economic evaluation of fuels, energy and equipment variations, then the engineer can elect to run only the Load Calculation Sub-program for the peak heating and cooling months. This would indicate maximum and minimum heating and cooling requirements for proper capacity equipment selection.

8. INPUT AND OUTPUTS OF EACH SUB-PROGRAM - EXAMPLE

Load Calculation Sub-program

The input to the Load Calculation Sub-program includes on tape, the weather data, and on cards, the geometry of the building and its surroundings; the thermal properties of wall and roof construction; the type and orientation of windows; and the operating schedules of occupancy, lighting, and equipment.

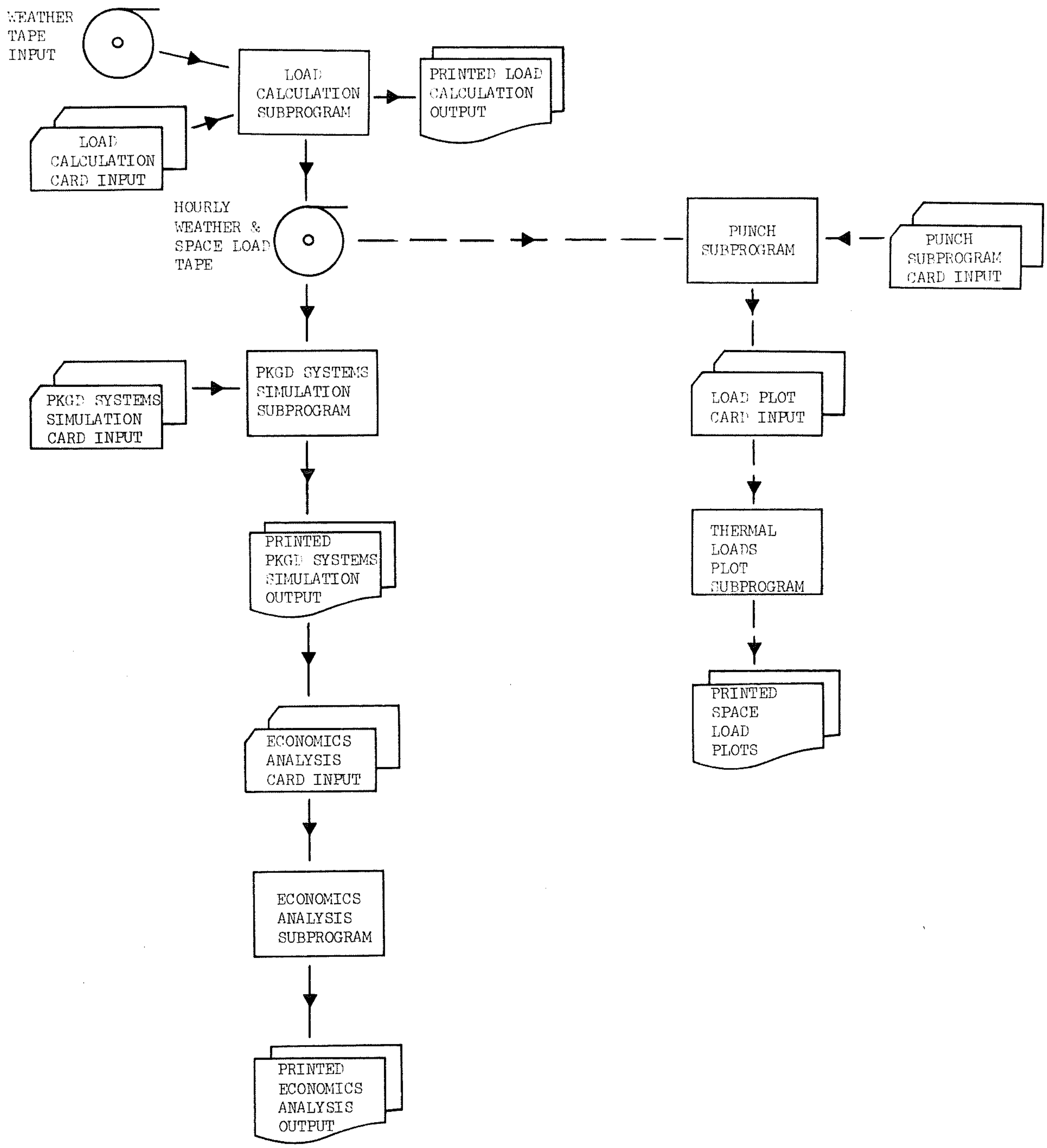


Figure 7 ANALYSIS OF SMALL BUILDINGS

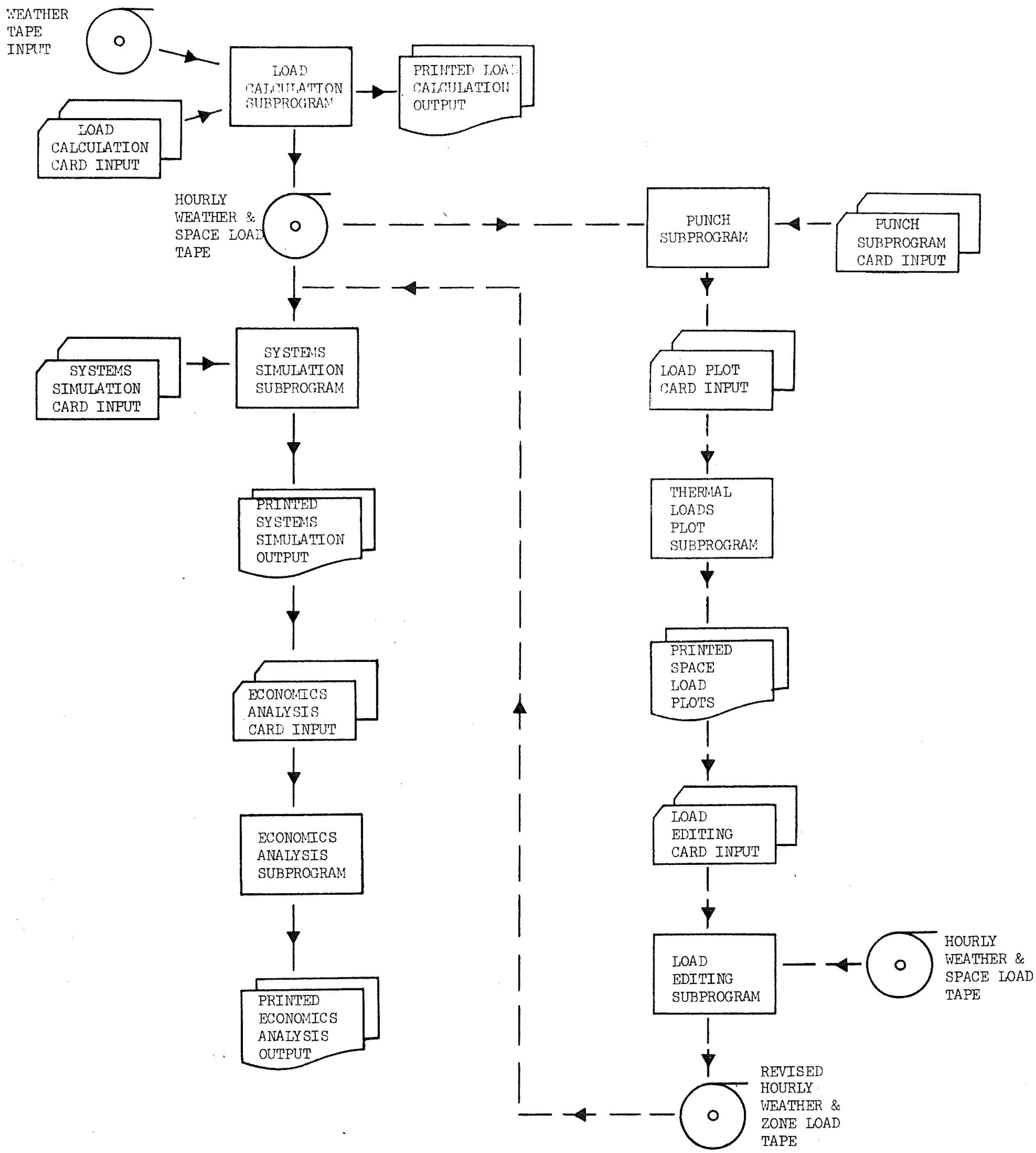


Figure 8 ANALYSIS OF LARGE BUILDINGS

The output from the Load Calculation Sub-program is well illustrated by the example: the GARD building located in Niles, Illinois was run through the program. Figures 9, 10 and 11 show the building's exterior; the configuration of the penthouse and cooling tower on the roof; and the floor plan, indicating overall dimensions and the eight spaces into which the building was broken for the analysis.

The mandatory output received from the Load Calculation Sub-program includes the building identification (Figure 12), weather year information and length of study (Figure 13), the building thermal and infiltration loads summary (Figure 14) indicating the peak heating and cooling loads that occurred for the weather year under investigation, and the space maximum and minimum heating and cooling loads summary (Figure 15). The Load Calculation Sub-program also creates an output tape on which is summarized for each hour of the year: the hour number; sun index; dry-and wet-bulb temperatures; wind velocity; humidity ratio; pressure; enthalpy and density of outside air; and for each space: the space number, space sensible load, space latent load, plenum return air lighting load, and the power consumption for lights and equipment.

Optional output from the Load Calculation Sub-program includes wall and roof specifications (Figures 16 and 17) for a given maximum U-factor, listing of data on load tape (Figures 18 and 19), and shadow pictures. Figures 20, 21, and 22 illustrate the shadow pictures for various building surfaces at the hour designated.

<u>Thermal Loads Plot Sub-program</u>

The inputs to the Thermal Loads Plot Sub-program are the space number, the number of days to be plotted, the starting date, and the tape output of the load program.

The output is a strip chart graph (Figure 23) detailing the heat gain or loss for each hour plus the maximum heat gain or loss for the period.

Systems Simulation Sub-program

