SOLAR ENERGY AND CONSERVATION AT ST. MARK'S SCHOOL

by William J. Jones and James W. Meyer

Energy Laboratory Report Number MIT-EL 77-001

February 1977

Energy Laboratory
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

May 11, 1977

Dear Sir:

Enclosed you will find two copies of the printing, SOLAR ENERGY AND CONSERVATION AT ST. MARK'S SCHOOL. The material enclosed is a summary report by Mr. William J. Jones and Mr. James W. Meyer concerning the results of the survey done at St. Mark's School.

As you review the compiled materials, I am sure you will find them informative. Comments are welcome.

Respectfully,

Diane M. Di Gioia

Diane M. Di Gioia
for
Mr. William J. Jones
Energy Laboratory

Enclosures

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ACKNOWLEDGMENTS

The work reported here was made possible by an unrestricted grant to the Massachusetts Institute of Technology from Mrs. Dora Stewart Lewis. We are indebted to Mrs. Lewis not only for the grant but also for her continued active interest and participation throughout the study, which we consider an essential contribution to the success of the program.

We are also grateful to the Administration and Staff of St. Mark's School, Southborough, Massachusetts for their understanding and cordial hospitality.

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ABSTRACT

This report is a result of a request to investigate the possibility of employing solar energy at a residential secondary school to reduce energy costs. Our approach was to explore this possibility in the context of a more general survey of opportunities to conserve energy (in particular, fuel) at the school. Our purpose was more to illustrate how to go about an appraisal of conservation opportunities plus implementation and evaluation of the most productive conservation measures, than a rigorous examination of the facility with detailed instructions on how to take care of specific problems.

A large number of actions that would result in net energy cost savings considerably greater than could be realized from solar systems were discovered. For a solar application, a domestic hot water system, supplementing that heated by tankless coils in oil burning furnaces, has the greatest potential for significant return on investment.

The school's total utility system (total energy, co-generation) meets all electrical and steam needs with the exception of the electric power required for one building. A heat recovery system on the diesel engines for the electric generators furnishes a sizeable portion of the steam.

Areas discussed in detail are: (1) optimization of the efficiency of oil fueled residential heating furnaces; (2) optimized operation of a total energy system; (3) lighting, insulation, air infiltration control; (4) heat management, scheduling and control. A methodology for preparing energy audits, energy flow charts and procedures for the evaluation of the need for the amounts of energy consumed for each individual purpose are also given. The importance of considering the application of solar energy in the broader conservation context is emphasized.

PRÉCIS

The objective of this program was to survey the potential for application of solar energy at St. Mark's School in the context of other opportunities to reduce fossil fuel use. As a residential school, St. Mark's typifies the characteristics of the facilities of many institutions and presents a reasonable spectrum of building types and usage while not being unwieldy in size. Thus, St. Mark's provided an excellent opportunity to determine energy use patterns and to evaluate in this context some of the many conservation options suggested for similar small institutions.

A selective audit of current energy use was made. As is usually the case, the energy systems are poorly instrumented for the kind of detail desired for a comprehensive energy audit. However, a sense of the overall consumption pattern was obtained by inspection of energy conversion equipment, an examination of operating procedures, and a study of bills and records.

One major cause of excessive energy demand is the lack of adequate sensors and controls on the system. Energy loss is due to poor or non-existent insulation in buildings and in pipes and duct work. Improved protection from air infiltration is needed, particularly for exterior doors and damperless fireplaces. Scheduled heating of buildings more in line with scheduled use was recommended as a major low/no cost opportunity to save fuel.

A spot survey of oil burning furnaces in a number of masters' dwellings was performed to determine efficiencies at the two-thirds point of the heating season. Many showed significant deterioration in performance since regular maintenance was performed the summer before. Because of this, a midwinter check of furnace performance was recommended in addition to the regular summer maintenance. Most units are equipped with tankless domestic hot water heaters. To ensure adequate recovery of hot water, firing rates of furnaces equipped with tankless heaters must often be much larger than that required to satisfy the space heating needs of the dwelling. Excessive firing rates lead to inefficient operation throughout the season, but in particular during the summer when the only demands on the furnace are for domestic hot water.

In light of the above, we recommended the installation of a solar supplement for domestic hot water heating in one of the masters' dwellings. Two design concepts were worked out, both employing solar collectors installed vertically on a southerly oriented wall of the building. A wall facing due south was not considered necessary because other orientations from southeast to southwest would not cause major loss of performance during a typical school year. The masters' dwellings are mainly unoccupied during the summer.

Other applications of solar energy were investigated but none were as cost effective as the solar hot water supplement. There is a local electric utilities program to install solar supplemented hot water systems in 100 New England homes. It will furnish important experience for regional manufacturers and installers of this novel equipment. When these results are known, the feasibility of solar energy utilization should be reviewed.

The power plant at St. Mark's was also studied. The school generates electricity and steam from diesel-driven generators and reject heat recovery systems on the diesel prime movers. There are also oil-fired steam boilers. Recommendations to minimize cost were made to improve the performance of the total energy (co-generation) system and a strategy was worked out to optimize the selection between gas and oil to drive the diesels and to "float" the oil-fired steam boilers as "slaves" on the steam line from the waste heat recovery units of the diesels.

An important result of this study was that we cannot yet make broad generalizations about methods of conserving energy. Each option must be considered in a localized and specific context.

The need of improved, portable, and inexpensive instrumentation to assist rapid energy auditing is demonstrably great. Because the use of present combustion testing equipment for oil burning furnaces is difficult and time consuming, few servicemen use it in practice, preferring to make adjustments on the basis of a practiced eye.

Operational methods of conserving energy can show substantial savings at little or no cost. An intelligent program of "what to do" cannot be developed, however, without detailed knowledge of current effects of "what is being done".

St. Mark's is not unique. Sister schools such as St. George's in Newport, R.I., and the Purnell School in Pottsville, N.J., (which was surveyed briefly) also present problems and offer opportunities for alternative source application. Small institutions cannot support full time the kind of professional help needed to cope with the problems. There are many similar public and private institutions needing assistance in this important area.

Outline of Report

SOLAR ENERGY AND CONSERVATION AT ST. MARK'S SCHOOL

A SURVEY OF THE POTENTIAL

OBJECTIVES: SAVE ENERGY (AND MONEY) FOR SAINT MARK'S SCHOOL
REDUCE FUEL CONSUMPTION
INCREASE EFFICIENCY/PRODUCTIVITY OF CONSUMED FUEL
DIVERSIFY THROUGH USE OF ALTERNATIVES

MEANS:
I. IDENTIFY THROUGH COMPREHENSIVE AUDIT OF ENERGY USE AND RECOMMEND APPROPRIATE, COST EFFECTIVE ENERGY CONSERVATION MEASURES
II. IDENTIFY AND RECOMMEND THE MOST APPROPRIATE AND COST EFFECTIVE APPLICATION OF SOLAR ENERGY

OUR APPROACH

O CONDUCT AN ENERGY AUDIT
- DETERMINE PATTERNS OF ENERGY USE IN AS MUCH DETAIL AS POSSIBLE. (DESIGN OF THE ENERGY SURVEY)
- LOCATE PREVENTABLE ENERGY LEAKS (WASTE)
- CLASSIFY LEAKS BY MAGNITUDE
- IDENTIFY ENERGY SOURCES, AVAILABILITY (PRESENT AND FUTURE) AND MAGNITUDE OF USE. (SURVEY CURRENT FUEL USE BY TYPE AND QUANTITIES)

O SUGGEST CONSERVATION MEASURES
- EVALUATION CRITERIA FOR CONSERVATION MEASURES
  - A. GENERAL
    - TECHNICALLY POSSIBLE
    - ECONOMICALLY EFFECTIVE
    - SOCIALLY ACCEPTABLE
    - "POLITICALLY" POSSIBLE
  - B. DETAILED
    - EFFECTIVENESS
      - HOW MUCH?
      - HOW EASY?
      - HOW COSTLY?
      - HOW SOON?
    - SCHOOL AND SOCIETY ISSUES
      - ENVIRONMENTAL
      - HEALTH AND SAFETY
      - SOCIO-ECONOMIC

FINAL REPORT
SOLAR ENERGY AND ENERGY CONSERVATION
at the
SAINT MARK'S SCHOOL

Executive Summary

I. Basic Conclusions

Opportunities for Conservation

1. Improved knowledge of the need for energy and development of appropriate management and control. This is the single most important approach at Saint Mark's.
   a. Developing an Energy Flow Chart and keeping it up to date, are basic to maintaining an energy audit. It will show where energy management is most cost-effective.
   b. Knowledge of energy flow to the operating engineer and the comptroller is as important as knowledge of cash flow--both are money. Control of generation in the central utilities plant and consumption of energy as well as correct purchase arrangements are no- or low-cost opportunities. Implementation can begin immediately.
   c. Supply energy based on need (temperatures suited for occupied space and empty space).
2. Reduction of Air Infiltration
   a. Voluntary: Improvement of control of energy supply for heating will make the opening of windows, to correct for overheating, unnecessary.
   b. Involuntary: Involuntary air infiltration is prevalent. The most important examples are: (1) fireplaces without dampers; (2) poor closure sealing of operating window sash; (3) incomplete closure of exterior doors; (4) air leaks at skylights; (5) absence of weatherstrip at most doors and windows; (6) inadequate caulking.
3. Improved adjustment and maintenance of oil burners in the Masters' Dwellings and an allocation formula for total oil per heating season. Oil consumption in the Masters' Houses, in many instances, is excessive.
   a. In an independent survey of selected units, we found that several oil burners could not be depended upon to maintain top performance over the entire heating season. More frequent service is indicated.
   b. With heating oil furnished by the school, there is little economic incentive for conserving it. Allocate on basis of a formula.
   c. Tankless hot water coils used in most of the dwellings to supply domestic hot water can lead to serious seasonal system inefficiencies of the heating plant. Install independent water heaters.
   d. Oil burner firing rates are in several instances excessive. Install smaller nozzles.
4. Improved Insulation
   a. Installation and maintenance of insulation on pipes and ducts is needed. Uninsulated steam distribution pipes cause especially serious losses. Improved pipe insulation is one of the most cost effective conservation measures.
   b. Both the proper utilization and the installation of storm windows not only provide improved insulation but also can effectively reduce air infiltration, particularly for older buildings.
   c. Some of the older buildings have little or no insulation in ceilings and walls. Installa-

tion of insulation in existing structures is often costly, particularly in walls. In roofs and ceilings, where insulation is more essential than in walls, the installation of insulation, fortunately, is usually easier. New foamed-in-place insulations can be an attractive option for older New England style buildings.

5. Heating, ventilating and air conditioning the new library
   This is an all-electric building (a little steam is used only for winter humidification). The library is the only building served by an outside electric utility company.
   a. We believe that the building heating and air conditioning system has not yet been properly balanced. A reappraisal of the control systems and set points should be made in light of operating experience over the past few years.
   b. It is very possible that its electrical and heating requirements may be supplied by the school's central power plant with a savings in money.
   c. We explored the feasibility of a solar supplement to the electric resistance heating of this building. Although electric heating costs are high, the solar supplement did not appear to be cost-effective because of a poor solar plant utilization factor for heating alone.
6. A solar supplement of domestic hot water for one Master's Dwelling
   A demonstration unit on one dwelling could be reasonably cost-effective if the solar system would enable the conventional oil heating plant to be operated more efficiently. We also have the opportunity to take advantage of the experience gained with the hundred hot water solar heating systems being installed in the New England area by utility affiliates of the New England Electric System in Westboro. Two preliminary designs have been prepared and are included in this report.
7. The central plant as a total utility or energy system
   The philosophy behind and general installation of the central power plant is sound. However, additional instrumentation controls are necessary for proper operation. On-site generation of electrical power can only have economic advantages provided the heat energy that is normally discharged as waste when electricity is generated, is recovered and put to useful purposes. At present, steam energy is supplied as demanded, not as needed.
   The decision to operate the natural gas or diesel fueled engines must be based on direct fuel cost and demand charges (both current and those which will be established for the next eleven months).

II. Recommendations

General

1. <u>We cannot recommend too strongly the formulation and implementation of a five-year program to repair, upgrade and improve the existing physical plant</u>.
2. We emphasize that studies, technical design, preparation of specifications, supervision and acceptance tests should be performed by professionals.

Conservation

1. We recommend the establishment of a comprehensive energy conservation program. Conservation is
   a. <u>not</u> a once and for all operation carried out by specialists for the benefit of their clientele.
   b. a <u>continuing</u> and evolving process which needs the contributions of <u>all</u>.

c. learning where and how we use energy -- where and how its use is excessive -- where and how we can correct these excesses.

d. doing, by all members of the community, those things needed to reduce energy use.

e. understanding what is right about measures that prove effective and why others went wrong.

f. maintaining the effective measures, correcting ineffective approaches, and planning new assaults on energy waste.

Conservation requires an understanding and acceptance of the concept of individual and collective responsibility for our environment and natural resources.

III. Management

We recommend gaining control and maintaining control of energy systems so that the following management approaches can be implemented:

1. Heat space to 68°F maximum (air conditioning not lower than 75°F)
2. (a) Schedule 68°F heating to match occupancy.
   (b) At other times drop back as far as conditions will permit. (Chapel and infirmary require special consideration.)
3. Ensure that installed controls are doing the intended job.
4. Provide additional controls where needed.
5. Seal all controls so that they cannot be adjusted by unauthorized persons.
6. Periodically balance the system as improved control develops.
7. Reduce involuntary air infiltration.
8. Control the amount and duration of lighting to fit occupancy.
9. Switch off perimeter lighting when not in use or when daylight is adequate.
10. Inspect domestic oil burners twice a year.
11. Maintain weather seals and proper operation of movable windows.
12. See that existing storm windows are properly used.
13. Review operation and balance of new library heating, ventilating and air conditioning (HVAC) system.
14. Provide gaskets and, where feasible, vestibules for exterior doors.
15. Install reflectors or reflective insulation behind radiators.
16. Install pipe and air duct insulation.
17. Install storm windows at least on north and west exposures.
18. Install ceiling and attic insulation.
19. Review economics of central power plant operation and operate so as to minimize costs.
20. Install solar domestic hot water supplement on one Master's Dwelling.
21. Relocate the garage to space where steam demand is more reasonable.

IV. Savings

Based on our observation at St. Mark's, and the experience of others, we estimate that savings of 20% in energy and fuel use can be achieved and maintained through the implementation of the majority of the above conservation measures.

SAVINGS THROUGH CONTROL AND MANAGEMENT OF SPACE CONDITIONING PLANT

Actions:

- Review and correction of thermostat location and function
- Introduction of automatic, timed, and manual controls
- Introduction of zoning and balance in an evolved and involved system
- Application of insulation on the distribution system
- Reduction and control of air infiltration
- Addition of building insulation

Savings:

- Can expect 20% - 30% savings from these measures
- Of the $50,000 annual cost of residual oil, at least $10,000 can be saved

AN EXAMPLE OF SAVINGS

2 1/2" uninsulated pipe carrying 6 lbs. of steam (250°F) loses 33,000 Btu/hr per hundred feet. If one inch of insulation is applied, losses drop to 4,500 Btu/hr per hundred feet.

Savings: 28,500 Btu/hr. (Equivalent to 10¢/hr at plant)

Cost of Insulation: $200 installed

Cost recovered in 2000 hours of operation: 84 days or 3 months - thereafter the savings are $72/month.

THERE ARE OVER ONE HUNDRED FEET OF NON-INSULATED PIPE BETWEEN THE CENTRAL PLANT AND THE GARAGE.

I. INTRODUCTION

A. A Brief Description of St. Mark's School.

Saint Mark's School, located in Southborough, Massachusetts, is a private, residential preparatory school. About 250 students and 65 faculty comprise the community. The school is made up of four forms, or classes, corresponding to the ninth through twelfth grades. A typical school calendar runs from early September to graduation in early June. See Tables 2 and 3, pages 15 and 16.

The main building complex was constructed circa 1890, the Field House and Ball Cage added in the mid-1930's, and the New Library and Arts Building were completed in 1970. Situated on campus, or nearby are twenty-six single or multiple family Masters' Dwellings.

Under the gift of Mrs. Dora Lewis a study was conducted at St. Mark's to identify opportunities for energy conservation and solar energy supplement. Since there are many school communities like St. Mark's, it was, and is, hoped that the observations and recommendations can be used, with profit, at the others.

This integrated community with its diversity of building types, age and architecture along with a cheerfully cooperative staff proved to be a most interesting laboratory in which to carry out our study. The size of the institution made it a workable entity permitting us to focus on some of the specific complexities of the energy problem while not losing the more general picture of the school and its work-a-day life as a whole.

B. General Objectives of Study

> A MOST IMPORTANT ASPECT OF ENERGY MANAGEMENT AT SAINT MARK'S SCHOOL IS TO IMPROVE THE CONTROL OF THE HEATING OF LIVING AND WORKING SPACES
>
> "Saved energy" is the only "alternative source" that is within our immediate grasp. It is our only option in the next several years. It will do more to close the gap between demand and supply than some of the more "popular" alternatives.
>
> Conservation can also continue to accomplish much more in the decades to come. Saving requires discipline; discipline requires cooperation; cooperation requires understanding.

Options for the conservation of energy in a complex of buildings and activities such as that at the Saint Mark's School can be broadly categorized under three headings.

1. Frugality which is often assumed to have a pejorative effect on our accustomed life style, need not be so perceived. It does mean economies in our expenditure of energy resources, economies motivated by cost and responsible use of resources (good energy husbandry--the avoidance of waste).

2. Productivity, an option that means improved efficiency in our conversion and utilization of energy resources--the reduction of waste through technical improvements and better management.

3. Diversity, the substitution of a renewable resource for one that is not; or what is more likely, the supplementing of a non-renewable source with an alternative. Solar energy appropriately applied can be an attractive supplement contributing to the conservation of fossil fuels and increasing the diversity of our energy options.

C. Approach for Energy Conservation

There are three essential ingredients in a successful energy efficiency/productivity program:

(a) Management and supervision;
(b) Measurement and records;
(c) Maintenance and modification.

1. People are the most important local resource for effective conservation. Administration, faculty, staff and student personnel all have vital roles to play. A crucial problem is the harnessing of this team to reach major common objectives. The team will only work well when the goals and paths to them are clearly worked out and well understood by the entire school community. One person should be identified, not to do the conservation tasks, but to see that the community knows and understands what has to be done and is enthusiastic about helping get on with it.

This person, an "Energy Conservator," must be designated to be responsible for the coordination of the efforts of the community and for publicity of the results of such efforts. The motto of the Energy Conservator should be:

> "Economy manages; frugality saves; providence plans. Thrift at once earns and saves, with a view to wholesome and profitable expenditure at a fitting time, in both the near and far term."

2. Records of energy consumption on a detailed level (building, room, etc.) are essential to intelligent management of energy use. Information on the total and disaggregated costs of the energy supplied is also needed to ensure that a proposed conservation measure in fact saves money and is worth the cost and effort. Some desirable measurements will require additional instrumentation, but if full use is not made of available current data plus past records there will be little basis for judging the relative effectiveness of conservation options.

3. The importance of energy systems maintenance and modification for savings cannot be stressed enough. St. Mark's heating system is typical of systems which have evolved over the years. They become complex and highly interactive in their actual functioning. Information is more often than not incomplete or non-existent. As energy management and control systems are brought to bear to effect substantial reductions in energy use, there will be periods of substantial imbalance in system operation. The change from a system that supplies equal heat to the most difficult spaces and corrects for the overheating of the remainder by opening windows or doors, to one where a better distribution of required heat is accomplished by control (manual or automatic) to specific local requirements will produce occasions of temporary discomfort until the system is adjusted.

<u>Responsibility of St. Mark's community</u>

It is essential that the whole school cooperate in achieving rebalance and that, during the "tuning period", no one attempts to defeat or circumvent the procedures used in reaching towards the conservation objectives. The community must learn to regard as critical every step in an attempt to ensure that their heritage of natural resources is not needlessly squandered by their elders and their peers.

To gain understanding, we must identify those measures that are:

(a) working, and try to understand why;

(b) not working, and identify what is needed to make them work better.

Only then can we implement those changes indicated.

We suggest that the community be organized and function as a conservation corps to assist the administration and staff (or "Energy Conservator") in maintaining the total scholastic environment at the least cost in energy and environmental impact. Every individual should be encouraged to correct the oversight of others--the open window, the door left ajar, the lights left on. These small oversights, when aggregated, incur large, needless, and damaging loss. Because of the visibility of such practices, change of habit should be both easily implemented and economically worthwhile.

Cautions

The introduction of any energy conserving procedure, devices, equipment, etc., must be preceded by a careful and detailed analysis of the technical, economic, social health and safety consequences.

For example, reduction of temperatures in the library might discourage its use. A cutback on oil heating might encourage the use of electric heaters as supplements, a very costly and often dangerous procedure.

The designs of many equipments and government installation codes have evolved from long, painful and costly experience. Changes must carefully be pre-examined. The following is an excellent example of what we have in mind.

> A friend of St. Mark's sent the clipping, Appendix I, to the plant engineer with the suggestion that the modifications, as shown be made to the heating systems in the Masters' Houses. It was given to us for comment.
>
> We did not have to prepare a reply for, in a subsequent issue of the same magazine from which the clipping was taken, there were a number of letters from readers pointing out the hazards (Appendix II).
>
> It should be noted that the original article was published in one of the best "home mechanic", and often scientific, magazines published. It is assumed that a sizeable number of professional engineers read the magazine for ideas and information.

Weigh carefully all recommendations for procedures and equipment that are suggested, by anyone at all, to determine the consequences.

D. Summary of What Was Done

We conducted a selective audit of current energy use at St. Mark's to reveal opportunities to conserve energy and to provide a solar supplement. After getting a sense of the overall consumption pattern, we concentrated on areas apt to provide near-term, low-cost options for energy conservation and for opportunities to increase the economic leverage of a solar supplement.

We looked into:

(a) opportunities for conservation through improved controls throughout the school;
(b) opportunities for conservation by discovering and correcting leaks in the buildings;
(c) construction and operation of the central power plant;
(d) possible "heat leaks" in the central distribution system;
(e) the heating requirements of the new library; and
(f) the hot water supply and needs of the kitchen, laundry and gymnasium.

We conducted on-site infra-red surveys, coordinated with the school's administrative and engineering personnel, which revealed the pattern of heat leaks. We attempted early identification of those areas where substantial savings could be made. (Appendix III)

The new library was examined with considerable interest because it is the only building operated independently of the central utilities plant. Heating, lighting and air conditioning are derived from electricity purchased from an outside utility company.

Ordinarily, from the plant utilization point of view, supplementary solar energy-derived heat for the library would not be efficient. However, solar energy can prove attractive where the cost of electricity is high and the installed heating system permits easy adaptation to supplementary solar energy-derived heat. We believe, however, that a more detailed study of the use of central plant steam to heat the library will prove to be more cost-effective than solar energy.

Hot water demand is usually uniform and of significant size. The mounting of a solar energy collector on the Ball Cage was considered because the installation would not detract esthetically from the school. The fact that the majority of the masters' dwellings employs tankless hot water heaters (uses the heating system to make domestic hot water) led us to a study of their operation.

We believe that our studies can result in the development of opportunities for students and non-technical staff of St. Mark's School to become involved in energy conservation, a critical area for our nation's future.

Physical plant personnel alertly uncovered opportunities for conservation and carried out many of our suggestions on the spot or in a very short time. A summary of our efforts and suggested near-term improvements is given in Table 1.

Table 1

Summary of What Was Done

1. General Survey of Facilities
2. Survey of Space Conditioning and Institutional Factors by MIT's Environmental Engineer
3. Developed Preliminary Patterns of Energy Consumption Based on Business Office Records
4. Arranged for an Independent Late Season Measure of Efficiencies of Oil Fired Furnaces in Masters' Dwellings
5. Explored Waste Heat Use and Potential of Compression Ignition Electric Plant
6. Made a Preliminary Feasibility Study of Substituting Steam for Electric Heat in the New Library
7. Suggested On-the Spot Improvements:
    - Shut off ventilation air in winter
    - Close damperless fireplaces
    - Measure condensate return losses--look for leaks indicated
    - Improve casement window closures
    - Time clock control of heat and electricity
    - Cage losses, snow load and steam melting
    - Insulate pipes
    - Investigate modulating controls
    - Insulate roofs of older buildings
8. Investigated a Solar Heating Supplement for the New Library
9. Conducted On-Site Infra-red Survey
10. Developed a Preliminary Design Concept for Demonstration of Solar Assisted Domestic Hot Water Heating in One Master's Dwelling.

II. Specific Investigations and Results

A. An Energy Flow Chart for St. Mark's Physical Plant

Today, energy flow is as important to proper management as cash flow. Good energy management requires a "road map" or "navigation chart" of the physical facilities. An energy flow diagram permits the development of an energy budget and an energy audit.

In fuels engineering energy flow diagrams are known as Sankey diagrams. These diagrams cannot be made at one sitting. They evolve from the best beginning possible, and as better information is gained, are modified and corrected. The importance of beginning as soon as possible with whatever is on hand cannot be overemphasized. It is only from this start that one can learn of the need for and nature of additional information (Appendix XIX).

We attempted a "beginning" by trying to obtain a layout (plan) of the St. Mark's buildings, the interconnections for water, heat, electricity and hot water, major controls such as switches and valves, metering equipment, and locations of the energy transfer and conversion stations.

The only data available were on a drawing prepared by or for the New England Fire Insurance Rating Association in 1953. It does not include several new buildings, nor does it show utilities. There were records of fuel consumption from fall 1973 to spring 1975 and some incomplete notes of varying detail and manufacturers' flyers on some equipment.

The drawing did and can continue to serve as a beginning. The routing of supply lines, areas serviced by them, location and characteristics of devices, etc., are not now known in any detail and must be added. The location and function of thermostats (some may no longer be connected to controls) and the areas and/or rooms which are affected must be included. Sometimes thermostats located in one room affect temperatures of rooms and areas quite removed from the sensing point.

From the energy flow chart it should be possible to learn:

(a) where and in what form energy is generated and with what capacity;

(b) where and in what way energy is transformed (converted from steam to hot water);

(c) the complete paths of all transmission systems;

(d) the location, function, and characteristics of each component in the system;

(e) the location, function, and characteristics of control sensors;

(f) the location, function, and characteristics of controls;

(g) the buildings, rooms or areas affected by each existing control sensor.

For an excellent procedure on the development of energy use profiles and identification of energy conservation opportunities, it is recommended that the Plant Engineering and the "Energy Conservator" as well as the Business Manager each obtain a set (two volumes) of "Guidelines for Saving Energy in Existing Buildings." Volume 1 is Conservation Paper Number 20, "Building Owners' and Operators' Manual - ECMI, FEA/D-75/359. Volume 2 is Conservation Paper Number 21, "Engineers', Architects' and Operators' Manual - ECM2, FEA/D-75/358. Both are obtainable from the Office of Buildings Programs, Federal Energy Administration, Washington, D.C. 20461. Together these contain over 700 pages of first rate information.

Steps, such as illustrated in the following figures (Nos. 1 through 7) should be taken in the development of a flow chart of energy at the St. Mark's School:

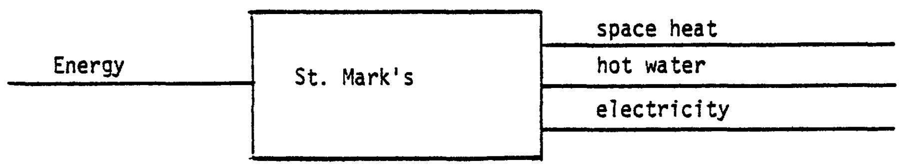

Fig. 1

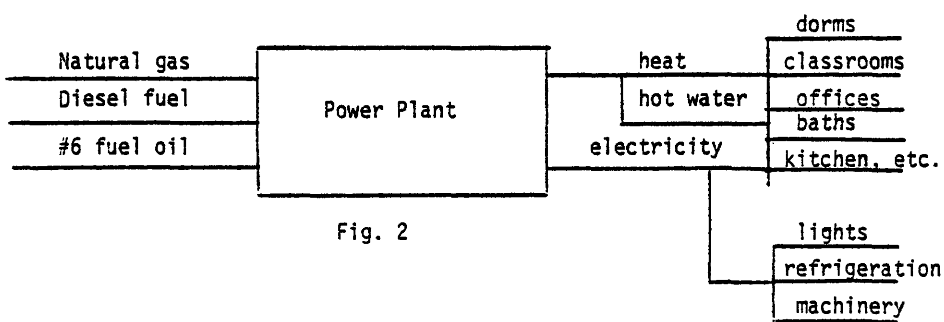

Fig. 2

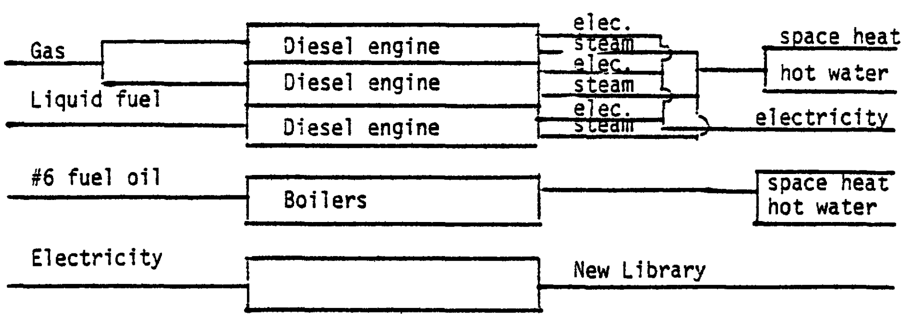

Fig. 3

Now start considering individual components:

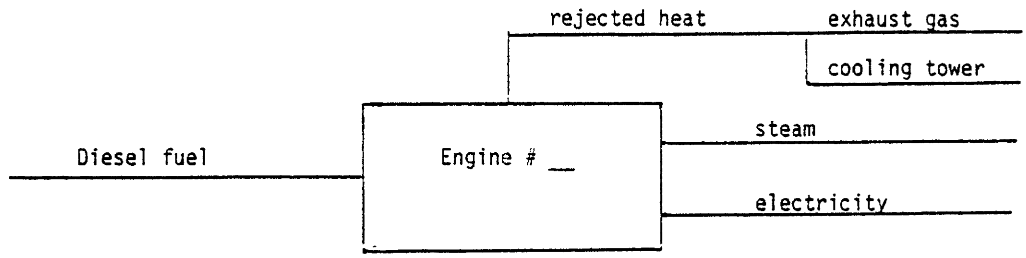

Fig. 4

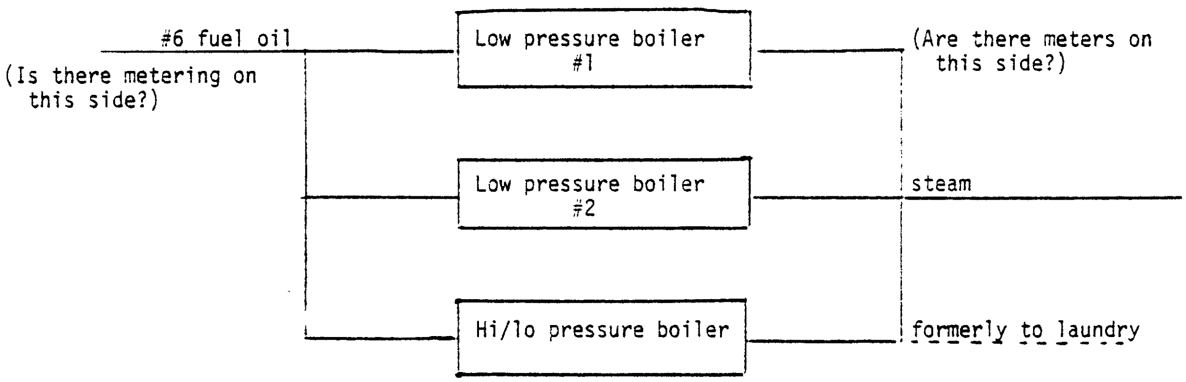

Fig. 5

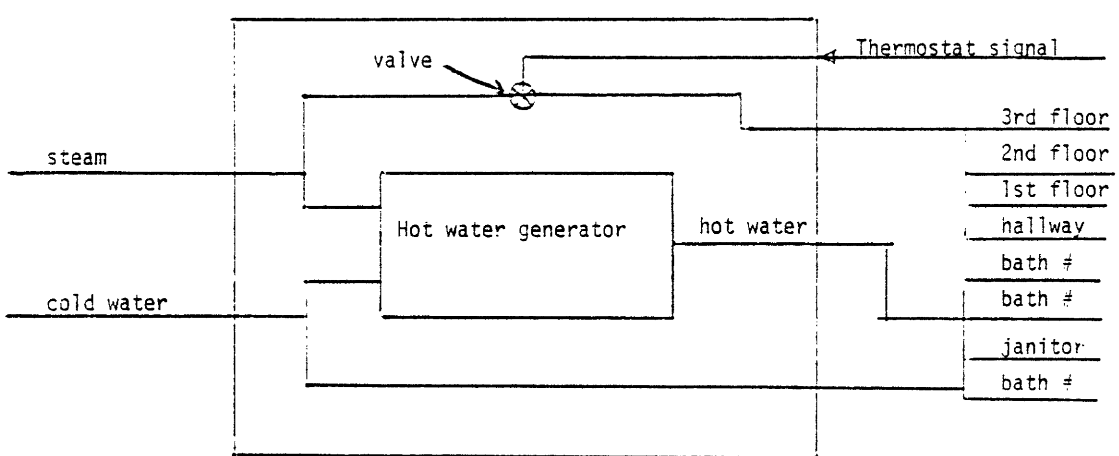

Fig. 6

Continue the process but examine each step well for clues as to where energy is not necessary or not being used efficiently, and control is indicated.

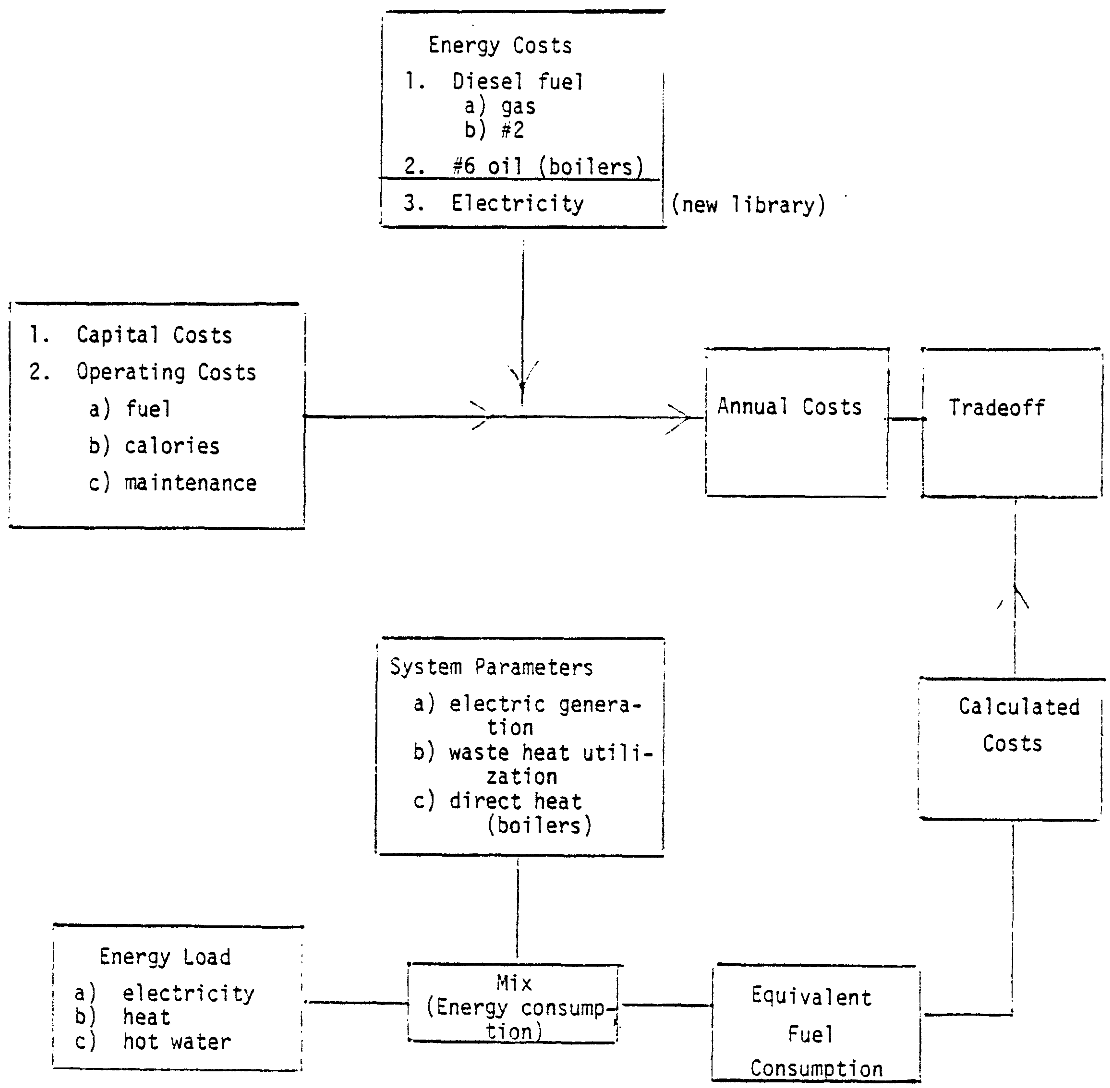

Fig. 7

Suggested Guide for Calculating Comparative Costs

NOTE: (1) Include in all calculations

a) heat rate
b) waste heat capture
c) electrical generation

rated load
half load
1/3 load

(2) Compare

a) purchase all electricity
supply only heat/hot water
b) total energy system
c) seasonal mix
TE in winter
purchase other time

Continue this process but examine each step well for clues to opportunities to improve conversion and use. Isolation of various loads under difficult conditions may be warranted.

For example, in Figure No. 6 there is a symbol ⊗. It indicates a switch or valve that permits one to shut off and disconnect a portion of the system or component. The symbol is present in all fuel supply lines but only in the output of the electrical system. There are none in the steam lines.

We checked the boiler piping and the heat recovery portion of diesel generators. This means that when a single diesel unit and/or a single boiler was operating, steam was being fed into the inoperative units and heating them uselessly. Therefore, automatic back pressure valves should be installed in the output pipes of each engine and boiler.

When this recommendation was made we were told that, as originally designed as constructed, there were back pressure valves in the piping to prevent waste of steam, but they had been disconnected and some had even been removed because of troubles.

This approach to correcting the trouble may have been easy then but it is expensive now.

As one proceeds, numbers should be introduced. The same number of Btu's purchased as electricity or fuel should be accounted for in the delivery system, whether used or rejected.