The inputs to the Systems Simulation Sub-program are the output tapes of the Load Calculation (or Editing Support) Sub-program, the fan system characteristics, the chiller operating characteristics, and the types of heating/cooling combinations and energy sources to be analyzed. To illustrate the output of the Systems Simulation Sub-program, the air conditioning system contained within the GARD building was simulated. Figure 24 schematically shows the system which is a high pressure dual-duct air distribution system with a central gas boiler for heating and a centrifugal water chiller for cooling.

Figures 25 through 28 show the outputs of the System Simulation Sub-program for the GARD building analysis. Fan system characteristics and supply air requirements for each fan system and control zone within the building are summarized in Figures 25 and 26. The sources of the numbers appearing on these outputs are as follows:

(1) type of fan system - input

(2) fan brake horsepower - calculated, based upon fan total pressure (input) and total air quantity circulated by fan

(3) number of zones - input

(4) set-point temperature - input, assumed to apply to all zones of the fan system

(5) total air flow - the sum of the zone supply air requirements which are calculated based upon actual peak heating and cooling loads determined by the Load Calculation Sub-program and ventilation air requirements.

(6) minimum outside air - calculated, based upon USPS standards of 10% of circulated air or one air change, whichever is greater, plus exhaust air requirements.

(7) exhaust air quantities - input

(8) percent ventilation air - calculated as the ratio of minimum outside air quantity to total air flow.

Figure 27 summarizes the heating, cooling and distribution equipment sized by the program for use in estimating hourly energy consumptions. The type of chiller and boiler is chosen by the engineer and inputted to the program, thus allowing the program to size this equipment as well as pumps, cooling towers and other energy consuming equipment. No fudge factors or safety factors are used in sizing equipment. The actual peak building heating and cooling requirements calculated by the Load Calculation Sub-program with ventilation air requirements added to them, are used to size all components.

Figure 28 illustrates the energy consumption summary that is received from the Systems Simulation Sub-program. Each month, for the duration of the analysis, the consumption and demand figures for each energy source used in the building is summarized. At the top of the table, energy consumption is summarized in terms of Btu's of heating and cooling that the boiler and chiller had to provide to the building during each month. By means of this energy consumption summary and local energy rate schedules, these data can be turned into estimates of dollars.

Economic Analysis Sub-program

The inputs to the Economic Analysis Sub-program are the monthly energy costs, the installed equipment costs, equipment life, maintenance and overhaul costs, and anticipated annual percentage increase of labor and material.

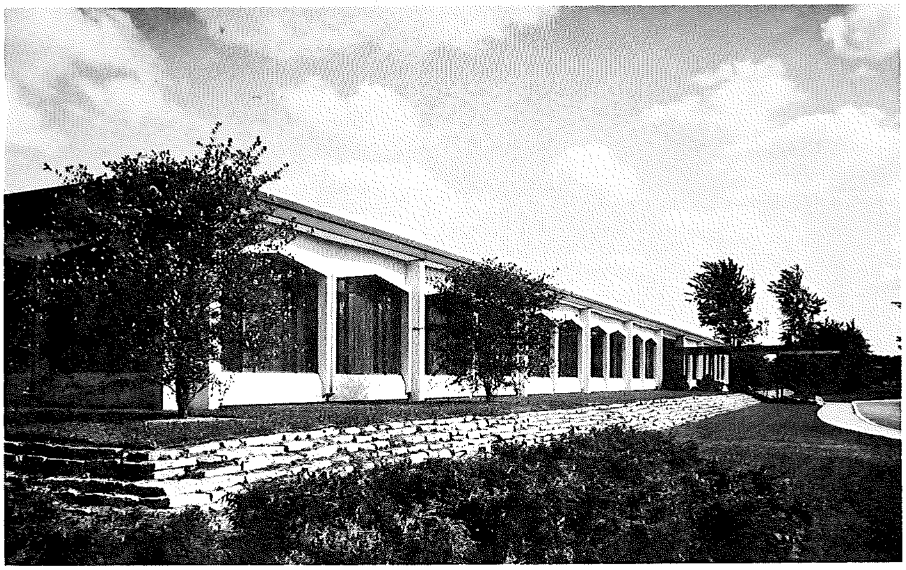


Figure 9 GARD BUILDING

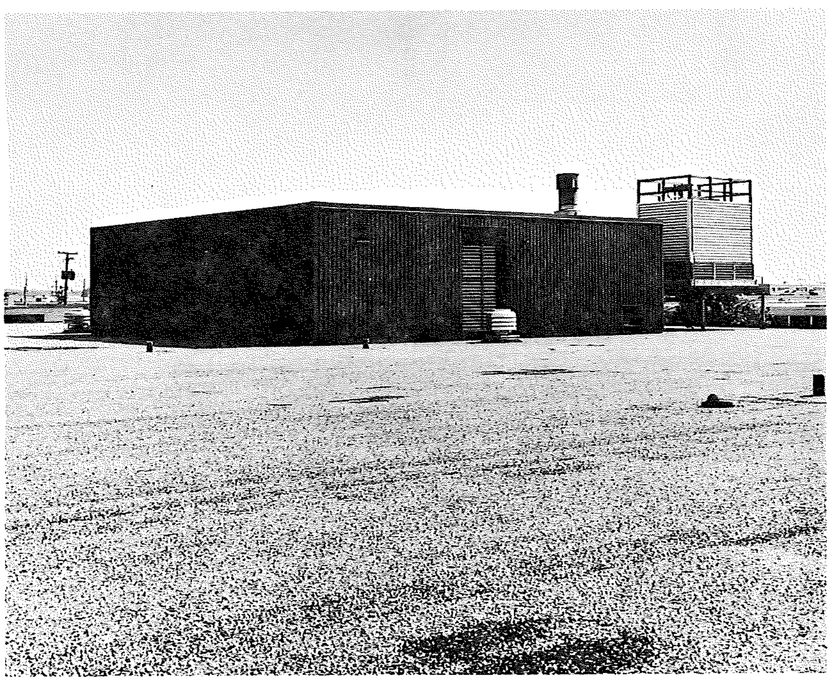


Figure 10 PENTHOUSE AND COOLING TOWER

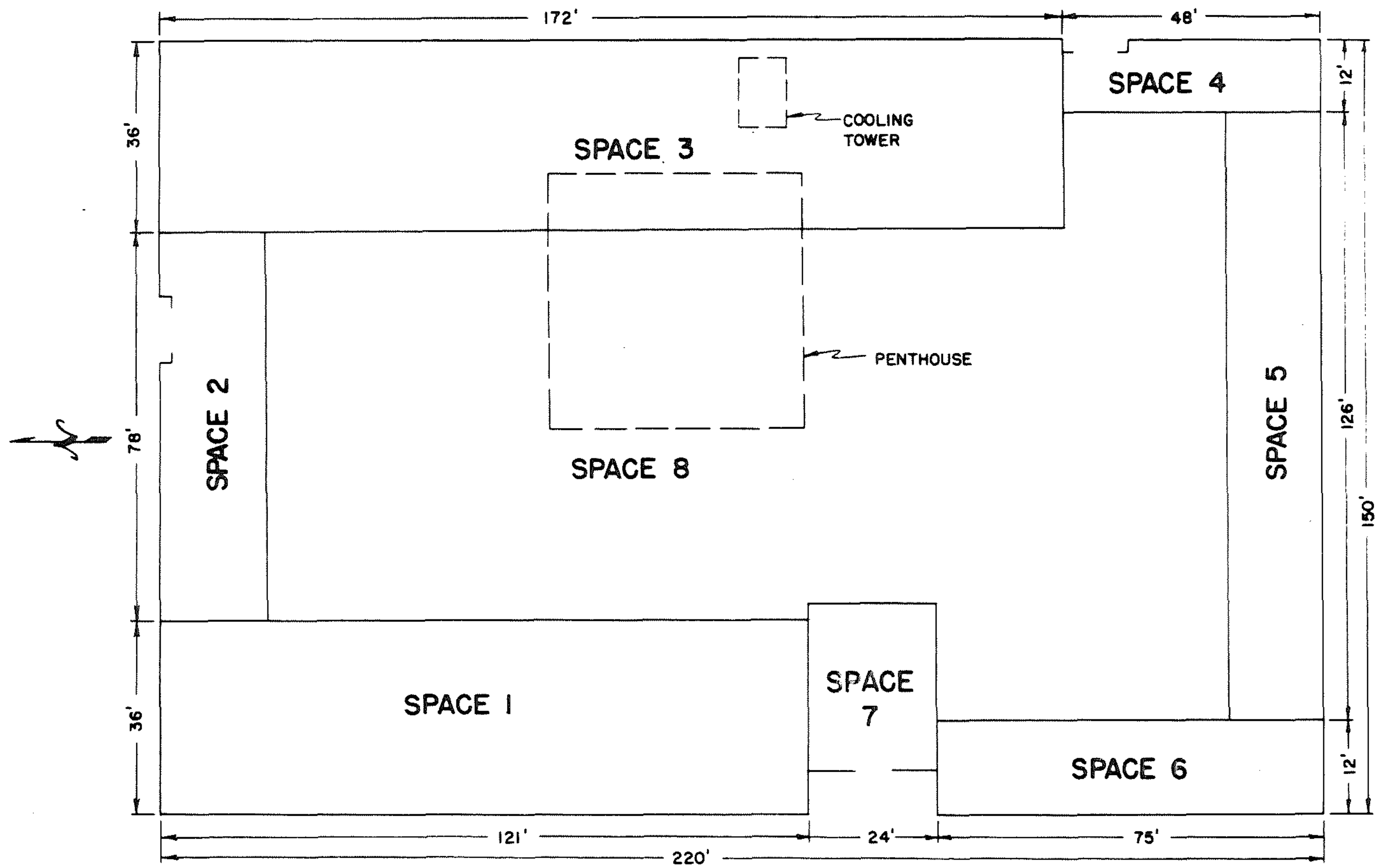


Figure 11 Floor Plan of GARD Building

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ANALYSIS OF ENERGY UTILIZATION OF

GARD OFFICE BUILDING

FACILITY

NILES, ILLINOIS

ENGINEER     - M. LOKMANHEKIM AND R. HENNINGER
PROJECT NO   - 91364
DATE         - 7 MAY 1971
```

Figure 12 BUILDING IDENTIFICATION

```
IN THIS RUN

- U. S. WEATHER BUREAU 1440 WEATHER TAPE OF STATION 14819 IS USED.

- THE FIRST DATA OBTAINED FROM WEATHER TAPE IS FOR 0TH HOUR OF 01/01/1957.

- THE LENGTH OF THIS STUDY IS 365 DAYS.