One will find that energy cannot be accounted for and that one "customer" uses much more or less than a similar one. It is time, then, to investigate and probe and not to give up until a scientific explanation can be had.

If similar units use approximately the same amount of energy, it may mean that all are operating inefficiently and wasting the same amounts of energy,

Recommended Conservation Measures

- Improve control systems of buildings and heating plant
- Reduce air filtration losses
- Improve furnaces in masters' dwellings
- Improve insulation on accessible pipes and ductwork
- Install insulation in selected buildings
- Install storm windows

B. The Main Complex

Management, Control and Scheduling Heat Allocation

1. Scheduling

Different rooms on the same floor, and different floors of the same building section, have demands for heat which vary widely in amount and in time schedule. This is due to orientation (north, south, etc. facing), activities conducted therein, and occupancy schedules.

To meet these different requirements the solution at St. Mark's seems to have been to supply at least enough heat for the coldest areas at all times. To reduce over-temperatures in those areas that were uncomfortably warm, windows were opened and left open long after occupancy. We observed examples of this throughout our study.

The prudent thing is to supply only enough heat to each area, when the area is occupied, to raise the temperature to the comfort level for the activity taking place in that area. When not occupied, the temperature should be maintained at a much lower level. Such "scheduling" costs little or nothing and can provide important energy savings. General guidelines are:

(1) Do not heat buildings when they are unoccupied (except for pre-heat periods required to raise the rooms' temperatures to 68°F prior to occupation).

(2) Shut down heat before the end of the occupied time thus using the buildings' thermal capacity to maintain comfort, for the rest of the time.

(3) Determine the "pre-heat" and "before close" times for various areas by experiment.

(4) Take into account the activity and the number of people who are normally present.

This can be easily accomplished with modulating valves, temperature regulators, and time clocks. Modulating control valves would permit delivery of only the required amount of heat (steam, hot water, air) as called for by a thermostat locating in the area of interest. Further, the supply would be governed by a time clock to cut back the ambient temperature during periods of scheduled non-occupancy. (For example, the gymnasium is now heated day and night to the same level.)

Thermostats, sealed against unauthorized adjustment should be set from experience. Manual shifting of the thermostat settings proves to be unreliable even if responsibility is definite and limited. Clock-controlled thermostat settings will provide automatic lowering and raising of the temperature during scheduled unoccupied and occupied periods. The time clock can be programmable and set so that during "non-occupied" periods, the temperature is maintained only at a "stand-by" level by the thermostat. The temperature should be allowed to increase and to maintain the "occupied" level during pre-specified periods as directed by another portion of the thermostat.

Tables 2 and 3 indicate the daily, weekly, and seasonal schedules of the school for an average year. Presently, the policy is to continue to maintain the same temperature whether or not an area is occupied. This is a habit that can be easily and profitably altered. There is no need to heat the rowing tank rooms, or the auditoria, etc., to the same temperature 24 hours per day, 7 days per week for nine months of the year.

Table 2

SCHEDULED USE OF PLANT FACILITIES

ST. MARK'S SCHOOL

FALL & SPRING DAYLIGHT SAVING TIME		WINTER:EST
Rising bell	6:45 a.m.	The same except for a two-week period between fall and winter sports programs during which the Gym is used one hour earlier.
Breakfast	6:45 a.m. to 7:;5 a.m.	
Staff (kitchen)	6:00 a.m. to 8:00 p.m. (with an hour break in mid-morning and 1 hour mid-afternoon.)	Hockey Rink 3:00 p.m. to 11:00 p.m. SM & community use
Clean-up work program	7:40 a.m. - 8:00 a.m.	
Assembly in Benson Auditorium	8:00 a.m. - 8:15 a.m.	
Classes	8:20 a.m. through 2:20 p.m.	Cage (tennis) 9:00 a.m. to 10:30 p.m. SM & community yse
Cafeteria lunch	12:00 Noon to 1:15 p.m.	
Activities (rehearsals, choir practice, meetings, etc.)		
Sports (Field House) Gym	3:00 p.m. to 6:00 p.m.	
Chapel (Tu., Th., Sun.)	6:00 p.m. to 6:20 p.m.	
Dinner	6:20 p.m. to 7:00 p.m.	
(Kitchen - see bkft. above)		
Study Period	7:30 p.m. to 10:00 p.m.	
Library closed	10:00 p.m.	
In rooms	10:15 p.m. to 11:00 p.m.	

WEEKENDS

Essentially same, but with more extended use of Field House (Gym)

Table 3

AVERAGE YEAR SCHEDULE

Periods	Ranges
Start of School: (early varsity sports - 7th to 10th)	mid-September (14th-18th)
Thanksgiving Recess:	Wednesday to Monday (Nov. 26 period)
Christmas Vacation:	December 16th to 18th/January 4th to 6th
Mid-winter Weekend:	February 4th to 6th / February 7th to 9th, Thursday to Monday
Spring Vacation:	March 12th to 16th/April 1st to 5th
End of School:	June 4th to 8th

NOTE: Use of school buildings during summer months has been minimal (i.e., summer tennis camp last year only). We* would, however, like to develop use of facilities during the summer vacation period.

*St. Mark's School. Material for Tables 2 and 3 furnished by the school.

We recommend that each definable section have its own valve, thermostat and clock. The schedule for furnishing "occupied/non-occupied" energy should be prepared for areas, buildings and, if possible, rooms. Time clocks (24hour/7day) and dual thermostats are set for those conditions. Charts, similar to that of Figure 8, should be prepared, reviewed, approved and posted. "Over-ride" to extend both the "occupied" and "unoccupied" conditions can be included but must have an automatic re-set to the normal schedule after one day on the "occupied" override settings. This is a simple, easily duplicated, direct system. It would be easily understood, operated and maintained by present personnel.

In all cases of heat control, one should insist on thermostats and valve operating motors that are capable of proportional response. A proportional control system is one in which the steam valves are automatically positioned at the point between fully open and closed that results in the delivery of steam in the exact amount needed to maintain the desired temperature.

Computer Control

There are schemes by which a multiplicity of situations in a huge complex can be controlled from a central point by a computer. Considerable effort is required to arrive at the optimized system and a relatively high level of resident, technical skill is necessary for programming, adjustment, and maintenance.

The computer is an accurate and sophisticated instrument that can replace some manpower in energy management (heat and light loads). The computer, as fast and reliable as almost any machine, is no more accurate nor sophisticated than the software (programmed instructions) that it receives. The person(s) who prepares the instructions controls the accuracy and degree of sophistication. The programmer must have accurate, consistent and detailed information about ambient (internal and external) conditions and a philosophy of behavior under a multiplicity of situations for the computer to be effectively employed.

The computer needs all the information required for proper manual management and control, and sometimes more. The computer cannot give you an energy flow chart--you must provide it with one. A computer control system is only cost-effective if the total demand charges and electric energy costs' total are in excess of $12-$15K per month and there are data and personnel to make it work.

A COMPUTER SYSTEM IS NOT RECOMMENDED AT ST. MARK'S UNTIL MANY OTHER IMPROVEMENTS WILL HAVE BEEN MADE.

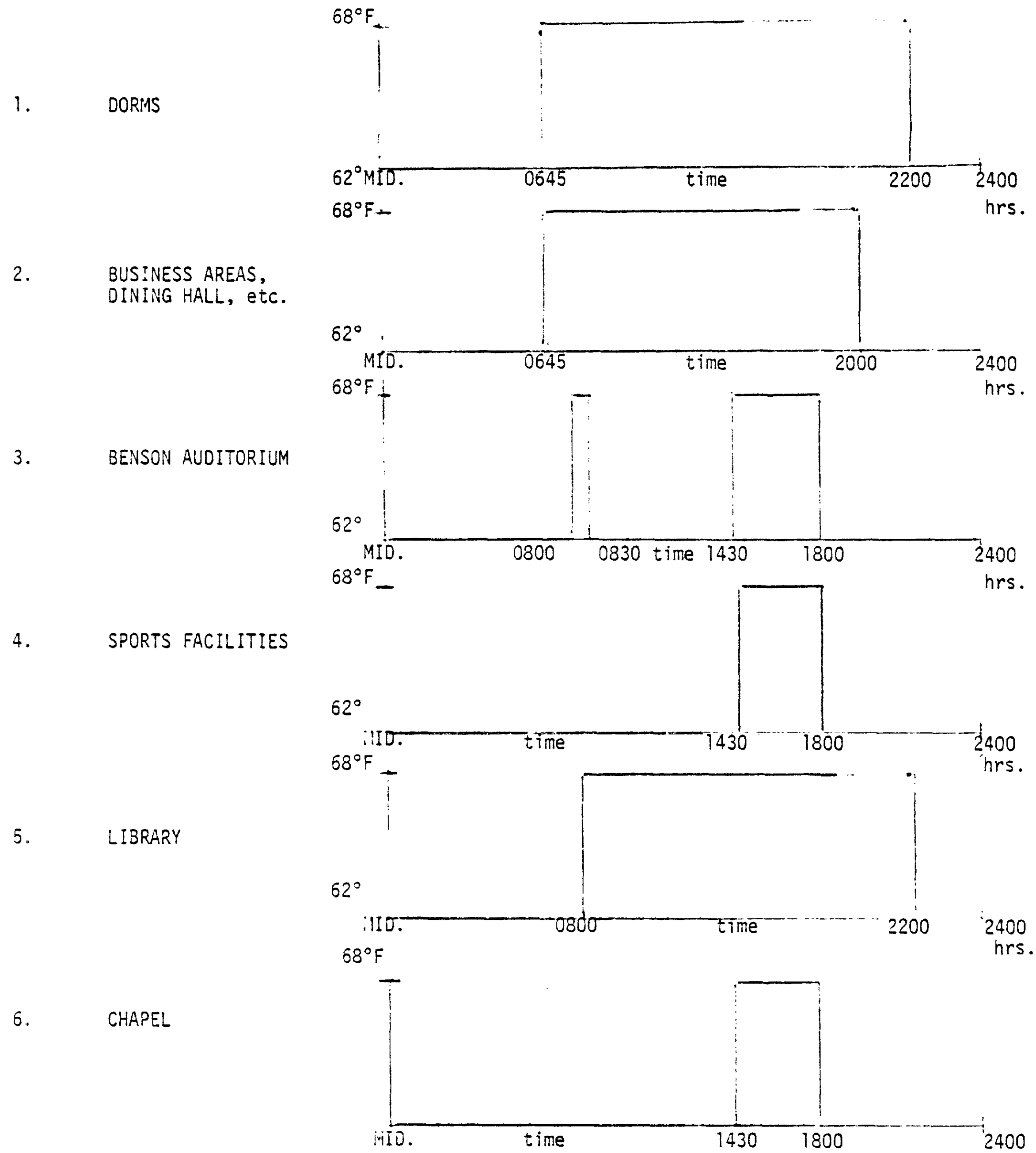

Fig. 8

Area Heating Schedules

Notes: 1) Must be adjusted for the thermal time lag of each space

2) Modify for weekends and holidays

Thermostat Locations

We have to comment on the present situation at St. Mark's where sensors frequently monitor temperatures at points quite removed from the locations being heated. In addition, the locations have widely different functions, hence widely different heat supply needs. A few examples follow:

I. A thermostat is located in the plant engineer's office. The office has southern exposure. It controls the heat to:

- (a) shops on the same level that are separate rooms and isolated from the office by corridors. The engineer's office and shops are occupied from about 0645 hours until 1600 hours. The shops face east and north.
- (b) main dining room located one floor above that has forced hot air and radiators. The dining hall is two stories high and has north, east and southern exposures with large expanses of single pane windows. The dining hall is occupied for two and one half hour periods three times per day.

II. The thermostat for Dormitory E is in the House Master's living room. There is rationale for this if the thermostat is subject to adjustment. However, it is possible to prepare tamper-resistant housings and, coupled with the "conservation and stewardship ethic" that should be part of the community's attitudes, tampering problems should be minimized. More to the point, we are not convinced that all portions of Dormitory E require equal amounts of heat at all times.

III. The thermostat in Mr. Gardner's office controls heat supply to the second and third floors of the south wing (west side only).

IV. There is a pair of differential thermostats, one outside in the eaves and one in the House Master's quarters, that control the heat in Dormitory C.

V. There is a heating sub-system under the chapel corridor that supplies heat to classrooms, the second floor dormitory and one other room in West 2.

The whole of St. Mark's School must be reviewed room by room, hallway by hallway, to determine what the heating requirements are and what the present sensor, control, supply situation is. Sections of a building that have similar scheduled occupancy and somewhat similar heat requirements can be grouped for heat control and controlled by a single thermostat. Sections for which the occupancy schedule and the heat requirements are different, should have individual thermostats or radiator-mounted thermostatically controlled valves (Appendix XX).

2. Control: Energy Management by Scheduling

Scheduling costs little or nothing and can provide important energy savings. General cautions are:

1. Do not heat buildings when they are unoccupied (except for pre-heat periods required to raise the rooms' temperatures to 68°F prior to occupation).
2. Shut down heat before the end of the occupied time, thus using the buildings' thermal capacity to maintain comfort for the rest of the time. Building "heat-up" and "heat-loss" characteristics differ. Within a building the rate of temperature change will differ floor by floor.
3. Determine the "pre-heat" and "before close" times for various areas by experiment.
4. Take into account the activity and the number of people that are normally present.

C. REDUCTION OF AIR INFILTRATION

Proper adjustment of a control system is difficult, if not impossible, if air infiltration is random. Air infiltration is air leaking into and out of buildings through cracks, open windows. It is a heat loss or gain. There can be heat loss through a tight building. Air infiltration is not required for ventilation and is costly. Proper adjustment and balance of control systems and the elimination of uncontrolled air infiltration losses are next in importance in the several stages of improved and efficient energy use.

1. Windows

Open windows should not be required to correct for overheating. We discussed this in a previous section. Windows, therefore, in the winter are for light and view only. Each window in the school should be inspected to see if it closes properly and that its operating mechanisms are in good order. We noted a number of casement style windows with broken actuators. It was impossible to close them. In some older buildings, properly installed fitted storm windows reduce heat loss more by reducing infiltration (around the original windows) than by the improved thermal insulation they present. If the existing window sash does not fit tightly, it might be better to first install storm windows and then, at a later date, repair the sash.

2. Vents

Vents should have flaps that close securely when not needed.

A skylight in one bathroom was always observed open about two inches. It was not possible to close it completely. The radiator valve in the bathroom was "closed" but the radiator was very warm.

3. Doors

Stair wells, hallways and corridors, combined with poorly closing entrance doors, present fire hazards in addition to causing considerable heat loss. Many outside doors do not fit properly, a result of many years of operation and the abuse inherent in youthful vigor. Most of these doors open into stairwells so that the "stack" or "chimney" effect worsens the leakage and distributes the cold outside air to upper floors.

A calculation of the openings around and between one pair of doors at a single entrance door at the school indicated that the air flow was the same as if a window were wide open. This situation prevails to some degree at over 75% of the entrances.

Rugged, self-closing "institutional" type doors along with entrance vestibules, wherever possible, should be considered. The revolving door is effective in reducing air infiltration through high-traffic entrances but there may be little opportunity to use them at the school.

All doors should be inspected once a month to insure proper and complete closure.

Advanced designs of weatherstripping are available today that can do much to correct leaks resulting from wear. In some cases, however, door jambs will have to be repaired and hinges straightened and tightened.

4. Fireplaces

School fireplaces are often used in the evenings. Dampers were usually open when the fireplaces were not in use. Several of the fireplaces have no dampers. Severe drafts could be felt.

The average fireplace is approximately 10% efficient and, in addition, siphons about 400-500 cubic feet of room air, that has been heated by expensive oil.

Benjamin Franklin was concerned that, because of the demands of fireplaces for wood, trees surrounding Philadelphia had been cut down so extensively that men, horses, and wagons were beginning to have to travel for more than one day in order to bring back one day's supply of firewood. This meant that wood had to be collected all through the spring, summer, fall and winter.

He improved the design, making fireplaces smaller, enclosing more of the masonry within the living quarters, and made suggestions which were included in the now famous "Franklin stove".

Central heating systems have replaced the fireplace as a necessary device. The principal energy (oil) cost of a fireplace is when it is not used and the damper is open.

Fireplaces at St. Mark's are at once unnecessary and necessary. The task, therefore is to reduce the cost of use to a minimum.

One should not expect anyone to remember to come back, after the fire is completely extinguished and, having determined that there is no possibility of combustion gases coming off, to close the damper.

A recommended solution is to install fire-tempered glass enclosure doors. These doors reduce heat loss. They permit the visual effect and pass radiant heat. They prevent the heated air of the room from being drawn up the chimney when there is no fire.

With glass doors the supply of air from the room is cut down, the fire burns more slowly, permitting it to radiate a larger portion of the generated heat through the glass into the room; the flue temperature is reduced and the amount of wood burned in one evening is lower.

An alternative to the glass fire enclosure would be to provide one of sheet metal which could be put in place by the last person to leave the room. Painted a flat black, the metal enclosure would be attractive and would transfer more heat to the room, when in place, than would the glass enclosure. Disadvantages include the need of a place to store the enclosure while enjoying the open fire in the fireplace, and the necessity of one hundred percent cooperation in seeing to it that it is in place when needed.

D. THERMAL INSULATION*

1. Storm Windows

It is not possible to operate a heating system economically in buildings without storm windows or "thermopane" glass. The resulting savings factor is one of the highest values of conservation measures.

Elsewhere we discuss heat supply procedures which will result in the occupants of all rooms being obligated to keep the storm windows shut in order to be comfortable.

If storm window designs are not chosen properly they may alter the appearance of a building. This can be avoided at St. Mark's. The frames' dimensions, configurations and reinforcing bars can be adjusted, located and painted so that they are not easily noticed. There are already storm windows painted black at certain windows around the main entrance lobby which are very unobtrusive. At "leaded glass" types of "memorial" windows and other fixed windows where the storm window needed never be opened, single glass panes or single sheets of rigid plastic can be used.

2. Roofs

Attic (roof) insulation is another one of the very important energy-saving improvements that can be made at St. Mark's. There are uninsulated warm air duct systems in uninsulated attics. The roofs function only to keep out rain or snow. The heat loss must be considerable. At this latitude, all roofs (attics) of occupied buildings should have the equivalent of 6 inches of glass fiber batts. In the Benson building (theater) insulation properly installed and left uncovered would also contribute favorably to the acoustics.

3. The Insulation of Pipes and Ductwork

In a central utilities plant which includes an extensive pipe distribution system, such as that at St. Mark's, very substantial energy savings can be realized by the installation and the careful maintenance of insulation on steam and hot water pipes, on air handling ductwork, and on the pumps and heat exchangers.

In our survey we observed considerable overheating in tunnels (basements) and other interior spaces containing the heat generation, conversion, and distribution systems. In some areas overheating is so bad that basement windows are permanently left open in order to keep the area cool. In other

*see Appendix XXI

areas outside air is admitted through louvers, purposely left ill-fitting doors and other cracks, as necessary to maintain comfort.

It is instructive to compare the losses for hypothetical cases of a hundred feet of 2 1/2 inch pipe carrying six pounds of steam (250°F) in the insulated and uninsulated condition. The uninsulated steam pipe loses 33,000 BTU (which requires 1/3 gallon of oil to make) per hour. If one inch of insulation is installed the losses drop to 4,500 BTU (1 1/2 ounces of oil) per hour.

The production of this heat loss costs about 13¢ an hour (this year). We estimate that the cost of installed insulation per 100 feet will be $200, therefore, recoverable in only 2000 hours (85 days) of operation.