- THE INITIAL OUTSIDE SURFACE TEMPERATURE IS 17 DEGREES FAHRENHEIT.
```

Figure 13 WEATHER YEAR AND LENGTH OF STUDY INFORMATION

BUILDING THERMAL AND INFILTRATION LOADS SUMMARY

COOLING DESIGN HOUR	TEMPERATURE DEGREES FAHRENHEIT DB	TEMPERATURE DEGREES FAHRENHEIT WB	HUM. RAT. LBS WATER PER LB DRY-AIR	PRESSURE INCHES OF MERCURY	PLENUM LOAD BTU PER HOUR	BUILDING THERMAL AND INFILTRATION LOADS BTU PER HOUR SENSIBLE RAD.+TRAN.+INTER. +PEOPLE	SENSIBLE INF.	LATENT PEOPLE	LATENT INF.	TOTAL LOAD BTU PER HOUR
4024 16.HOUR OF 17 JUNE	96.	77.	.016157	29.44	0.	600297.	0.	32735.	0.	633032.

HEATING DESIGN HOUR	TEMPERATURE DEGREES FAHRENHEIT DB	HUM. RAT. LBS WATER PER LB DRY-AIR	PRESSURE INCHES OF MERCURY	BUILDING THERMAL AND INFILTRATION SENSIBLE LOAD BTU PER HOUR
319 7. HOUR OF 14 JAN.	-7.	.000357	29.61	-549274.

Figure 14 BUILDING THERMAL AND INFILTRATION LOADS

SPACE MAXIMUM AND MINIMUM HEATING AND COOLING LOADS SUMMARY

* * *

SP.NO	MAX. HEAT. BTU/HOUR	HOUR	MIN. HEAT. BTU/HOUR	HOUR	MAX. COOL. BTU/HOUR	HOUR	MIN. COOL. BTU/HOUR	
1	-102188.	7.HOUR OF 14 JAN.	-4.	2.HOUR OF 30 APR.	141423.	16.HOUR OF 17 JUNE	15.	1.HOUR OF 18 MAY
2	-42376.	7.HOUR OF 14 JAN.	-9.	4.HOUR OF 1 JULY	34823.	17.HOUR OF 17 JUNE	0.	7.HOUR OF 29 JUNE
3	-141839.	7.HOUR OF 14 JAN.	-2.	13.HOUR OF 3 JAN.	167166.	16.HOUR OF 17 JUNE	4.	4.HOUR OF 13 SEP.
4	-27366.	7.HOUR OF 14 JAN.	-6.	14.HOUR OF 13 NOV.	22021.	9.HOUR OF 17 JUNE	0.	20.HOUR OF 13 MAR.
5	-70283.	7.HOUR OF 14 JAN.	-3.	18.HOUR OF 13 OCT.	73210.	13.HOUR OF 18 SEP.	0.	22.HOUR OF 11 OCT.
6	-44066.	7.HOUR OF 14 JAN.	-5.	21.HOUR OF 21 SEP.	51700.	16.HOUR OF 17 JUNE	0.	4.HOUR OF 7 JUNE
7	-13655.	6.HOUR OF 14 JAN.	-1.	22.HOUR OF 3 MAY	20187.	16.HOUR OF 17 JUNE	1.	7.HOUR OF 11 SEP.
8	-107503.	7.HOUR OF 14 JAN.	-12.	4.HOUR OF 2 SEP.	147626.	16.HOUR OF 30 JULY	88.	5.HOUR OF 6 JULY

Figure 15 SPACE MAXIMUM AND MINIMUM HEATING AND COOLING LOADS SUMMARY

WALL SPECIFICATIONS- EXTERIOR- BRICK OR ROUGH PLASTER
MAX. OVERALL U= 0.152 BTU/HR-FT2-F
WINTER CONDITIONS OUTSIDE

STD. ASHRAE WALL SELECTION IS AS FOLLOWS

LAYER	DESCRIPTION	THKNS FT.	CONDTVTY B/HR-FT-F	DNSTY LB/FT3	SP HT B/LB-F	RESISTANCE HR-FT2-F/B
1	4.000 IN. MASONRY, BRICK, COMMON	0.333	0.417	120.00	0.200	0.0
2	0.500 IN. CEMENT MORTAR	0.0	0.0	0.0	0.0	0.0
3	4.000 IN. CONCRETE, SAND + GRAVEL AGGREGATE (NOT DRIED) 140 LB/FT3	0.333	1.042	140.00	0.250	0.0
4	AIR SPACE	0.0	0.0	0.0	0.0	0.97
5	1.000 IN. INSULATING MAT'L BLANKET, MINERAL WOOL, FIBROUS	0.083	0.027	0.50	0.157	0.0
6	0.375 IN. BUILDING BOARD, GYPSUM OR PLASTER BOARD	0.031	0.094	50.00	0.259	0.0
7	0.500 IN. GYPSUM PLASTER, SAND AGGREGATE	0.042	0.470	105.00	0.200	0.0
8	INSIDE SURFACE STILL AIR	0.0	0.0	0.0	0.0	0.68

OVERALL U= 0.156 BTU/HR-FT2-F

Figure 16 WALL SPECIFICATION OUTPUT

ROOF SPECIFICATIONS- PITCHED ROOF
MAX. OVERALL U= 0.211 BTU/HR-FT2-F
SUMMER CONDITIONS OUTSIDE

STD. ASHRAE ROOF SELECTION IS AS FOLLOWS

LAYER	DESCRIPTION	THKNS FT.	CONDTVTY B/HR-FT-F	DNSTY LB/FT3	SP HT B/LB-F	RESISTANCE HR-FT2-F/B
1	0.500 IN. ROOFING, ASBESTOS-CEMENT SLATE SHINGLES	0.042	0.833	120.00	0.200	0.0
2	0.063 IN. BUILDING PAPER, VAPOR-PERMEABLE FELT	0.005	0.087	44.00	0.324	0.0
3	0.781 IN. BUILDING BOARD, PLYWOOD	0.065	0.067	34.00	0.650	0.0
4	AIR SPACE	0.0	0.0	0.0	0.0	0.85
5	0.750 IN. INSULATING MAT'L, ACOUSTICAL TILE (WOOD OR CANE FIBERBOARD)	0.063	0.035	15.00	0.200	0.0
6	INSIDE SURFACE, STILL AIR	0.0	0.0	0.0	0.0	0.92

OVERALL U= 0.215 BTU/HR-FT2-F

Figure 17 ROOF SPECIFICATION OUTPUT

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*                         IN THE FOLLOWING PAGES                             *
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*                                                                            *
*                THE FIRST LINE OF EACH PRINTED BLOCKS GIVES                 *
*                                                                            *
*   TIME            - HOURS, STANDARD TIME FROM FIRST HOUR OF JANUARY        *
*   SUN INDEX       - IF EQUAL TO ONE SUN IS DOWN, IF EQUAL TO ZERO SUN IS UP *
*   DRY-BULB TEMP. - DEGREES FAHRENHEIT                                      *
*   WET-BULB TEMP. - DEGREES FAHRENHEIT                                      *
*   WIND VELOCITY  - KNOTS                                                   *
*   HUMIDITY RATIO - LBS WATER PER LB DRY-AIR                                *
*   PRESSURE        - INCHES OF MERCURY                                      *
*   ENTHALPY        - BTU PER LB DRY-AIR                                     *
*   DENSITY         - LBS DRY-AIR PER CUBIC FOOT                             *
*                                                                            *
*              THE FOLLOWING LINES OF EACH PRINTED BLOCKS GIVES              *
*                                                                            *
*   SPACE NUMBER                                                             *
*   SPACE SENSIBLE LOAD - BTU PER HOUR                                       *
*   SPACE LATENT LOAD   - BTU PER HOUR                                       *
*   PLENUM RETURN AIR LIGHTING LOAD     - BTU PER HOUR                       *
*   SPACE LIGHTING AND EQUIPMENT POWER - KILOWATTS                           *
*                                                                            *