With improved insulation on pipes and ductwork, further savings will be realized because tunnels, mechanical rooms, access ways, etc. will no longer be so badly overheated as to require the admission of cold outside air and louvers, windows, etc. will be sealed.

Pipe insulation is frequently not replaced following repairs because of the emergency nature of the repairs or perhaps the press of other work. Sometimes insulation is omitted because it interferes with needed access or with the operation of a component such as a valve. Where frequent access is needed the use of aluminum foil insulation can help reduce losses while providing the accessibility needed.

4. Caulking

There is unmistakable evidence of heat leaks in most buildings around window and door frames. All window and door frames should be recaulked on the outside. Black caulking compound would blend with the black painted framings.

5. Garage

The garage is a major source of energy (heat) loss. There is no insulation in the walls or roof. One can see the sky through openings in the roof. The doors and windows fit very poorly.

Heat was originally furnished by an oil fired furnace located in the basement of the building, a converted barn. The furnace broke down in 1975. A steam line and condensate return were installed between the Central Power Plant and the garage. The pipes were routed through an abandoned conduit which passes under the county-owned road that bisects the school-owned property. Neither these pipes nor the underground conduit are insulated anywhere along their lengths. Within the garage, most of the insulation on the distribution system has been removed. Several of the steam traps and radiator valves leak both steam and water.

The record for fuel oil consumption for the garage, when the furnace was operable, follows:

Year	Gallons of Fuel Oil	Cost
71-72	5271.1	$ 939.94
72-73	3544.4	$ 615.82
73-74	3116.0	$1072.66
74-75	3088.0	$1092.41

3 year average - 3250 gallons

Annual Btu's required assuming 60% boiler/furnace efficiency

$3250 \times 0.6 \times 14000 = 2.73 \times 10^9$

275×10^6 Btu/yr.

600 degree day/year (average for Southboro, Mass.) 2 degree day/gal.

50,000 Btu/degree day

One can reasonably assume that heat energy consumption is much higher now.

We were told that the valves, regulators, steam traps, etc., in the garage have deteriorated since the steam pipe was connected. Further, with unlimited steam being furnished by the Power Plant, the place is much more comfortable.

The garage cannot be easily repaired and insulated. We believe that a quite different solution presents itself and should be explored.

There is an abandoned coal "bin" next to the Power Plant. The walls can be reinforced with poured concrete, an asphalt floor laid and a simple roof installed.

There is a very large amount of heat present in the Power House that has to, and is, vented to the atmosphere. This heat can be passed through the garage extension before it is vented to the outside. No steam would have to be furnished. There would be a 100% savings.

In our discussions with staff there was total agreement as to the feasibility and good sense for such a move. However, they were quick to point out the advantages of including additional features in the coal bin modification plans. Typical was, "...while we are at it, we could make the roof strong enough to serve as a parking area."

This is the trap into which we are all apt to fall.

We start out with a simple plan to cope with a single problem. The plan might cost $6000. We rationalize that "while we are at it, it would make sense to...and...,etc." We end up with an elaborate solution that costs many times more than is necessary. The original purpose is frequently lost altogether.

A minimum garage, utilizing the existing foundations and piers of the coal bin, makes economic sense. Any monies available for elaboration can be better spent elsewhere in the school for repairs and modifications to further decrease the cost of energy at St. Mark's.

6. Insulation Behind Radiators

Radiators near outside walls not only heat the rooms but deliver large amounts of heat directly to the outside. The amount is much in excess of that lost through the wall where there is no adjacent radiator. The additional heat loss occurs directly behind the radiator. Figure 9 illustrates this. The heat loss numbers assume a standard wall construction.

This loss is relatively easy to reduce. Cover a sheet of insulation (the rigid type is easier to handle but not necessary) with an aluminum foil, the shinier side facing the radiator. Insert the assembly between the radiator and the wall. It is best not to allow the insulation to touch the radiator but no special effort need be taken to avoid contact.

The staff at St. Mark's can make a schedule for so many such installations per week and perform the work at almost any time.

WE STRONGLY RECOMMEND THAT THE FOLLOWING TWO VOLUMES BE PURCHASED AND USED AS GUIDES IN ENERGY CONSERVATION:

"ENERGY CONSERVATION GUIDELINES FOR SAVING ENERGY IN EXISTING BUILDINGS" Vol. I,
Conservation Paper Number 20 ECM-1

"BUILDING OWNERS AND OPERATORS MANUAL" Vol. II, Conservation Paper 21
Engineers, Architects and Operators Manual ECM-2

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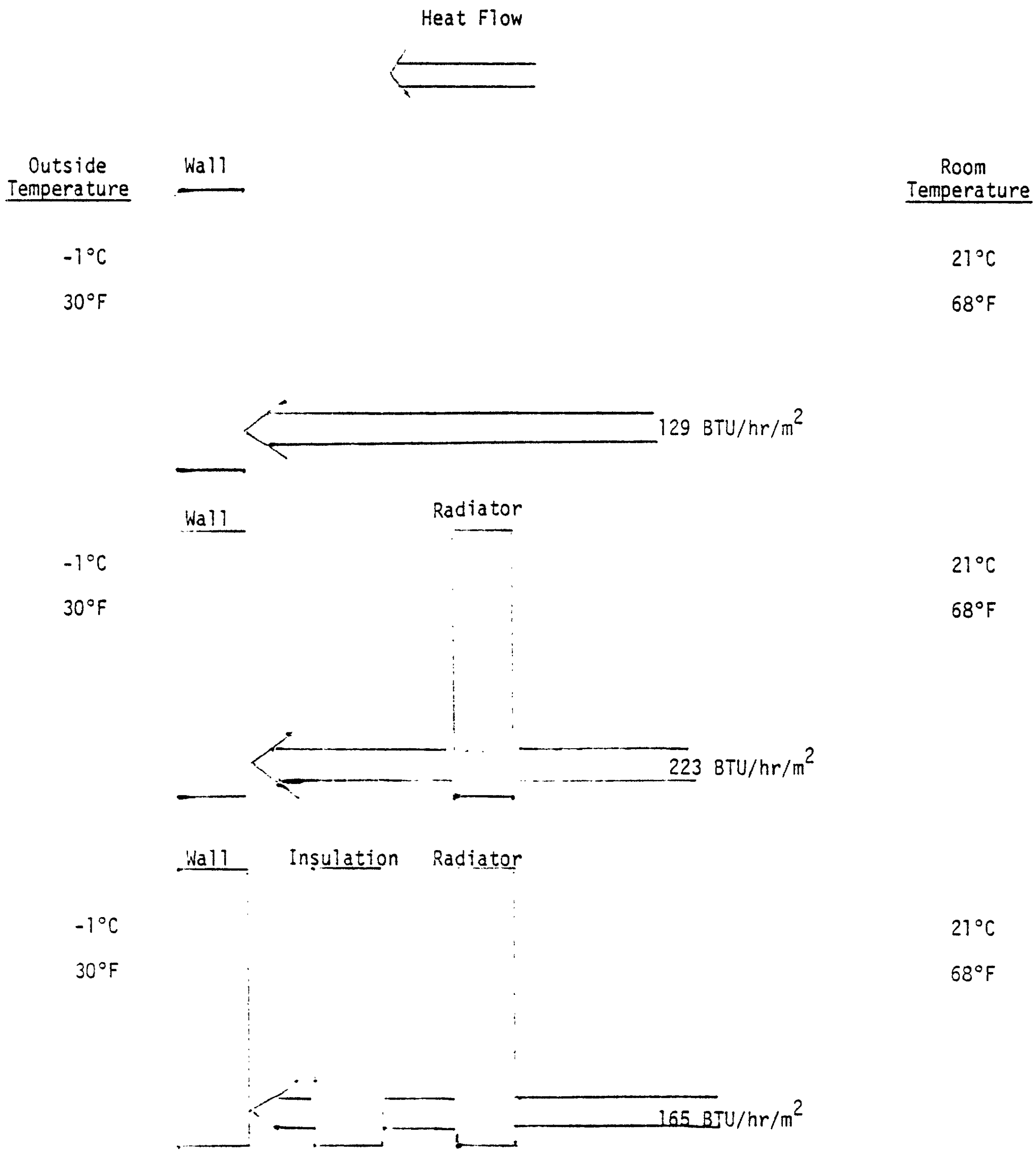


1 sq. meter = 10.76 sq. ft.

Figure 9

Heat Loss Behind Radiators

E. ENERGY CONSERVATION

I. Lighting

1. Light Levels

There are opportunities for energy and therefore money savings in lighting. (Appendix IV)

Over the past 30 years there has been a nationwide trend towards higher and higher light levels. This trend has resulted from the belief that low illumination levels are a hazard to good eyesight. Low light levels have been shown to be no more of a hazard to your eyes than soft sounds are to your ears. While both extremes should be avoided, light levels certainly need not be the same in hallways and in work or living areas.

Inadequate light for a task such as reading can lead to fatigue and tension. At low light levels the pupil of the eye enlarges to let in more of the light. At larger pupil openings, the depth of focus of the eye's lens is not as great (just as in the case of a camera operating with a large aperture stop). The eye focuses by changing the shape of the lens so that, when the depth of focus is small, corrections are frequent and critical for good visual acuity. These efforts at correction result in fatigue and tension.

Over-illumination and glare should be avoided because they can damage the eye as well as produce fatigue and tension. In high levels and glare, the iris must make frequent compensating adjustments to accommodate the eye to high and changing levels. We have reason to suspect that today's complaints of fatigue and tension are more often caused by over-lighting than under-lighting.

Appendix IV contains a form, Table 8, that might be established for the lighting/lamp schedule of St. Mark's.

> "Recently completed building lighting system designs have shown that office buildings and stores can be adequately lighted with an average of about 2 watts/sq. ft., and religious buildings and parkinglots with 0.5 watts/sq. ft. There are many opportunities in existing buildings to reduce energy consumption by lighting to the levels suggested in ECM-1. For instance, existing windows can be used advantageously for day-lighting to reduce lighting electrical requirements by using existing or new switches to turn off lights at the perimeter when daylight is sufficient; task areas are well-defined, therefore non-uniform lighting can be provided to suit them; equipment with greater lighting efficacy is now available; and building usage has been established, permitting programming of systems to light spaces to the levels they require on a selective, as-needed basis. Caution: Some areas have minimum allowable light levels - refer to O.S.H.A. requirements as outlined in ANSI A11 1-1965 (R-1973)." *

2. Use of Light

There is the ill-founded belief that it is cheaper to allow the lights to remain on than to turn them off. The circumstances under which this is true are in the minority.

*"Energy Conservation, Guidelines for Saving Energy in Existing Buildings", FEA, Washington, D.C.

The lives of incandescent lamps and fluorescent lamps and their associated ballasts are shortened by frequent switching. One should follow this rule of thumb: "Only if a lamp is to be used within less than 20 minutes is it more economical to leave it 'on'."

3. Sources of Light

A most important opportunity for saving energy in lighting is to take advantage of daylight when it is available. Too often large rooms with windowed walls are uniformly lighted by artificial means because some of the interior areas are inadequately lit by daylight. This is because all the lights in a room are controlled by but one switch. If this is the case, the feasibility of installing additional switches should be explored. Sometimes strategically placed small individual lighting can correct imbalances resulting from daylighting.

4. Substitution of Lamps

Avoid replacement of one type of lamp with another on a wattage rather than an illumination basis, for instance, do not replace a 500-watt incandescent lamp with a 500-watt high-intensity discharge lamp or 500 watts of fluorescent lamps. Instead determine what level of illumination is needed, then choose the lamp required.

For example, if it is agreed that the light from the 500-watt incandescent lamp is sufficient, we accept a light level of 10,500 lumens (21 lumens per watt) being furnished by the incandescent lamp which has a lifetime of only 1,000 hours. In weighing possible replacement with a high-efficiency lamp, we could choose one of the following:

a. A mercury lamp that delivers 11,500 lumens (46 lumens per watt) from a 250-watt lamp which has a lifetime of 24,000 hours. The mercury lamp will provide 10% more illumination at 1/2 the energy cost and has a lifetime 24 times that of the incandescent.
b. A metal halide lamp the delivers 12,150 lumens (70 lumens per watt) from a 175 watt lamp which has a lifetime of 12,000 hours. The metal halide lamp provides 20% more light at 1/3 the energy cost and has a lifetime 12 times that of the incandescent.

Substitution of either of these lamps would provide large savings in lighting energy costs without any lowering of the light level.

5. Maintenance of Light Sources

We point out that lighting fixtures must be kept clean to remain efficient. Scheduled cleaning of fixtures, reflectors, diffusers, and lamps is essential to maintaining proper illumination levels at lowest energy costs.

Recommendations

a. The trend has been to over-illumination. Recommended lighting levels are attached as Appendix IV.
b. Turn off lights that will not be used within the next half-hour.
c. "Decorative" lighting should be eliminated where no longer appropriate. Where appropriate, such lighting should be used only when "decoration" is desired.
d. Incandescent lamps should be replaced, as feasible, with fluorescent lamps. The complaint that fluorescent light is "harsh" can be avoided by proper selection from among the types, e.g., "cool white", "deluxe warm", etc., now available.
e. Outdoor night lighting should employ high-intensity discharge units. These units can have 80% conversion efficiency even after 16,000 hours of use.

II. HOT WATER CONSERVATION

It is difficult to introduce and effectively maintain an ethic of water conservation. Americans have taken to heart the saying, "Cleanliness is next to godliness" and now lead the world in consumption of water for sanitary purposes. This national habit will be voluntarily modified, if at all, only over a very long period of time.

While we have not made direct measurement of the average water consumption per student, our observations of a typical day suggest that it is higher than the national average, principally because of the showers following athletic activities.

There are devices which can be placed in the bath fixtures which will reduce the flow rate without attracting attention. Appendix V includes a description of one such device with comments by an office of a Sheraton Corporation hotel. We do not recommend the particular brand exclusively. We do recommend that it or similar devices be placed in all faucets. Appendix XXI is a copy of the section on domestic hot water in the "Guidelines for Saving Energy in Existing Buildings" cited above.

F. THE NEW LIBRARY

1. General Description

The new library is an all-electric building independent of St. Mark's central utilities except for a 2 1/2" steam line which provides low pressure steam for winter humidification. The library is served on a B-1 rate by the Massachusetts Electric Company (Appendix VI), an investor-owned utility. Electric power usage is metered separately. Monthly consumption is plotted in the histograms of Figures 10 and 11.

Heating and cooling are derived only from electricity. The air conditioning system employs electrical resistance duct heaters modulated by solid state controlled rectifiers and relays.

The air handling system consists of a duct distribution system with fixed dampers controlling the ventilation air taken into the building. We understand that outside air must be shut off in winter to permit the building to be heated adequately. In a building with high traffic such as this particular library, incidental outside air infiltration is usually entirely adequate to provide the necessary exchange fresh air.

Electric motor-driven centrifugal chillers generate the chilled water needed for cooling and dehumidification. The chilling capacity is more than adequate for the building load, particularly because the building is only lightly utilized during the summer months.

Our Findings

During our survey of the building there was evidence that the central system is not working well. A heater control relay was chattering, an indication of some circuit or control problems. We heard reports of difficulty in maintaining comfort conditions in the occupied space.

We analyzed the electric power usage in this building for two school years to estimate the fraction used for heating alone. Because lighting, people, and equipment also contribute heat to the building, we tried to be conservative by underestimating the resistance heater load. This estimate would also keep us from being too optimistic about the savings to be realized from an alternative source of heating such as solar hot water or steam from the central utilities plant. Our estimate of the electric power use for heating alone is 174,000 kwhrs annually.

Recommendations

An important first step, before any alterations to the system are made, is to carefully check the control system to be sure that it is functioning properly. Especially to be avoided is the operation of heating and cooling at the same time, a situation that obtains at present. We recommend that this control system's performance evaluation be made immediately. We urge that no modification be made until the present system can be and has been made to operate properly.

After some experience with the electric power consumption when the central system is optimally ad-

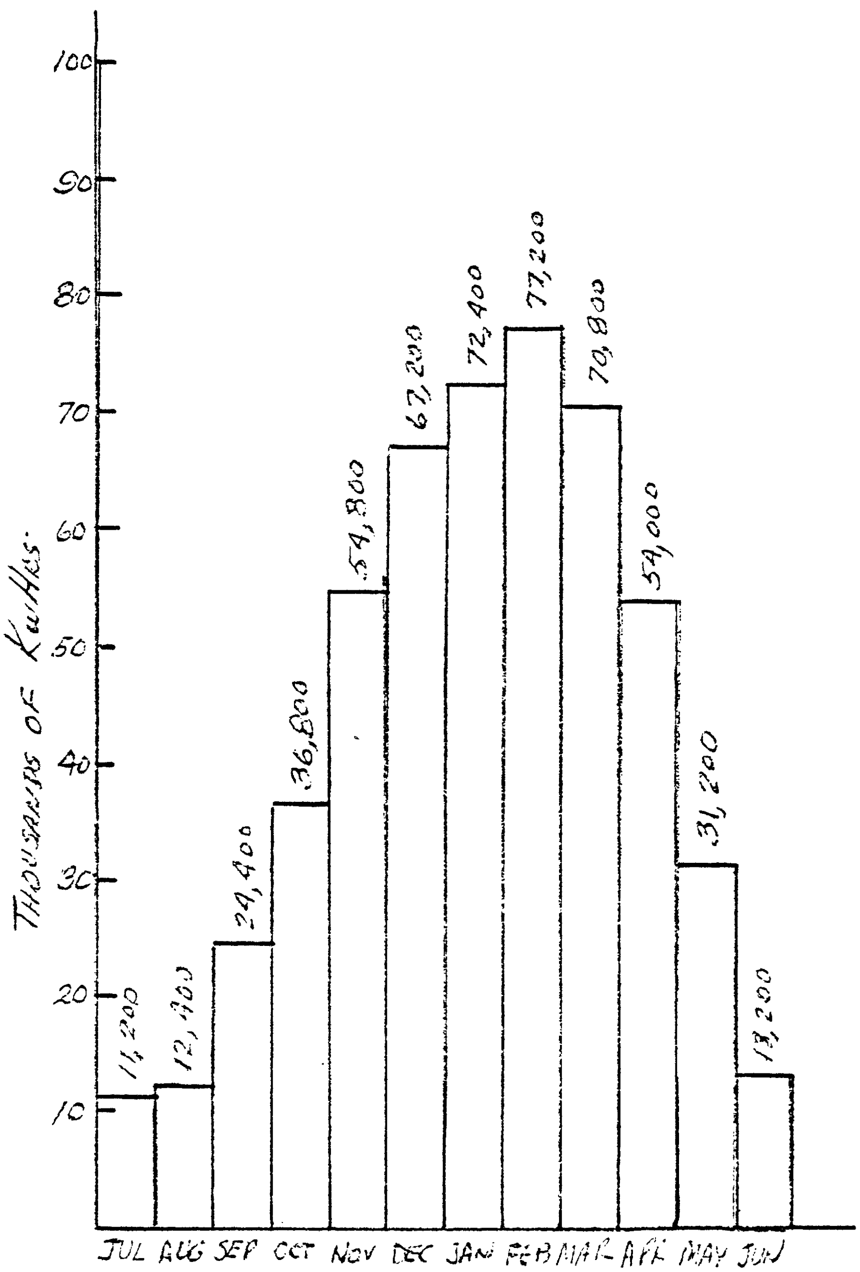


Fig. 10
Electricity Consumption New Library
1974 - 1975

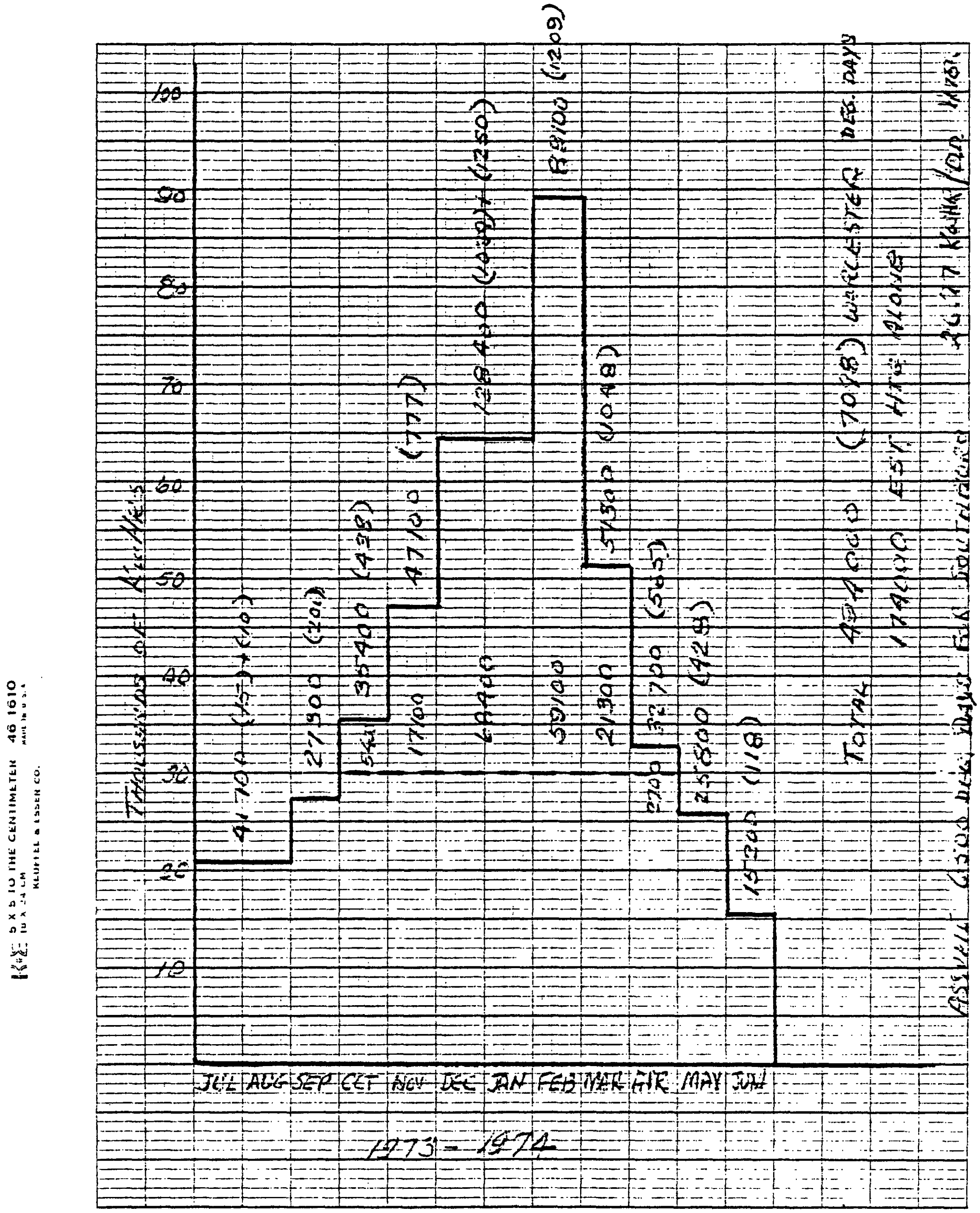


Fig. 11

Electricity Consumption New Library

1973-1974

justed, an engineering analysis should be made of the economies to be realized by substituting modulated steam heat exchangers for the resistance heating elements now used.

A comparison must be made of the cost of installing equipment and providing steam to meet the heating load with the cost of using electric power.

If only resistance heating is eliminated, the building will probably be placed under a different and probably more costly utility rate structure for the remaining electrical needs of the building.

Further analysis must be made to determine if the central utilities plant can furnish the additional load. We believe it can. Again we recommend this step only after the existing central system is optimally adjusted.

Solar Supplement

If we assume the estimate we made for the fraction of the electric power usage required for heating is correct, we can estimate the size of the collector and storage system needed for supplementary solar heating. In the Northeast it turns out to be the most economical to meet about half the heating load with solar energy and to arrange for sufficient storage to account for one sunless day. This would require 4,600 sq. ft. of collector and a 15,000 gallon water storage tank. There is a problem of where to mount a collector of this size (the science wing is a possibility).

In light of an estimated first cost of $115,000 for the installation, a solar supplement is not recommended for the new library.

G. FUEL CONSERVATION IN DOMESTIC OIL BURNERS

1. Rationale for Oil Burner Study

Laboratory and field tests of domestic oil burners have shown that substantial savings in fuel oil can be made at minimal cost. Savings of up to 30% have been realized by carefully adjusting, cleaning, and sealing the furnace system, often called a "tune-up." Actual savings depend on how badly out of tune a particular furnace becomes between servicings. In general, older furnace systems degrade faster than later models but this is not always the case.

Current practice in oil burner maintenance calls for annual inspection and tune-up. Most often this is done in the summer, an "off-peak" season for furnace servicemen. It has become important to determine whether annual servicing is adequate for a given installation. At current oil prices, more frequent tune-ups may be quite cost effective.

Three elements of the total efficiency of oil heating units are combustion efficiency, heat transfer efficiency, and duty cycle or downtime losses.

The efficiency of the combustion process in all but the most exceptional cases can exceed 99%.

The efficiency of heat transfer, the process of getting the heat of the combustion into the medium (air, water, or steam) used to heat the house, depends upon the configuration of the furnace system and the condition of the heat transfer surfaces. This efficiency, for a number of reasons, cannot exceed 80% and can vary from 50% to 80%. Excessive soot on the heat transfer surfaces is a major contributor to inefficient heat transfer because soot is a relatively good thermal insulator -- a clean furnace is more efficient. See Fig.12.

Duty cycle or downtime losses have to do with the way our heating units are operated to meet the varying demands for heat in the house -- basically an "on-off" cycle. To supply heat at capacity, the unit is operated continuously. The burner very rarely operates continuously. Most burners are cycled frequently with a moderate time "on" and a longer time "off". The "on" time is an especially small fraction of the "off" time during the moderate weather of spring and fall. Smoke and soot are greater at the beginning of the "on" cycle before the heating unit reaches stable equilibrium conditions.

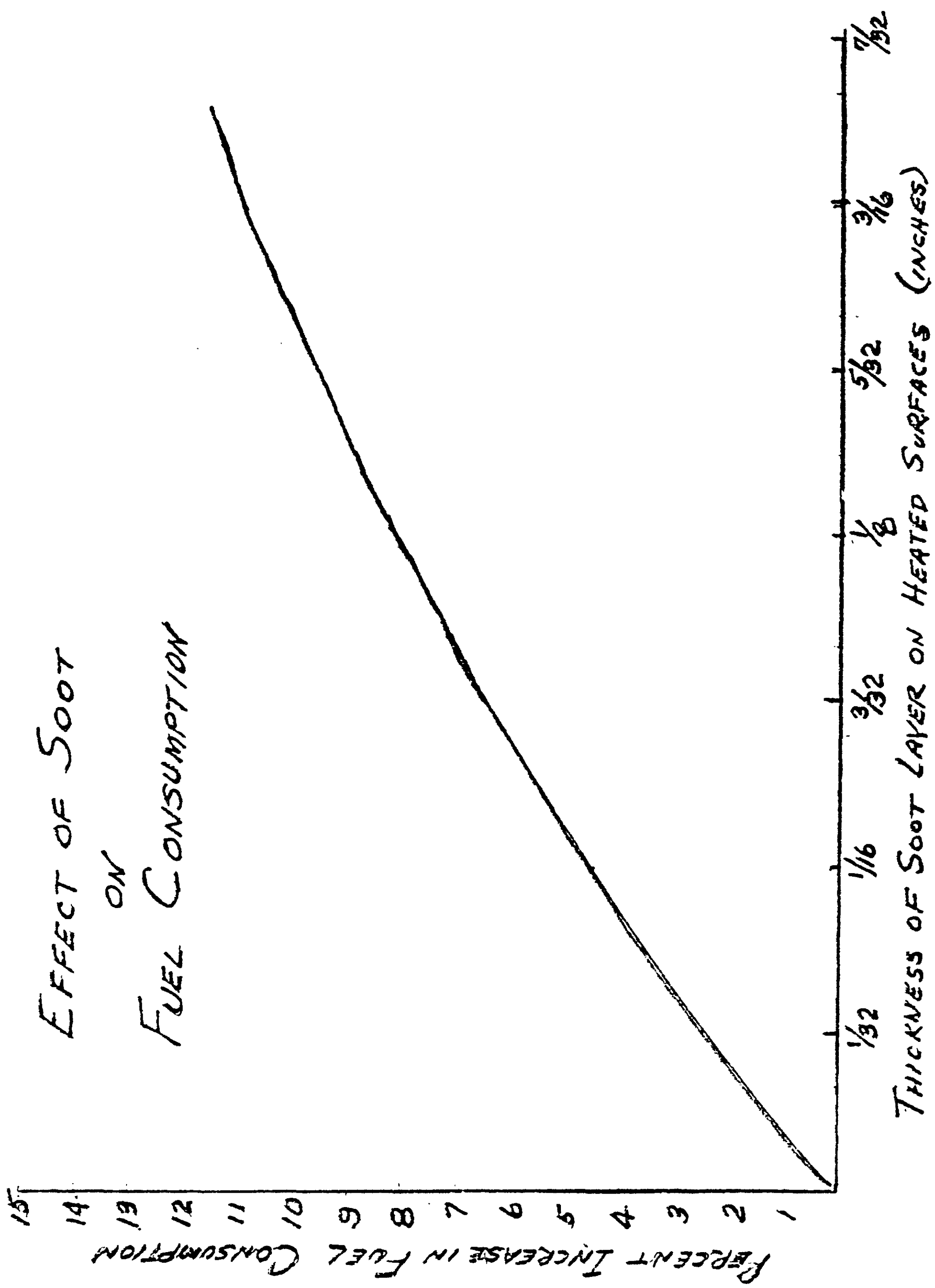


Fig. 12
Effect of Soot

Duty cycle losses occur because when the burner is turned "off", having met the demand for heat, hot air continues to pass out of the chimney as the unit cools. Heated air from the house is lost in the process and is replaced by cold air which infiltrates from the outside. The lower the duty cycle (the fraction of the total time the burner is "on"), the greater are these losses. Automatic dampers which close the flue when the burner is off can eliminate these losses. Some equipment of European manufacture is equipped with devices to eliminate duty cycle losses. None is made for domestic use in the United States. Duty cycle losses averaged over a heating season are typically 15%. There are safety considerations to take into account if an automatic damper is used.

It is possible to reduce duty cycle losses by reducing the firing rate (burning) of the burner. At a reduced firing rate the burner is "on" longer to produce a given amount of heat. Because of the substantial safety factors allowed in the sizing of most residential heating units, the firing rate can be reduced by about 25% in most cases without affecting comfort. We can see from Figure 13 that a typical situation shows that 90% of the time heat load is 60% or less. Even further reductions are possible in those houses where thermostats have been turned down. The burner firing rate can be reduced simply by replacing the nozzle with one of smaller capacity. Nozzles are usually replaced annually so the reduction in firing rate would not involve extra cost. Figure 14 illustrates the penalty paid in efficiency for over-design and system operation at only a fraction of full load. The figure shows that if the plant is 100% overdesigned we operate the furnace at only half capacity for full load and only 30% capacity 90% of the time. This further reduces boiler efficiency by 15% to 20%.

This quest for improved efficiency pays greater dividends than might appear to casual consideration. Small improvements in inefficient units pay larger dividends in fuel saved. For example, a 50% efficient furnace requires 10 gallons of oil to produce five gallons equivalent of heat. Five gallons equivalent are lost. If performance is improved to 55%, about nine gallons of oil are required to produce five gallons equivalent of heat; a 10% savings in fuel for a 5% improvement in efficiency! It is therefore important to attend to the least efficient systems first.

The table in Figure 15 shows the fuel saved for various initial and final efficiencies achieved.

2. <u>A Study of Oil Burner Performance in Selected Masters' Dwellings</u>

a. <u>General Comments</u>

As a result of our survey and comparison with other field oil burner studies, we conclude that oil consumption in the Masters' Dwellings is, with a few exceptions, excessive. There can be many reasons for this, but we have mainly limited our considerations to the technical. Because incentives are so important to the realization of conservation goals, the others are worth considering.

b. <u>Incentives for Reduction (Institutional)</u>

St. Mark's now meets all the demand for fuel oil in the dwellings. Since oil is a non-substitutable "free good" under these conditions, there is no economic incentive for the residents to practice energy saving -- only that of conscience and a recognition of the national need to conserve our dwindling resources. We all need more than that.

We fully recognize the problems involved in setting up a fair and equitable allotment system of fuel oil. Yet we believe an allotment system to be in the best long-range interest of St. Mark's and its staff. The savings that would surely result from such a system could be very useful in meeting other critical and continually rising operating costs of the school.

We understand that the questionnaire circulated under Project Conserve, Appendix VII, was completed for each of the Masters' Dwellings. The data contained in these questionnaires and the results of the analyses can help establish equitable allotments for each dwelling. One season's experience with new

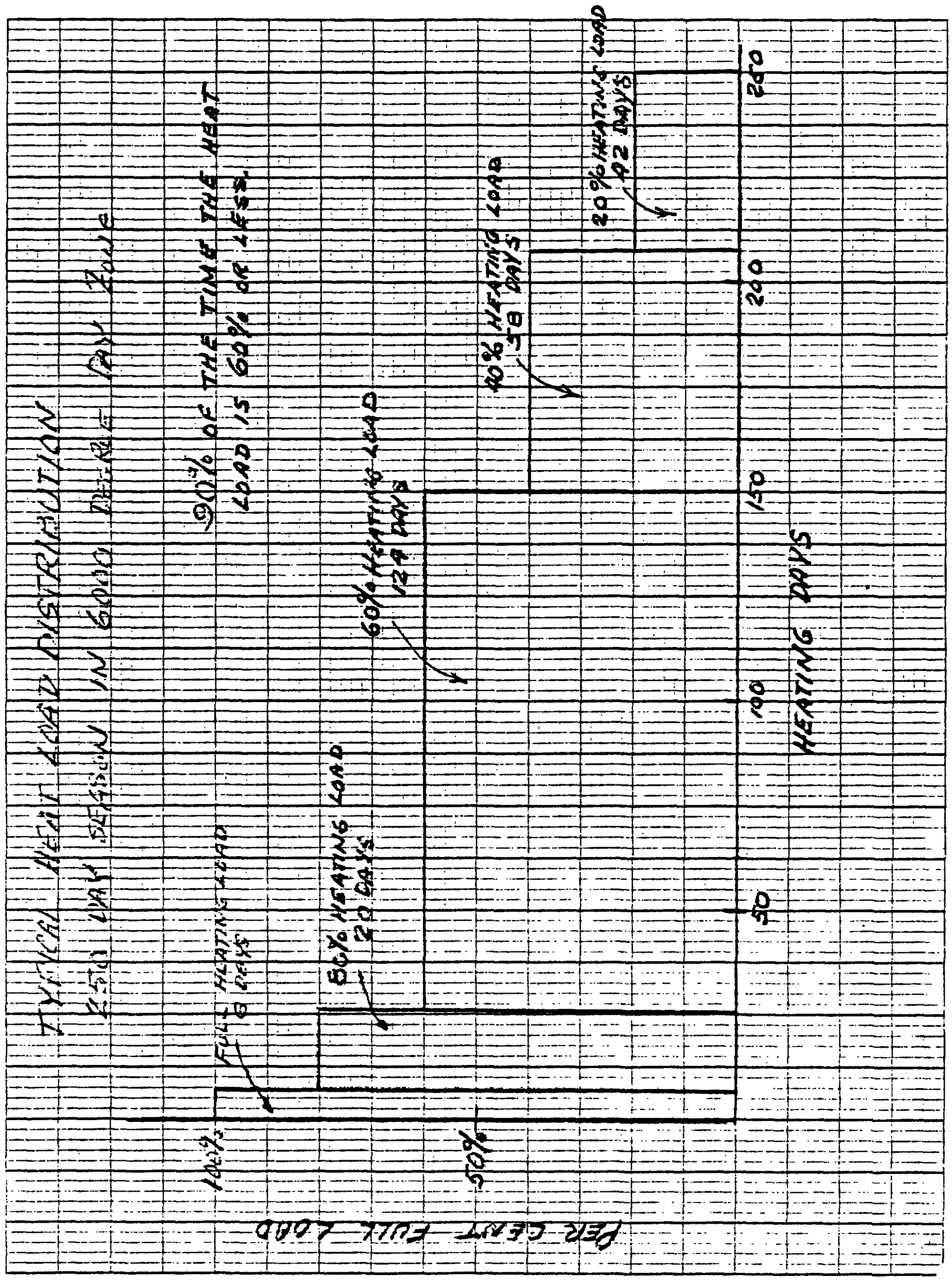


Fig. 13

Typical Heat Load Distribution

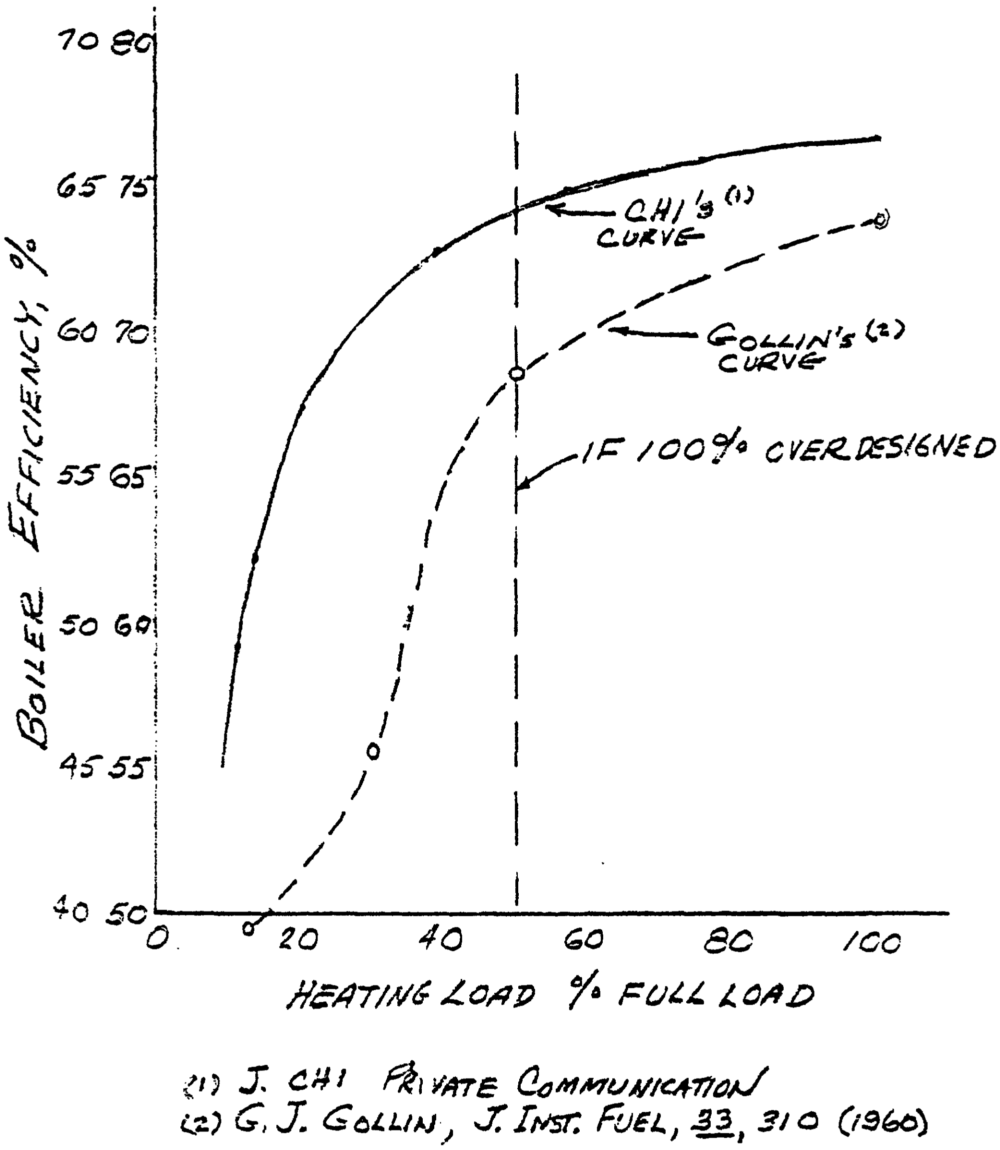


Fig. 14

Boiler Efficiency as a Function of Heating Load

EFFICIENCY AFTER TUNEUP (η_A)