*                                                                            *
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*            NOTE - THE LOADS EXCLUDES OUTSIDE VENTILATION AIR LOADS         *
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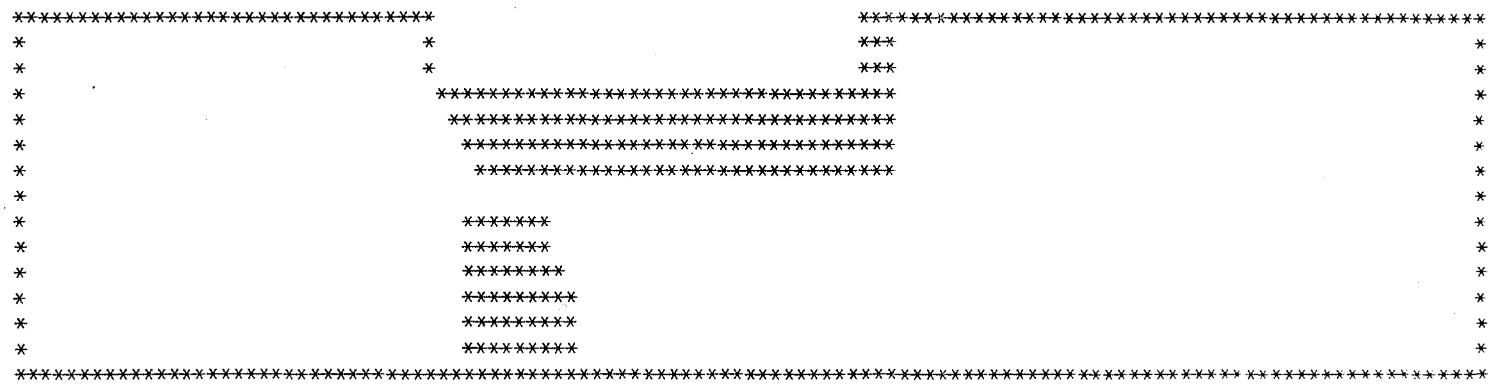
Figure 18 FORMAT OF LOAD TAPE PRINTOUT

24	1	9.	8.	9.	.000760	29.76	2.97	.084054
1	-84085.15			.00		.00	.00	
2	-34972.60			.00		.00	.00	
3	-117508.69			.00		.00	.00	
4	-22311.35			.00		.00	.00	
5	-56935.47			.00		.00	.00	
6	-35888.25			.00		.00	.00	
7	-11224.05			.00		.00	.00	
8	-91414-31			.00		.00	.00	

Figure 19 EXAMPLE OF LOAD TAPE PRINTOUT



THE PRECEDING SHADOW PICTURE IS FOR
DELAYED SURFACE NUMBER 15 OF SPACE NUMBER 3
AT 1400 HOUR OF THE FIRST DAY OF JUNE

AREA OF THE SURFACE = 5836.60 FT**2
SHADED AREA OF THE SURFACE = 728.68 FT**2

Figure 20 SHADOW OF PENTHOUSE AND COOLING TOWER ON PART OF ROOF

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THE PRECEDING SHADOW PICTURE IS FOR
DELAYED SURFACE NUMBER 2 OF SPACE NUMBER 1
AT 1400 HOUR OF THE FIRST DAY OF JUNE

AREA OF THE SURFACE = 64.29 FT**2
SHADED AREA OF THE SURFACE = 19.83 FT**2

Figure 21 SHADOW OF OVERHANG AND SIDE COLUMN ON THE WALL SURROUNDING WINDOW

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THE PRECEDING SHADOW PICTURE IS FOR
DELAYED SURFACE NUMBER 20 OF SPACE NUMBER 8
AT 1000 HOUR OF THE FIRST DAY OF JUNE

AREA OF THE SURFACE = 14367.96 FT**2
SHADED AREA OF THE SURFACE = 640.51 FT**2

Figure 22 SHADOW OF PENTHOUSE ON ANOTHER PART OF ROOF

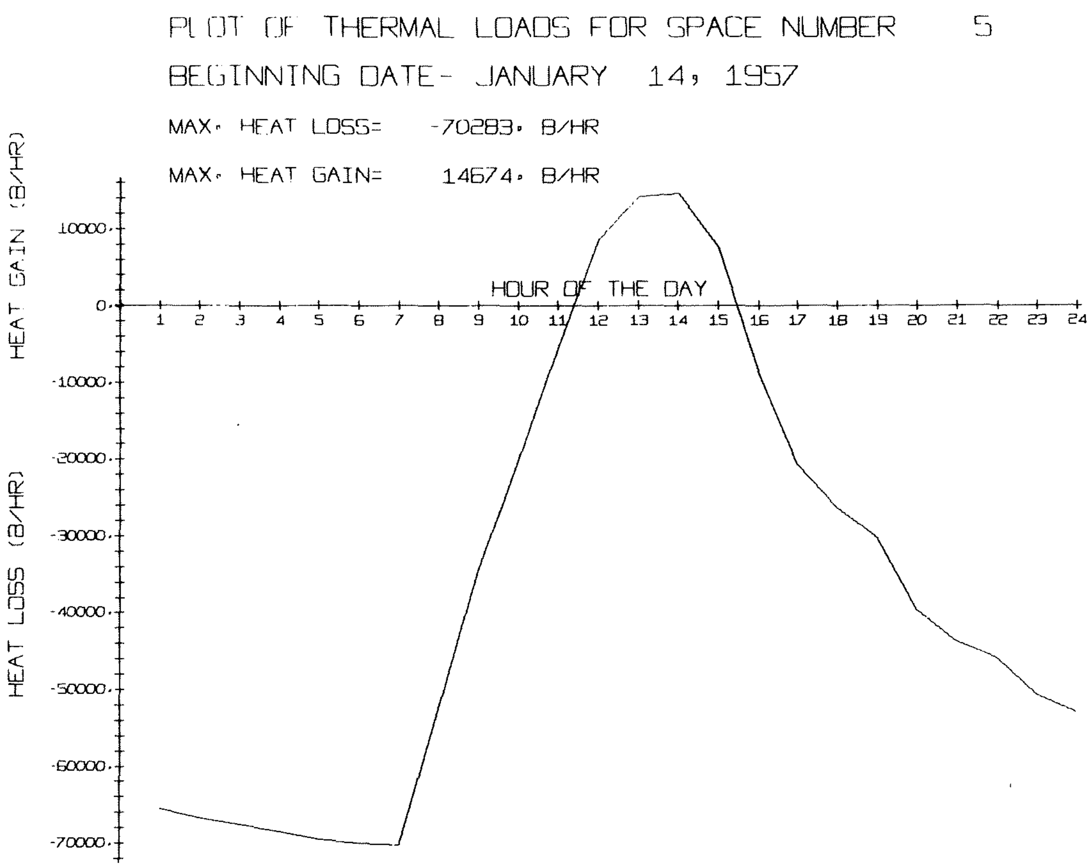

Figure 23 A ONE-DAY THERMAL LOAD PLOT OF A SPACE

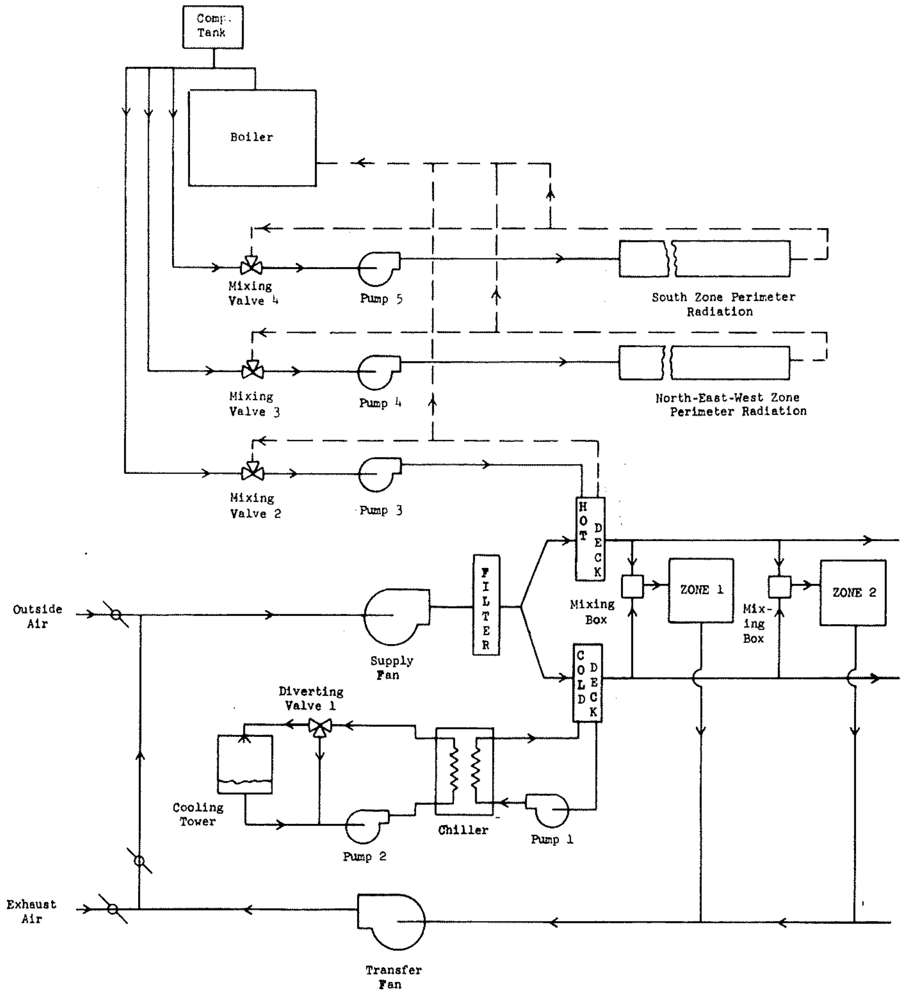

Figure 24 SCHEMATIC OF AIR CONDITIONING SYSTEM OF GARD BUILDING

GARD OFFICE BUILDING NILES, ILLINOIS 7 MAY 1971 91364
SYSTEM SIMULATION AND ENERGY ANALYSIS

SUMMARY OF FAN SYSTEM CHARACTERISTICS

FAN SYSTEM	TYPE	FAN BHP	NO. OF ZONES	SET POINT	TOTAL CFM	MIN. O.A. CFM	EXH. CFM	PERCENT VENT. A
1	DDS	31.7	8	72.0	26820.	10214.	5550.	38.1

Figure 25 SUMMARY OF FAN SYSTEM CHARACTERISTICS

GARD OFFICE BUILDING NILES, ILLINOIS 7 MAY 1971 91364
SYSTEM SIMULATION AND ENERGY ANALYSIS

SUMMARY OF ZONE AIR FLOWS

FAN SYSTEM	ZONE	SUPPLY CFM	EXHAUST CFM
1	1	5317.	0.
1	2	1355.	0.
1	3	6118.	0.
1	4	839.	0.
1	5	2834.	0.
1	6	2006.	0.
1	7	766.	0.
1	8	7585.	5550.

Figure 26 SUMMARY OF ZONE AIR FLOWS

SUMMARY OF EQUIPMENT SIZES

TYPE OF CHILLER	=	HERMETIC CENTRIFUGAL
NO. OF CHILLERS	=	1
SIZE OF CHILLERS	=	108.4 TONS

TYPE OF BOILER	=	GAS
NO. OF BOILERS	=	1
SIZE OF BOILERS	=	1595.0 MBTU

NO TERMINAL REHEAT USED

COOLING TOWER FAN REQUIREMENT 28805. CFM 1.0 IN. S.P. 5.7 BHP