ORIGINAL EFFICIENCY (η_0)	55%	60%	65%	70%	75%	80%	85%
50%	9.1%	16.7%	23.1%	28.6%	33.3%	37.5%	41.2%
55%		8.3%	15.4%	21.5%	26.7%	31.2%	35.3%
60%			7.7%	14.3%	20.0%	25.0%	29.4%
65%				7.1%	13.3%	18.8%	23.5%
70%					6.7%	12.5%	17.6%
75%						6.3%	11.8%
80%							5.9%

% Efficiency Improvement ($\eta_A - \eta_0$)

35%

30%

25%

20%

15%

10%

5%

$$\% \text{ SAVINGS} = \frac{\eta_A - \eta_0}{\eta_A} \times 100$$

Fig. 15

Percent Fuel Savings for Increased Efficiency firing rates and new preventive maintenance techniques will provide additional needed data. With this basic information, trial allocations of fuel oil can be made. There should be no penalty to the householder for factors beyond his or her control, but he or she should be required to pay for that extra consumption that was a voluntary decision on his or her part. To add a carrot aspect to this stick, savings resulting from this approach must be specfically identified and put to a use recognized by the whole community, e.g., library books, etc.

c. Opportunities for Savings

Because combustion chambers in heating units are designed to accommodate the firing rate for the rated capacity, there can be a small loss of heat transfer efficiency (typically 2%-4%) at the reduced firing rate, but this is far overshadowed by the reduction in duty cycle losses. The lower firing rate will reduce sooting so that, over the season, actual heat transfer losses due to a lower firing rate will be minimal. A practical minimum nozzle size may be over 1 gallon per hour to provide adequate recovery of hot water. This method of heating domestic hot water is quite efficient--only 50% averaged over a year. A recent field survey indicated that the average efficiency of heating hot water alone during the summer was only 18%.

d. What Was Done

We believe it is possible to affect reductions in fuel oil usage in the Masters' Houses by at least 10% at small or no cost. We did the following:

1. Studied the available maintenance and tune-up records for the oil burners of the Masters' Dwellings. Obtained consumption records and degree day information. Obtained a K factor* for each house. (Appendix VIII)

2. Had an independent oil burner company measure furnace performance in 10 houses in March to determine if and by how much performance has deteriorated since the last tune-up. (Appendix IX)

3. On the basis of information derived in steps 1 and 2, recommended a trial reduced nozzle size for each house. The new nozzles can be installed by the regular serviceman on the occasion of the next annual tune-up. (Appendix X)

3. Suggested New Trial Firing Rates

We have seen how excessive firing rates can represent a major loss in an oil burning furnace. Research and field measurements have indicated that most furnaces are overfired because pyramiding safety factors have led to overdesigned heating installations**. This is even more often the case where householders have elected to turn down their thermostats from previous norms to 68°F and possibly also a night set-back to a lower temperature.

A theoretical nozzle size was computed on the basis of K factors provided us by the fuel oil dealer and a 0°F design temperature for the heating system. We know that a change in firing rate will in turn affect the efficiency and the K factor. The establishment of final firing rates will necessarily be an iterative process. We do not suggest changes to firing rates below 0.5 gal/hr even when indicated by the theory because of potential reliability problems with nozzles with very small

*K factor: The number of degree days per gallon of fuel oil consumed. Example: A house consuming 1500 gallons of fuel oil in a 6000 degree day heating season would have a K factor of 4 degree days per gallon.

**Bonne Ulrich, A.E. Johnson, J. Glatzel and T. Torborg, "Analysis of New England Oil Burner Data: Effect of Reducing Excess Firing Rate on Seasonal Efficiency," Final Report Contract NBS-514736, Honeywell Corporate Research, Bloomington, MN, Aug. 29, 1975.

orifices. Another consideration is that burners are designed to perform well at their maximum rated firing rate. At rates substantially less than that, the burner may not create the necessary turbulence and firing pattern to ensure complete combustion.

In those installations having integral tankless hot water heating, the hot water recovery rate may not be adequate at firing rates less than 1.2 gal/hr. In those houses where the indicated firing rate for satisfactory heating is much less than 1.2 gal/hr, it would be wise to consider installing a hot water storage tank sometimes called reserve hot water storage tanks with trade names such as "Aqua-booster" or "Waterbank" or storage with a solar supplement to permit the lower firing rate.

Appendix X lists calculated nozzle sizes, nozzle sizes now in place, and recommended trial nozzle sizes.

4. Cautionary Comments

Since the "energy crisis" began, there has been increasing interest in oil heating systems. Improvement of oil burning efficiency is, for New England, a most important approach to conservation. The effect of "firing rate" on average efficiency has been discussed, as has the importance of cleanliness of the heat exchange surfaces.

Automatic damper installations are also often suggested. The two are the barometric "flapper" damper which automatically controls the draft when the fire is burning, and the other, common in early kitchen and "pot-bellied" parlor stoves, is the "butterfly" damper which is used to manually adjust the flue opening.

When the burner is "off" in a modern oil fired furnace, the draft in the chimney continues to pull the warm air of the house through the heating unit and the draft regulator to the outside.

The result is an 8-10% seasonal loss in an optimally adjusted system. Atmospheric pressure and wind velocity over the chimney affect significantly the draft and hence oil burner efficiency. The burner and damper controls adjusted on a calm, "nice" day will not perform as well under quite different conditions. Efficiencies of the burner, due to "normal" draft variations are said to change as much as 8-9% for short periods (hours).

A number of schemes and devices are being invented, suggested and marketed to reduce this loss but we know of none that has been certified thus far as safe for installation on oil furnaces. A scheme cited earlier in this reported is described in detail in Appendix II.

What we have recommended are those measures, tune-up, reduced nozzle size, etc. that can be reasonably expected to conserve fuel without any risk to health and safety. Other measures, in our opinion, must be carefully tested by competent personnel to ensure their performance without hazard.

It is against Massachusetts law for non-licensed persons to install or make adjustments of any automatically oil fired burner. It is believed that St. Mark's personnel can measure efficiency etc. provided that no control or part is adjusted. It might be advisable for one of St. Mark's plant personnel to receive training and obtain a license to permit necessary adjustment and tuning.

5. Discussion of Results

Field measurements indicated deterioration in performance of some heating systems in the period following the regular summer tune-up to March. We recommend mid-season checkups on all units to see which are in need of readjustment. It is hoped that these checks can be performed by physical plant personnel. Mid- to late December would be a good time to make the checks--just prior to the heavy heating load months of January and February. It may not be possible for them to run the full gamut of tests required for a complete combustion analysis. In that case we suggest the following:

1. If very little time is available, we suggest the measurement of stack temperature, and a

visual appraisal of smoke in the flame and sooting of the boiler. If the stack temperature has changed significantly from its tuned value, or if smoke and sooting has developed, the furnace needs attention.

2. A measurement of CO_2 is the next test to add, if time permits. The percentage of CO_2 is a sensitive indicator of the amount of excess air entering the furnace either through the burner or through air leaks in the system. The following table indicates this relationship:

% CO_2	% Excess Air	Efficiency	% CO_2	% Excess Air	Efficiency
3	400		9	66	
4	280	poor	10	51	good
5	200		11	37	
6	155	low	12	26	high
7	120		13	17	
8	86	fair	14	9	excellent but too critical
			15	0	

Table 4: Efficiency as a Function of CO_2

It should be possible to adjust most burners to have at least 8% CO_2. A frequent problem with older furnace burners having low CO_2 is incidental leakage of air. These burners should be carefully sealed to prevent this.

To gain further information, we compared the March measurements on three identical furnaces in three different houses (Appendix XI). Each system had a different nozzle, CO_2 reading, stack temperature and amount of smoke. The burner technicians reported these in houses #26 and #43 as questionable. Certainly they had low CO_2 and high stack temperatures. The reasons for the differences should be explored further. Air leakage is to be suspected. Where stack temperatures are high, such as #43, the heat exchange surfaces in the boiler may be excessively sooted. The smoke reading of #3 is too high. Smoke should range between 0 and 1. Again, midseason checkups should permit adjustment for higher CO_2 readings and the maintenance of low stack temperature.

6. Recommendations

We do not recommend wholesale replacement of burners or equipment for we believe that much can be done with the existing plant to save fuel. What is required is attention to a greater degree than we have paid in the past. Interesting results of recent field tests* have shown that rotary burners, rarely installed today because of avowed maintenance problems, have and maintain the greatest overall efficiency. They were more efficient than the flame retention, the shell head, the low pressure, and the conventional burners by but a few percentage points, but nonetheless better.

A summary of savings to be expected by these conservation measures is contained in the following chart:

SAVINGS FROM OIL BURNER CONSERVATION MEASURES

TYPICAL DWELLING: 2000 gals/yr

. Reduce firing rate . Reduce excess air

. At least biennial monitoring of performance

. Eliminate tankless hot water coils

. Seal furnace from air infiltration

TYPICAL SAVINGS FROM COMBINATION OF ABOVE: 15%

15% of 2000 = 300 gals/yr 300 gals/yr @ 40¢/gal = $120/yr.

*L. Katzman and R. D'Agostine, "A Study to Evaluate the Effect of Performing Various Energy Saving Procedures on Residential Oil Burner Installations in the New England Area and to Gather Information on the Steady State and Dynamic Performance of These Installations", Walden Research Division of Abcor, Inc., 201 Vassar Street, Cambridge, MA (undated).

H. <u>The St. Mark's Power Plant (A Total Energy System)</u>

1. At St. Mark's electricity, steam, and hot water, generated at the central power plant under the supervision of St. Mark's employees, provide all the energy required by the school with the exception of the new library. The library is an all-electric facility energized via a cable to the Massachusetts Electric Company (an investor-owned utility).

   a. Electricity is generated by one or more of three (3) compression-ignition (Diesel) internal combustion engines. Two operate on natural gas, one on liquid fuel (diesel oil).
   b. At the start of the study steam was generated by two each oil-fired (#6 oil) low-pressure (6 psi) and one high-pressure (15 psi) oil fired (#2 oil) burner boilers. The high pressure boiler steam was used exclusively in the laundry for washing and drying. During the study the laundry services were curtailed and the high pressure adapted to low pressure and connected to the space heating and domestic hot water system.
   c. The "waste heat", derived from jacket cooling water and exhaust gases of the diesel engines, is converted at varying efficiencies into steam. This steam is then coupled to the output steam lines of the low-pressure boilers for distribution throughout the school.
   d. The distributed steam is used for space heating (radiators) and at several local spots produces hot water for use in the kitchen, showers and at wash basins.
   e. A negligible amount of the on-site generated electricity is used for heating or air conditioning.
   f. Relatively small quantities of liquefied gas are used in the kitchen.

2. General Comments
   a. It is not known whether St. Mark's, by operation of its "total energy" plant, enjoys any economic gain, contributes to the minimization of energy consumption or environmental impact, or increases its security against electric utility failures.
   b. The capital costs have not been recorded separately. The dates of equipment and spare parts purchases are no doubt in files but are not easily extracted. We may assume that the central power plant is fully paid for, but we are unaware of an accounting system which attaches lifetimes to each of the several components, records the maintenance and operating costs, and sets aside a retirement fund for replacement of capital equipment when replacement is required.
   c. There is no instrumentation to permit determination of how much electricity or steam is used at the school.
   d. One cannot properly evaluate the present system unless one has data about the energy demand and details of capital, operation and maintenance costs.
   e. It appears reasonable to assume that there are some savings in fuel and total costs as compared with a conventional system (electricity supplied by a utility and heat by in-house boilers). This assumption becomes more valid if one does not include amortization of capital investment since it was apparently never included in an accounting system. The diesel electric units have some salvage value on the second-hand market.

3. Discussion
   a. <u>Central Utilities (Total Energy) Plant</u>

The term "total energy" refers to systems that employ engines to generate electricity and use the heat that has to be rejected by the engine to make hot water and steam. (See Appendix XV for the rationale.)

At nearly all generation facilities in the U.S.A. the rejected heat is "dumped" into the atmosphere or into bodies of water (lakes, rivers, oceans, etc.). There are technical reasons for the existence of rejected heat. There are few reasons why it cannot be used.

Approximately two-thirds of the energy content of the fuel (gas, coal, nuclear, oil) used in single stage electric power generation is rejected as "waste heat". This phenomenon follows laws of physics and cannot be avoided. Utilization of this normally discarded low-temperature heat for other purposes results in energy conservation because additional fuels need not be used for the other purposes. There is, in addition, the minimization of environmental impact because total fuel consumption is reduced.

This type of plant, called a "total energy plant", is one in which every effort is made to utilize all of the energy content of each unit of fossil fuel. The St. Mark's central power plant was designed to be a total energy system.

b. Evaluation

What we would have liked to have developed was a model* of the annual fuel consumption so as to be able to calculate how much of the heat, recoverable from electric generation, could be utilized. The inputs that would have been needed were:

1) energy profiles, giving hour-by-hour data of electric and thermal loads for representative days of the year;
2) heat rate and waste heat recovery rate for the electric generation plant under different electric load conditions;
3) the equipment capacities;
4) efficiency of the independent boiler units;
5) capital and retirement costs;
6) labor, rent equivalent, maintenance and other costs;
7) costs of fuels.

We would then have been able to calculate the fuel and other costs for the St. Mark's total energy system and compare then with a conventional system, one which used electricity from a public utility and burns fuel for all thermal needs (hot water, steam, etc.). The following is based on limited measurements and does not include capital, operational or maintenance costs.

c. Electric/Heat Rates

The electrical portion of the power plant originated when St. Mark's was isolated from reliable electrical service. Even though commercial electric power became reliable, it was maintained partly out of tradition. With the huge and sudden rise in fuel and energy costs, its continued operation seems to make economic sense.

Because this total energy system is in place, the principal question is not whether to have one, but rather to ask whether it is producing savings up to its potential; and if not, what should be done to improve its productivity?

Essential to an engineering and economic analysis is an energy load profile for the buildings of the school serviced by the central utilities plant. The load profile is another feature of a comprehensive energy flow diagram. The load profile has undoubtedly changed since the central utilities plant was installed. Current information is needed. The needed load profile is one that reflects the hourly requirements for electric power on a 24-hour basis (including minimum, average and peak demands), and the simultaneous ability to use the waste heat.

As the electricity is generated, the rejected (waste) heat is generated. It is desirable for the instantaneous demands for electricity and hot water and steam to match that which is being produced.

If the need for steam and hot water exceeds that which is being produced as a result of the electrical generation (which is satisfying the electricity demand), the difference can be supplied

*See Figure 7.

conveniently and efficiently by the boilers.

If the demands for electricity and steam are in a ratio such that not all of the waste heat being produced can be utilized, the excess waste heat has to be dumped (at St. Mark's) into the atmosphere by means of cooling towers.

Unused waste heat can be stored (there are no facilities for this at St. Mark's) for use at another time when conditions are reversed. Careful study of the situation at St. Mark's is necessary to determine if it would be cost-effective.

We can only estimate fuel savings for St. Mark's Total Energy Central Plant over a conventional system since these savings cannot be combined with all appropriate costs to compare the total energy system with a conventional one so as to determine what is best for St. Mark's

Figure 16 is a simplified illustration that shows:

1. The diesel system efficiency for only electric generation is nearly as high as that of the utility (conventional system), 33 percent.
2. It is possible to convert some of the diesel "waste heat" into steam or hot water.
3. The efficiency of a conventional boiler that produces steam or hot water has a maximum efficiency of about 75 percent.
4. If the thermal load (demand for steam) is larger than can be recovered from the diesel, the additional thermal load can be met by a conventional boiler. The boiler and the total energy (TE) system are then operating together.
5. The fuel savings can be estimated. For a more accurate picture it is necessary to introduce the operating and maintenance costs to determine if the annual costs of the St. Mark's TE system are in fact less than a conventional system (purchase of electricity from a utility and on-site generation of steam).

5. Cost Analysis of St. Mark's Total Energy System

Assume the energy in each unit of fuel consumed by a diesel engine is divided as follows:

30 percent to the rotating shaft as mechanical energy
30 percent as heat to the jacket water cooling system
30 percent as heat in the exhaust gas (normally passed through a muffler)
10 percent as radiated heat and absorbed by the oil, etc.

The 30 percent delivered as mechanical energy is converted at about 93% efficiency into electricity. The overall efficiency for electricity generation is therefore about 28%.

In the total energy system at St. Mark's a sizeable, about 60%, portion of the heat rejected by the diesel as jacket water heat and exhaust gas heat is captured in the form of steam. It is this steam that is piped throughout the school to heat the buildings and to generate domestic hot water. The reject heat in the jacket water and exhaust gas is about 60% of the heat energy in the fuel; 60% capture means that 36% of the reject heat is recovered for useful purposes.

In summary, for every gallon of oil consumed (one gallon of #2 distillate contains about 140,000 btu) St. Mark's ideally obtains:

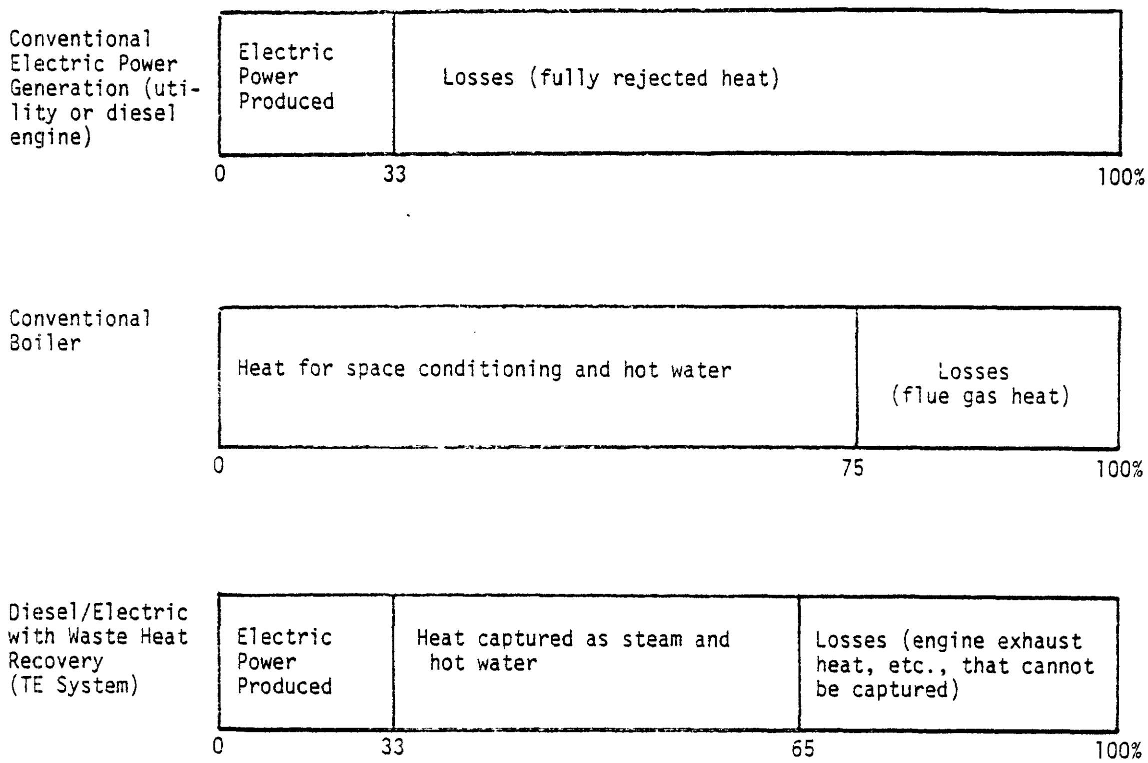


Figure 16

Electric Generation/Useful Heat/Losses of 3 Systems

a. 13 kilowatt hours of electricity

b. 50,400 btu of useful heat

The questions are how does the St. Mark's installation operate in practice, and what are the costs compared to a conventional system?

Data for one and one-half hours of operation of the St. Mark's TE system on one day in May, 1976, obtained from the meters of that part of the system:

a. 2.5 thousand cubic feet of natural gas were consumed to produce 165 kilowatt hours of electricity. The number 2 oil-fired boiler was operating, so it should be assumed that whatever waste heat was recovered was not sufficient to meet the coincident thermal demand. (This at St. Mark's is not necessarily so.)

Because of less than full load capacity, the electricity generation efficiency was 20% as compared with the ideal case of 28%. The difference is due primarily to the fact that the diesel operates most efficiently at 55 to 75 percent of maximum load. The load at this time was about 44% of the maximum load.

Heat recovery possibilities fall off, too, when the diesel engine is operated well below maximum load. We assume 50 percent recovery of the waste heat or 30 percent thermal efficiency.

6. Example Cost Analysis

As an informative exercise let us compare the costs of producing a quantity of useful energy (steam and electricity) at St. Mark's and the conventional procedure of purchasing electricity from a utility and making steam on-site. We will adjust the demand for energy an average of 80 kilowatts of electricity for each of 24 hours per day for 30 days. We assume that all of the steam produced by the total energy system was consumed and that in the conventional case that amount of steam would have to have been produced on-site.

I. Conventional Case (Purchase electricity/make steam)

a. Electricity

- The state-approved electric rate of the local utility, Massachusetts Electric Company, is included in Appendix VI.
- An average of 80 kilowatts for 24 hours per day for a 30 day month. This comes to 57,600 kwh of electrical energy.
- The utility general rate, C-22, calculation is as follows:

$1.96	for first 20 kwh	=	= $ 1.96
.06473	for next 80	=	= 5.784
.05873	for next 200	=	= 11.746
.04763	for next 1700	=	= 80.971
.03573	for excess over 2000	=	= 1986.588
Current fuel adjustment is $0.01517 per Kwh			= $ 837.92
			$2960.84 Total Cost Purchased Electricity

- 57,600 kwh of electricity at 3025 btu per kwh = 1.742×10^8 btu
- At 20% electrical generation efficiency 8.71×10^8 btu of energy input are required.

b. Steam

- We assume that with a TE system we would obtain 30 percent of the energy, 2.61×10^8 btu's, in the fuel as steam.
- To produce this quantity of steam in the boilers would have required, at 80 percent efficiency, 2325 gallons of fuel oil at a cost of $ .33 per gallon or $767.00.

c. The total cost then for the electricity and the steam produced by conventional means would have been $3727.

II. Total Energy

There are two natural gas fired engines and at the time of the observation one of them was operating.

a. Gas

The following calculations are for natural gas fuel operation of the TE system:

- 8.71×10^8 btu's total thermal input are required.
- Natural gas has approximately 1000 btu's per cubic foot.
- 8.76×10^5 cubic feet of gas are required, 8.7×10^2 thousand cubic feet.
- The current cost for gas, MDPU #46 dated 1 January, 1973 for Service Classification No. 6 Prime Mover Rate, Appendix XII, is:

Gas	=	$ .07 per cubic foot
Adjustment	=	.10 per cubic foot
Effective gas rate		.17
		$1.70 per 1000 cubic feet

- $1470 for 8.7×10^2 thousand cubic feet (energy).
- Demand charges are $7.00 per 1000 cubic feet per day.
- This demand charge for that date was 29×10^6 btu's for 24 hours or 29,000 cubic feet.
- The billing demand charge is the highest 24 demand established within the current month or the preceeding 11 months.
- The applicable demand was 47, established during the previous winter.
- The demand charge calculates to be $329.
- The total gas bill would be $1799.

b. Oil (diesel)

- 8171×10^8 btu's of total thermal energy input are required.
- 140,000 btu's per gallon results in 6,220 gallons of diesel fuel.
- At $ 0.33 per gallon this comes to $2053.

The comparative costs for the assumed situation are as follows:

Table 5·

	Conventional System	St. Mark's Total Energy System Oil	St. Mark's Total Energy System Gas
Purchased Electricity $	2960	- - -	- - -
Generated Steam (On-site boiler) $	767	- - -	- - -
Fuel Costs $	- - -	2053	1470
Demand Charges $	- - -	- - -	329
TOTAL $	3727	2053	1799

This indicates that the operation of St. Mark's TE system can result in substantial savings in fuel costs. The operational and maintenance costs were not included.

It also demonstrates that there are substantial savings to be enjoyed if the natural gas diesels are used instead of the liquid fuel diesel in the generation of electricity.

In a more exact analysis of the operating costs of a total energy plant (diesel engine with heat recovery) as compared with the cost of power from other sources, fuel consumption and cost as related to load is an important factor. In addition, one should know the heat value of the fuel being consumed at the time of the tests.

The foregoing is for the situation in which the diesel engines are operating at optimum load conditions. We also did not measure the heat value of the fuel.

Another type of analysis that can be made which will reveal the importance of considering demand change effects that can results in costs is described in Table 11 (Appendix XIII).

For the purposes of our study the "back of an envelope" type of calculations are sufficient to reach conclusions as to whether the St. Mark's system can, and does, save money under the present set of conditions. It appears to be cost effective (see Appendices XIII,XIV) so "fine tuning" procedures, analysis operation and other optimization actions are justified.

Figures 27, 28 have been adapted from one published by the Caterpillar Tractor Company, the manufacturer of the diesel engines at St. Mark's. It illustrates how fuel consumption per unit of horsepower (which can be equated to kilowatt-hours) varies as a function of percent of the load for which the engine is rated. (Appendix XV)

What this means is that the savings shown in Table 5 are optimum. In actual practice they are less.

Recommendation

The Business Office of St. Mark's should discuss fuel costs, billing rates, and oil delivery with the suppliers, taking into account the cost of stored liquid fuel. (The interest cost on the money invested in oil may very well be considered a sort of demand change when making the economic analysis.)

The powerplant operating personnel and the chief engineer of the school should participate in the exercise. Mr. Peter Dirkin of the gas company has stated that he would assist.

This procedure is recommended over the rate use of a table of numbers calculated by someone else. As the prices of the gas and oil change and the Massachusetts Department of Public Utilities rate alters, any table would have to be recalculated as the mix of fuels used at various times of the year and under different load conditions may very well be quite different.

Comparative Costs of Fuels for Power Plant Operation

TABLE 6

Load Factor %	Cost of Natural Gas per 100 Cubic Feet per Unit of Electricity Generated	Equivalent Cost of Liquid Fuel per gallon	Posted Price of* Diesel Oil per gallon
38	$3.12	$0.437	$0.449
70	2.76	0.386	0.449
100	2.61	0.365	0.449

*The actual price that would be paid by St. Mark's is a result of negotiation.

The results indicate that:

a. the higher the load factor on the natural gas drive diesel engines, the lower the cost of the gas
b. at low load factors the cost of operating the gas driven engine to produce electricity is higher than the cost of operating the liquid fuel (oil) engines
c. at high load factors the cost of operating the gas driven engine to produce electricity is lower than the cost of operating the liquid fuel (oil) engine

What has been demonstrated is that the selection of the type of engine (hence fuel) to produce electricity bears directly and importantly on the cost of the produced electricity. Just as important is the number of hours that each type of machine is operated, which can influence the magnitude of the differences in cost.

It is not correct to say, "We will operate for baseload only the natural gas engines, and the liquid fuel engine for peaking." The demand costs must be taken into account.

The established demand cost is the highest 24-hour demand established during the billing month, or the preceding 11 months.

7. Comments on the St. Mark's Power Plant

I. First and of highest priority is to reinstall all instrumentation, shut-off valves, modulating valves and back-pressure valves that have been removed, disconnected or otherwise modified. Secondly, install instrumentation so that one can know what is happening. It is not possible to operate the system economically and safely if one cannot determine how much steam is leaving the power plant and which units are supplying what.

We were told that the system had been modified every time there had been trouble with one of the above components and there was no money or interest on the part of management to keep the system intact.

The system is not operating at maximum efficiency.

The failure to provide for adequate maintenance has resulted in the loss of a greater sum of money and, in addition, placed the system in jeopardy of costly damage. Back pressure valves are necessary on the engine side so that the engines are always looking at a fixed pressure. Otherwise:

(1) "flashing" in the cooling system will occur. Hot spots will result in damage to the vapor phase unit and possibly the engines.

(2) heat recovery efficiency will change

(3) conversion from the jackets may remain constant, but

(4) certainly conversion efficiency from the exhaust will fall off.

If the boilers were set up so that they never let the system drop below 6 psi, then a back pressure valve might not be used. But if the load demand varies, there is a need of back pressure valves for the required fast response to protect the diesel.

II. In the "total energy" plant, after electricity is generated, the normal "waste heat" is used to produce hot water and steam. Frequently, the demand for electricity may result in the production of unwanted steam. Conversely, there are occasions when there is a requirement for more steam than is being generated as a consequence of the demand for electricity. In the first case, excess steam is "dumped" to the atmosphere by cooling towers. There is then no advantage during such periods, for the complexity of a "total energy" plant. In the second instance the advantages of a "total energy" plant may be realized.

If there is a need for more hot water or steam than can be produced as a result of the then current demand for electricity, it is to be produced by the oil fired steam boilers. The direct oil fired boilers should "float" on the system as "slaves", operating only to supply heat energy demands that are in excess of those available from the electric generation equipment. At St. Mark's the proper operation of the power plant under these conditions could be insured if adequate instrumentation were included on the steam lines and the back pressure valves, described in the section of the "vaporphase" equipment, were installed.

In the situation where unwanted steam is being generated (electric demand greater than the demand for the recoverable waste heat) steam and hot water storage tanks could be used — "could be used" but should be used only after extensive time-demand data have been collected and a thorough cost-effectiveness study is made.

For the near future the following should be done:

a. make sure that no boiler is operating as long as the cooling towers are operating. When the cooling tower is operating it means that recoverable waste heat is being dumped.

b. Improve the efficiency of the cooling towers by making sure they are clean, that the fans are properly lubricated, the louvres properly adjusted, and the pumps efficient. It takes electrical energy to operate the cooling towers and this energy is a drain on the power plant system.

III. The electrical system needs some additional instrumentation. The most obvious needs are kilowatt-hour meters on the output of each generator. It would help the "Energy Conservator" if there were several in the sub-system.

The calibration of the existing instruments should be checked. There appear to be discrepancies between the kilowatt (energy) meters and the calculations that are derived from the volt, ampere and power factor meters.

We tried to use a clip-on meter to verify our suspicions but could not safely do so. The electrical panel is not situated according to any code. The space between the rear of the compartment and a wall has only one entrance. One has to squeeze into the narrow opening. Any attempt to reach the bus from the front requires one to stretch through the fully energized bus and instrumentation leads. In order to make any diagnosis the system would have to be shut down, test instruments would have to be connected with the system turned off, and then the instruments disconnected and the system turned back on.

The individual meters might, by a properly dressed and competent electrician, be removed for calibration elsewhere without a shutdown.

I. Gas Incinerator

The solid waste of the school (trash, garbage, etc.) is incinerated. Although the gas has combustible characteristics, the moisture content is too high for it to permit self-combustion and natural gas must be used to aid the incineration.

We were unable to determine the ratio of gas to ton of refuse incinerated. Neither were we able to arrive at an understanding of the cost of removal of the incineration ash or the cost of St. Mark's labor in the processing of the waste.

We did observe operation and came to the following conclusions:

1. In view of the shortage of natural gas, we cannot in good conscience, recommend that natural gas be consumed in this fashion.
2. A knowledgeable person is required to operate the incinerator.
3. There are possible hazards to personnel involved in the operation of the incinerator due to the close conditions that exist.
4. In view of the relatively large quantitites of plastics in the trash, the absence of tall stacks, and the presence of so many young people, it is questionable whether one should incinerate trash at the school.
5. The storage of waste within the various buildings, while awaiting the periodic incineration, is less than desirable.
6. A contract with a commercial refuse removal firm whereby they install, and remove when full, a large metal closed bin ("dumpster") in a parking area, would be safer and more sanitary.
7. We suspect that if all true costs were taken into consideration, the employment of a commercial company for unprocessed waste removal would cost less than the present system.

J. <u>Solar Energy For Saint Mark's</u>

<u>Introduction</u>

The salient features of solar energy, solar systems, and factors affecting the economic feasibility of a solar energy alternative are listed below:

THE SOLAR ALTERNATIVE

The Nature of Solar Energy

- Dispersed and Diffuse
- Seasonal Variation -- Diurnal Variation -- Climatic and Weather Variation

General Solar System Characteristics

- Large Collector Areas Properly Oriented
- Substantial Storage
- Marginal Reliability at Present

Convert Technical Feasibility into Economic Feasibility

- Leverage for the Solar System through Conservation
- Maximum Utilization of Installed Capital Plant
- Substitute Solar for Most Costly Conventional System
- DO NOT SUBSTITUTE SOLAR FOR WASTED ENERGY

The essential facts relative to the use of typical flat plate collectors in a system designed to supplement space heating or domestic hot water are these:

THE SOLAR FACTS OF LIFE

- A range of 100,000 to 250,000 BTU's per square foot per year brackets the output of anything we can design or choose for most of the country.
- Each square foot of collector surface saves the equivalent of only one to 2.5 gallons of heating oil annually, assuming that the oil is converted with 70% efficiency. (1 gallon of oil contains about 140,000 BTU.)
- Today, that fuel is worth 40 cents to $1.
- On this basis, the entire solar system cannot cost more than $4 to $10 per square foot of collector if the investment is to be recouped in a reasonable time.

The New England Electric System (NEES) has found that the cost of a solar system for residential units, to supplement an electrically operated domestic hot water heater, ranges from $1500 to $2500. Member companies of NEES plan to install a substantial number of these units at a cost to the homeowner of only $200. The homeowner's investment ($200) would be recovered, because less electricity would have to be purchased, in about two years. The utility subsidy of the homeowner is ten times his investment. The subsidy represents free capital for the homeowner so from his point of view the installation is economically sound. A grant to the St. Mark's School restricted to solar energy aplications would also have the free capital effect on economic factors. Gifts of solar capital equipment can also change the economic picture substantially.

Hopefully, with innovation in design and fabrication, and the development of a demand to support mass production of innovative approaches, costs for solar energy systems will go down. Without these breakthroughs, we would expect solar system costs to inflate--but perhaps not at the same rate--as do fossil fuel costs.

Components of today's conventional solar collectors are presently being mass produced; cover glass, plastics, roll-bond collector plates, etc., so we can establish a floor cost of mass produced conventional flat plat collectors. This cost is still above that required to justify solar systems economically.

With a capital intensive installation such as solar heating systems, full time utilization is important. Ideally one would want to find a reasonably uniform, year-round use for the relatively low temperature heat energy produced by the conventional solar collector. Solar space heating does not have this characteristic. Heating is required only four or five months of the year and that varies greatly from a peak in January to nearly nothing in early fall or late spring. Neither does the demand for heat correspond very well to the availability of solar energy which is substantially greater in the summer than it is in the winter.

Hot water heat requirements are more uniform over the year, especially when such facilities as kitchens, laundries, and gymnasium showers are served. It is often the case, however, that substantial amounts of hot water might be provided by heat otherwise wasted in a central utilities plant. All options must be compared critically.

Because solar energy is unfortunately diffuse, collectors must be large and have a clear view of the sun throughout the day. These factors exacerbate the problems of fitting a solar system into an existing plant. Esthetics and construction, not sympathetic to solar energy collection, must be taken into account while meeting the technical requirements.

The variable nature of solar energy usually makes some form of energy storage essential. This is more true, the greater the dependence for energy upon the supplementary solar system.

Finally, it is economically unwise to call upon a solar system to meet energy needs made up in part by waste resulting from inefficiencies in equipment, correctable leaks, unwittingly wastrel practices and poor system management. We hasten to point out that such practices are our heritage from an era of plentiful, convenient and cheap fuels. Present habits and designs, rooted in history, should not be thought to reflect culpability on present operators. We can be blamed, however, if we do nothing to change these conditions.

Often, unnecessary energy demands can be eliminated at substantially less cost than that of a solar supplement. The proper context for the consideration of solar energy for for St. Mark's School includes the three broad categories of options for energy conservation enumerated earlier as made specific by the nature of the school, its location, operation, and physical facilities.

Once the appropriate conservation measures are implemented, we know that supplementary solar energy will further reduce fuel use. On the basis of very tangible economic factors, we have seen that it remains difficult to clearly demonstrate the economic superiority of solar energy in competition with fossil fuels even at today's prices.

There are intangible factors that might be considered to make the picture quite different. The price of fossil fuels today, even at the high levels now prevailing, does not include many intangible costs. The price does not reflect the environmental costs of the production, distribution, and consumption of fossil fuels. Neither does the price allow for the fact that we are exhausting our fossil fuel resources.

It is not unreasonable to put a personal or institutional value on these intangibles that can make an economic evaluation of solar energy entirely different. Today's "pioneers" in solar energy utilization have made this evaluation and have chosen to pay the cost with personal labor, treasure, or imaginative innovation. In so doing, they bequeath extended life of depleteable resources and an improved environment.

POSSIBLE SOLAR APPLICATIONS AT ST. MARK'S

An examination of the following potential applications of solar heating was made:

- A solar supplement to domestic or service hot water
    - kitchen
    - gymnasium
    - laundry
    - Masters' Dwellings
- A solar supplement of heating of the new library
- A solar supplement for tempering residual oil
- A solar supplement of heating of the art building
- Solar preheating of combustion air

K. Choosing a Solar Energy Supplement

Among the applications of solar energy to St. Mark's School explored, for reasons of a rather uniform demand throughout the year, and a reasonable match between the availability of solar energy and demand, a solar supplement to domestic or service hot water has at this time the best chance of being economic.