BOILER AUXILIARY HORSEPOWER REQUIREMENT (FAN,BLOWER,PUMP) 2.4 BHP

TOTAL FAN PLANT HORSEPOWER FOR BUILDING 31.7 BHP

SUMMARY OF PUMP SIZES

LOCATION	TOTAL GPM	TOTAL HEAD (FT)	TOTAL BHP
CHILLED WATER	230.	55.0	6.7
CONDENSER WATER	288.	50.0	7.6
HEATING WATER	159.	120.0	10.1

Figure 27 SUMMARY OF EQUIPMENT SIZES

POST OFFICE DEPARTMENT EQUIPMENT AND ENERGY CONSUMPTION ANALYSIS	FACILITY/ADDRESS	DATE/PROJECT	ENGINEER/SYSTEM IDENTIFICATION
	GARD OFFICE BUILDING NILES, ILLINOIS	7 MAY 1971 91364	M. LOKMANHEKIM AND R. HENNINGER SYSTEM NO. 1

	ENERGY CONSUMPTION					
	JAN.	FEB.	MARCH	APRIL	MAY	JUNE
MONTHLY BTU/1000						
HEAT (MHB)						
MIN. DEMAND	-160.6	-138.9	-111.3	-90.2	-77.4	-75.0
MAX. DEMAND	-1495.6	-1078.1	-1038.4	-837.0	-515.3	-368.3
CONSUMPTION	-595788.9	-381713.8	-362776.2	-207429.6	-111286.9	-15587.2
COOL (MCB)						
MIN. DEMAND	.0	144.4	118.9	120.8	117.6	116.3
MAX. DEMAND	.0	295.0	453.5	886.3	894.5	1245.0
CONSUMPTION	.0	964.6	5745.8	64022.8	97649.5	274993.6
ELECTRICITY						
LIGHTS AND MOTORS						
INTERNAL						
DEMAND(KW)	111.2	111.2	111.2	111.2	111.2	111.2
CONS.(KWH)	38892.9	34775.5	38465.9	38892.9	39460.2	36904.3
EXTERNAL						
DEMAND(KW)	.0	.0	.0	.0	.0	.0
CONS.(KWH)	.0	.0	.0	.0	.0	.0
HEAT						
DEMAND(KW)	9.3	9.3	9.3	9.3	9.3	9.3
CONS.(KWH)	6682.7	6162.9	6701.3	5050.6	3935.4	788.9
COOL						
DEMAND(KW)	.0	24.2	31.1	59.9	59.6	90.5
CONS.(KWH)	.0	133.8	485.2	5201.3	8263.0	21600.6
TOTAL						
DEMAND(KW)	120.5	135.5	142.4	171.1	170.9	201.7
CONS.(KWH)	45575.6	41072.2	45652.4	49124.9	51658.6	59293.8
GAS						
HEAT						
DEMAND(THERMS)	18.7	13.5	13.0	10.5	6.4	4.6
CONS.(THERMS)	7447.4	4771.4	4534.7	2592.9	1391.1	194.8
COOL						
DEMAND(THERMS)	.0	.0	.0	.0	.0	.0
CONS.(THERMS)	.0	.0	.0	.0	.0	.0
GENERATION						
DEMAND(THERMS)	.0	.0	.0	.0	.0	.0
CONS.(THERMS)	.0	.0	.0	.0	.0	.0
TOTAL						
DEMAND(THERMS)	18.7	13.5	13.0	10.5	6.4	4.6
CONS.(THERMS)	7447.4	4771.4	4534.7	2592.9	1391.1	194.8

Figure 28 SUMMARY OF VARIOUS ENERGY CONSUMPTIONS

POST OFFICE DEPARTMENT
EQUIPMENT AND ENERGY
CONSUMPTION ANALYSIS

FACILITY/ADDRESS
GARD OFFICE BUILDING
NILES, ILLINOIS

DATE/PROJECT
7 MAY 1971
91364

ENGINEER/SYSTEM IDENTIFICATION
M. LOKMANHEKIM AND R. HENNINGER
SYSTEM NO. 1

	ENERGY CONSUMPTION JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	TOTAL
MONTHLY BTU/1000							
HEAT (MHB)							
MIN. DEMAND	.0	-97.9	-93.2	-86.4	-118.5	-140.9	
MAX. DEMAND	.0	-196.3	-434.4	-647.8	-978.0	-1260.9	
CONSUMPTION	.0	-1957.7	-48891.6	-171922.7	-325282.0	-413638.9	-2634275.3
COOL (MCB)							
MIN. DEMAND	127.6	131.2	131.5	136.5	183.6	.0	
MAX. DEMAND	1198.5	1301.0	1007.9	574.2	260.6	.0	
CONSUMPTION	411340.0	343962.7	150345.9	30923.7	1515.6	.0	1381464.2
ELECTRICITY							
LIGHTS AND MOTORS							
INTERNAL							
DEMAND(KW)	111.2	111.2	111.2	111.2	111.2	111.2	
CONS.(KWH)	39460.2	39460.2	36904.3	40454.5	36904.3	37471.6	458046.8
EXTERNAL							
DEMAND(KW)	.0	.0	.0	.0	.0	.0	
CONS.(KWH)	.0	.0	.0	.0	.0	.0	.0
HEAT							
DEMAND(KW)	.0	9.3	9.3	9.3	9.3	9.3	
CONS.(KWH)	.0	129.9	2014.1	5439.0	6608.4	6905.4	50398.7
COOL							
DEMAND(KW)	86.5	100.8	68.4	38.0	23.7	.0	
CONS.(KWH)	30381.2	26735.8	13332.4	3208.0	161.3	.0	109503.2
TOTAL							
DEMAND(KW)	197.7	212.1	179.6	149.3	134.9	120.5	
CONS.(KWH)	69814.4	66325.9	52250.8	49102.1	43674.0	44377.0	617948.7
GAS							
HEAT							
DEMAND(THERMS)	.0	2.5	5.4	8.1	12.2	15.8	
CONS.(THERMS)	.0	24.5	611.1	2149.0	4041.0	5170.5	32928.4
COOL							
DEMAND(THERMS)	.0	.0	.0	.0	.0	.0	
CONS.(THERMS)	.0	.0	.0	.0	.0	.0	.0
GENERATION							
DEMAND(THERMS)	.0	.0	.0	.0	.0	.0	
CONS.(THERMS)	.0	.0	.0	.0	.0	.0	.0
TOTAL							
DEMAND(THERMS)	.0	2.5	5.4	8.1	12.2	15.8	
CONS.(THERMS)	.0	24.5	611.1	2149.0	4041.0	5170.5	32928.4

Figure 28 CONTINUED

The output on paper gives the monthly and yearly energy, machine and equipment costs, and the interest-adjusted cost imposed by the total owning and operating annuity.

9. CLOSING REMARKS

At the present time, different versions of the computer program are available to run on Control Data 3600, 6400, and 6600; Univac 1108; and IBM 360 computer systems. The program is written in Fortran IV, the most widely used scientific programming language, so that the program is easily adaptable to any computer system available to the user.

Where the size of the investment justifies the expense of repeated computations, the program may be used, as follows, in all stages of building decision-making.

1. Pre-design selection of the basic system and energy source.
2. Evaluation, during the design stage, of specific design concepts and modifications.
3. Evaluation, during construction, of contractor proposals for deviations from the construction plans and specifications.
4. Monitoring the operation and maintenance of the finished building so as to provide the greatest return on utility dollars.

Both the effort required for input data preparation and computer running times depend on the complexity of the building under consideration and the degree of analysis desired. Both input data preparation and computer running times decrease as the engineer gains experience with the program. Depending upon computer system used and the complexity of the building, the running time on the computer varies between 1/50 and 1/200 second per space per hour.

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