Because solar energy is so diffuse, we can expect only a total of about 150,000 BTU's per square foot per year from a conventional flat plate collector. This is the equivalent of 1 1/2 gallons of oil burned at 70% efficiency. We have seen from our study of oil burner efficiencies that the 70% figure is not often reached in the field. In fact, some field measurements have indicated that a furnace equipped with a tankless hot water coil and which only heats domestic hot water during the summer can be operating at efficiencies as low as 18% during that period even though much higher efficiencies are achieved during the peak of the heating season.

Let us see what this means to the economics of a solar domestic hot water supplement. Compared with oil burned at 70% efficiency and purchased at 40 cents per gallon, the annual output of each square foot of solar collector is worth only 60 cents. However, if the substitution is made for oil burned at only 18% efficiency, the annual return is equivalent to nearly 6 gallons of oil worth $2.40. At this rate an investment of $24 per square foot for the entire solar system would be returned in 10 years. This simple economic analysis ignores operating and maintenance costs which are apt to be high until we have had more practical field experience with solar water heaters. The experience of foreign firms who have been marketing solar hot water heaters for many years is encouraging, particularly for the most simplified versions. The analysis also assumes that the entire output of the solar water heater is put to use and is not "dumped" as surplus. The latter points to one of the hazards to designing a system to supply all the hot water needs with solar. Because solar energy is so variable, a total solar system would frequently have large surpluses of heat to be disposed of. Heat disposal also requires capital equipment. In New England it is most economic to design the solar system to provide about half the domestic hot water needs. This optimum has a rather broad range however, so that designs may vary from 35% to 65% if required for other reasons such as the feasibility of installing the needed collector area and storage equipment.

The above exercise has shown how important it is to get additional "leverage" for the solar system through a careful choice of its application. The domestic hot water application at St. Mark's is one which utilizes capital equipment effectively and uniformly in all seasons, it can make use of the additional solar energy available in spring, summer and fall when space heating needs are small or non-existent, and it substitutes for heat produced inefficiently with oil.

We must also point out, however, that the efficiency of the tankless system can be increased substantially by the addition of a well-insulated hot water storage tank not unlike that needed by the solar system. A phased program toward solar supplements could include as a first step the installation of hot water storage tanks. This is but another example illustrating the importance of exploring all of the options for reducing energy use at St. Mark's, for some may well turn out to be substantially less expensive for the same saving than a solar installation. It is quite clear that we can never logically substitute solar energy for energy wasted when it is within our power to reduce that waste.

The kitchen, gymnasium showers, and the laundry all use substantial amounts of hot water at St. Mark's. We considered a solar supplement for each of these demand centers but because we were unable to get adequate information on demand profiles, we believed preliminary designs would be too loose to permit rational decisions. Unlike the Masters' Dwellings, hot water for the above three is supplied by the central utilities system.

Because of low capital equipment utilization, a solar supplement for heating the new library was abandoned (see analysis sheet, Table 7). For the same reason, plus the possible availability of waste heat in the central utilities plant for the purpose, we examined only cursorily the tempering in winter of the residual oil burned in the plant. Solar preheating of combustion air was also considered but abandoned for the same reasons.

We believe that the roof of the art building could accommodate a large solar collector both structurally and esthetically. Only winter heating would be supplied by the solar system so plant utilization again makes this application less economically attractive.

We recommend the installation of a supplemental solar hot water heating system on one of the Masters' Dwellings because this is an application with good leverage and involves a modest capital investment. One hundred experimental and demonstration units are being installed by local utilities in selected residences in the area. This local experience will be invaluable to the installation at St. Mark's.

Table 7

SOLAR HEAT FOR NEW LIBRARY?

<u>HEATING ONLY</u>

Est. Req. 174,000 Kwhr/yr or 600 x 10^6 BTU/yr @ 60% eff. Plant req. 170 bbls of oil/yr (@ $15/bbl or $2550/yr for oil). 174,000 Kwhr/yr @ 4¢/Kwhr = $7000/yr; @ 3.5¢ = $6000/yr.

Data from MIT Solar House #1 (Oct-Apr): Absorbed by collector - 155 x 10^3 BTU/ft^2-season

Available for heating - 65 x 10^3/ft^2-season

Solar supplement for 1/2 heating load:

$$\frac{1/2 \times 600 \times 10^6 \text{ BTU/season}}{65 \times 10^3 \text{ BTU/ft}^2\text{/season}} = 4600 \text{ ft}^2 \text{ collector}$$

Cost: 4600 ft^2 @ $25/ft^2(system) = $115,000

<u>1974-1975 Total 512,400 Kwhrs</u>.

New Library Heating 1973-1974 - 174,000 Kwhr/yr; 174,000 x 3413 = 593,862,000 BTU/yr

Say, 600 x 10^6 BTU/yr; Average daily for 250-day season, 2.4 x 10^6 BTU/day

Oil has 6 x 10^6 BTU/bbl. Assume 60% steam plant efficiency ∴ 3.6 x 10^6 BTU/bbl; 167 bbls oil/yr

$2505/yr - 35 x 42 = $15/bbl

.02187	.01837
.0124	.0124
.0342	.03077

174,000 Kwhr/yr @ .04 = $6960/yr. elec. heat

- $2505

$4455/yr savings

Table 7 (continued)

@ .032 = $5568
- 2505
$3063/yr savings.

Data from MIT Solar House #1 1949-50-51 (Oct-Apr):

Absorbed by collector - 155,000 BTU/ sq. ft.; Available for heating 65,000 BTU/sq. ft.

To heat library with solar:

$$\frac{600 \times 10^6}{65 \times 10^3} = 9000 \text{ sq. ft.}$$

For 50% 4500 comparable with Timormine School

@ $25/sq. ft. system = $112,000 9851 sq. ft. floor area - 500 sq. ft - 15,000 gal. storage

L. Two Preliminary Designs

The preliminary designs of two systems for St. Mark's have been worked out. We have attempted to define the simplest systems that can do the job. Both systems utilize vertically mounted collectors. Vertical mounting on a southerly facing wall (due south not required) is easier to retrofit on an existing building. In addition, with the back of the collector against the wall of the house there will be less heat loss from the solar collector, and the presence of the solar collector adds insulation to that area of the house wall.

The curves in Figure 17 show the average daily insolation on a vertical collector for latitudes of 40°N and 45°N and for due south and south-southwest orientations. Note that the insolation peaks and remains relatively flat during most of the school year. During the summer, the dwellings are usually not occupied, so from an optimum utilization point of view the vertical installation is quite appropriate.

To avoid the complexities of heat exchangers and anti-freeze solutions, the collectors are designed to carry the potable water and will be self-draining to protect from freezing. In System A, Figure 18, the collector drains into a combination expansion and collector water storage tank whenever the pump is stopped. The pump operates whenever the temperature of the collector is hotter than the water in the cold part of the hot water storage tank. In System B, Figure 19, the collector is drained by the operation of the three-way valves when the temperature of the collector is low enough to be in danger of freezing. The collectors also drain in the event of power failure because the drain position of the three-way valves is the unenergized position. The circulating pump is controlled by a differential temperature controller as in the case of System A. Two commercially available flat plate collectors giving a total collector area of 50 to 60 square feet will be adequate for a single family dwelling. An 80-gallon water tank will provide the storage, and an electric heating element is installed to provide the electric supplement when needed.

Costs of the electric utility installations ranged between $1500 and $3000. A preliminary estimate of the cost of a system for a Master's Dwelling is $1800 installed. More accurate cost estimates can be made once a specific house has been selected for the installation, and the details of the plumbing installation worked out.

We suggest that the solar hot water system can be a useful educational tool. Students can monitor the performance of the equipment and evaluate its operation. This modest beginning in the application of solar energy can be expanded to other Masters' Dwellings as it becomes proven in the St. Mark's context.

An analysis of the savings to be expected from the solar hot water supplement follows:

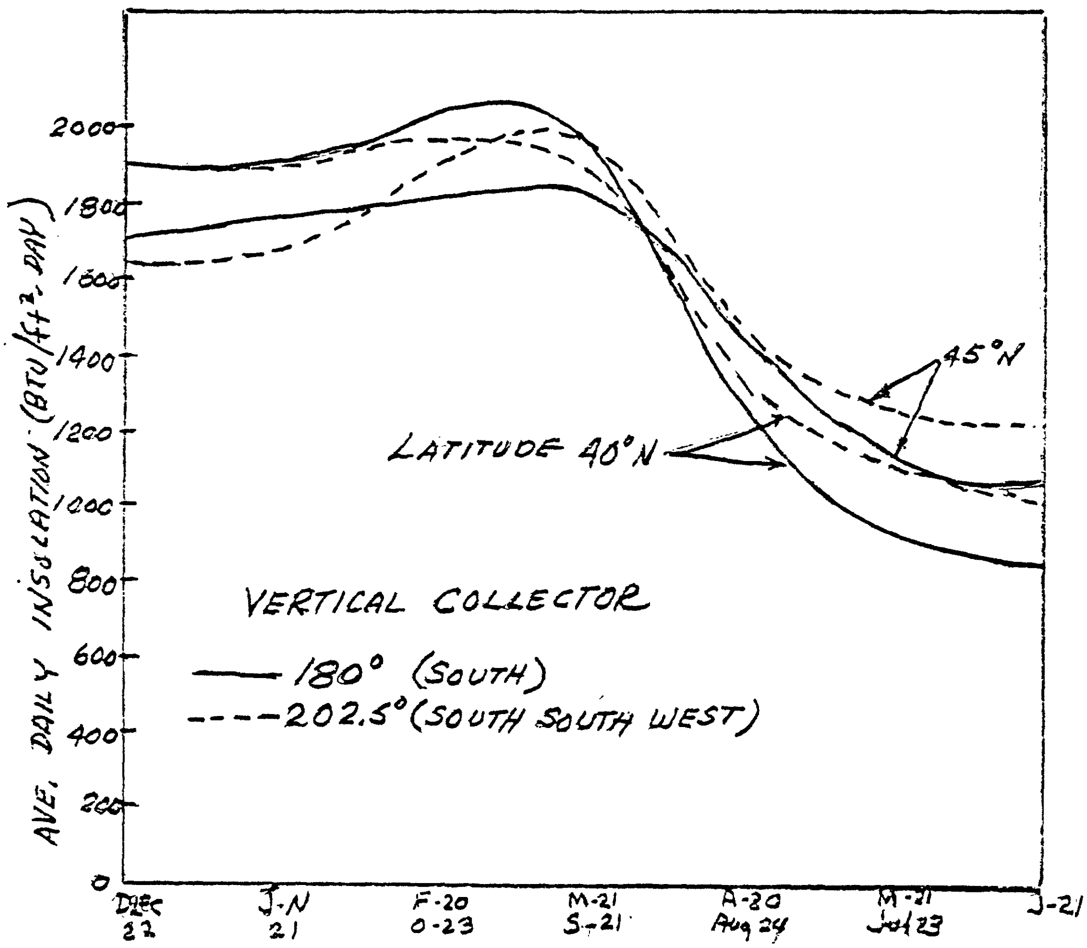


Fig. 17
Average Daily Insolation at St. Mark's

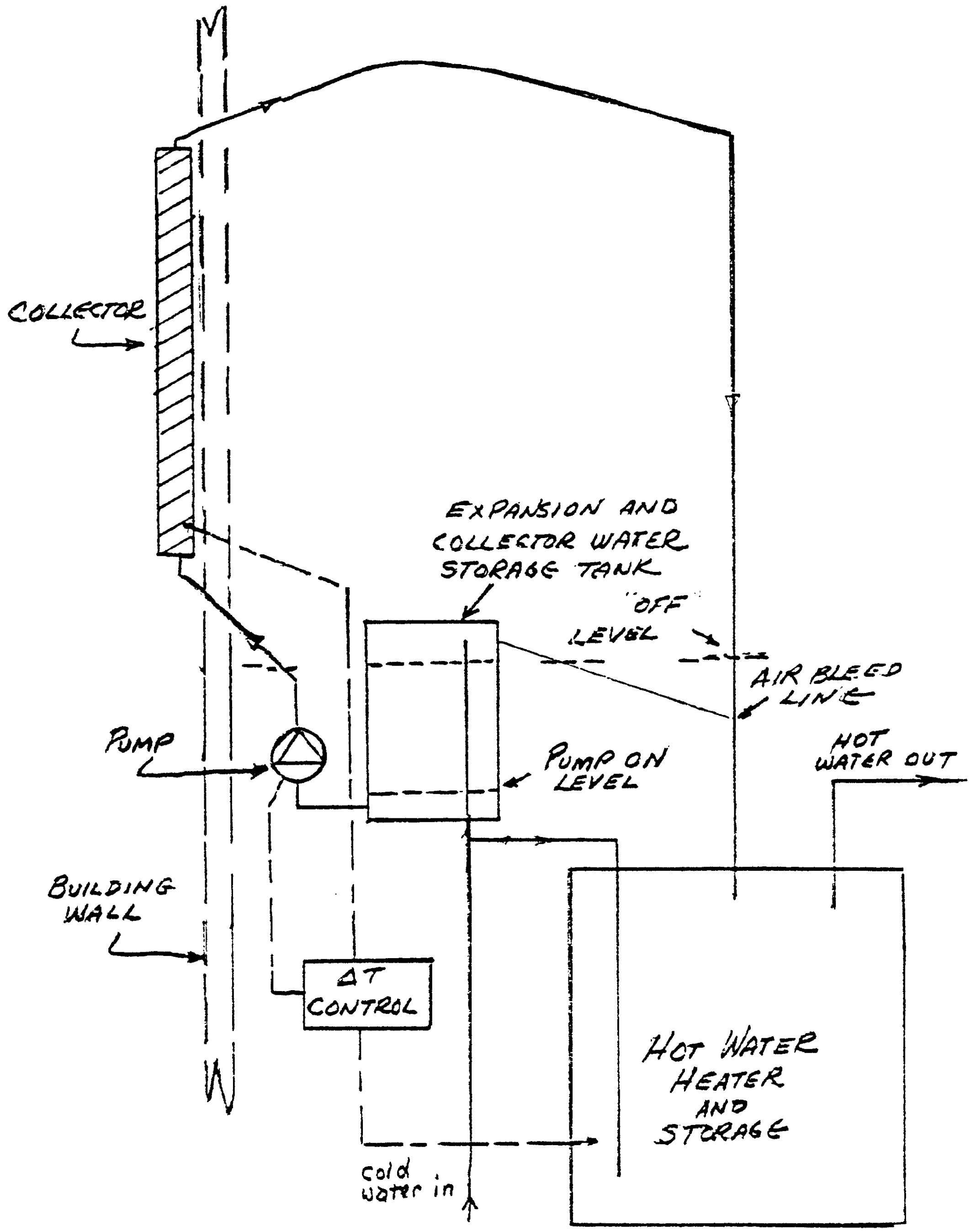


Fig. 18
Vertical Collector Gravity Drain
Solar Domestic Hot Water System A

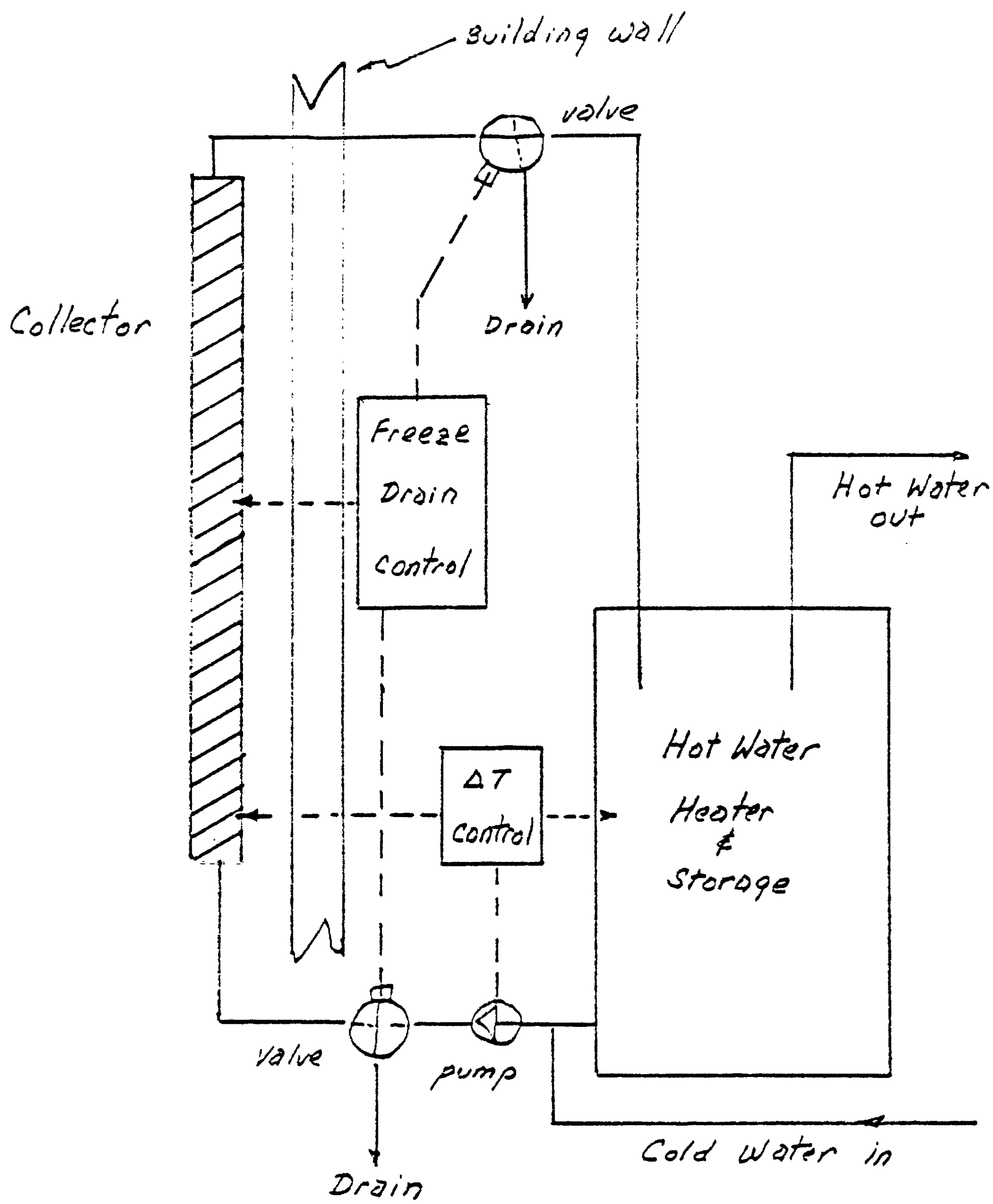


Fig. 19

Vertical Collector

Solar Domestic Hot Water System B

SOLAR HOT WATER IN MASTER'S DWELLING

Design: 20 gals/person-day: 80 gals/day-family; ΔT = 40°F to 140°F

Heat Req'd = 67,000 BTU/day

Vertical Collector: 1,500 BTU/ft^2 ave. daily

Assume 50% weather losses: 750 BTU/ft^2 ave. daily

$$\frac{67{,}000 \text{ BTU/day}}{750 \text{ BTU/ft}^2\text{-day}} = 90 \text{ ft}^2 \text{ collector}$$

80 gallon storage

10 months @ 30 days = 300 days; 300 days @ 67,000 BTU/day = 20 x 10^6 BTU/yr.

20 x 10^6 BTU = 6 x 10^3 Kwhrs.

Oil @ 40¢/ga and 50% eff costs \$6/10^6 BTU

Savings = \$6 x 20 = \$120/yr.

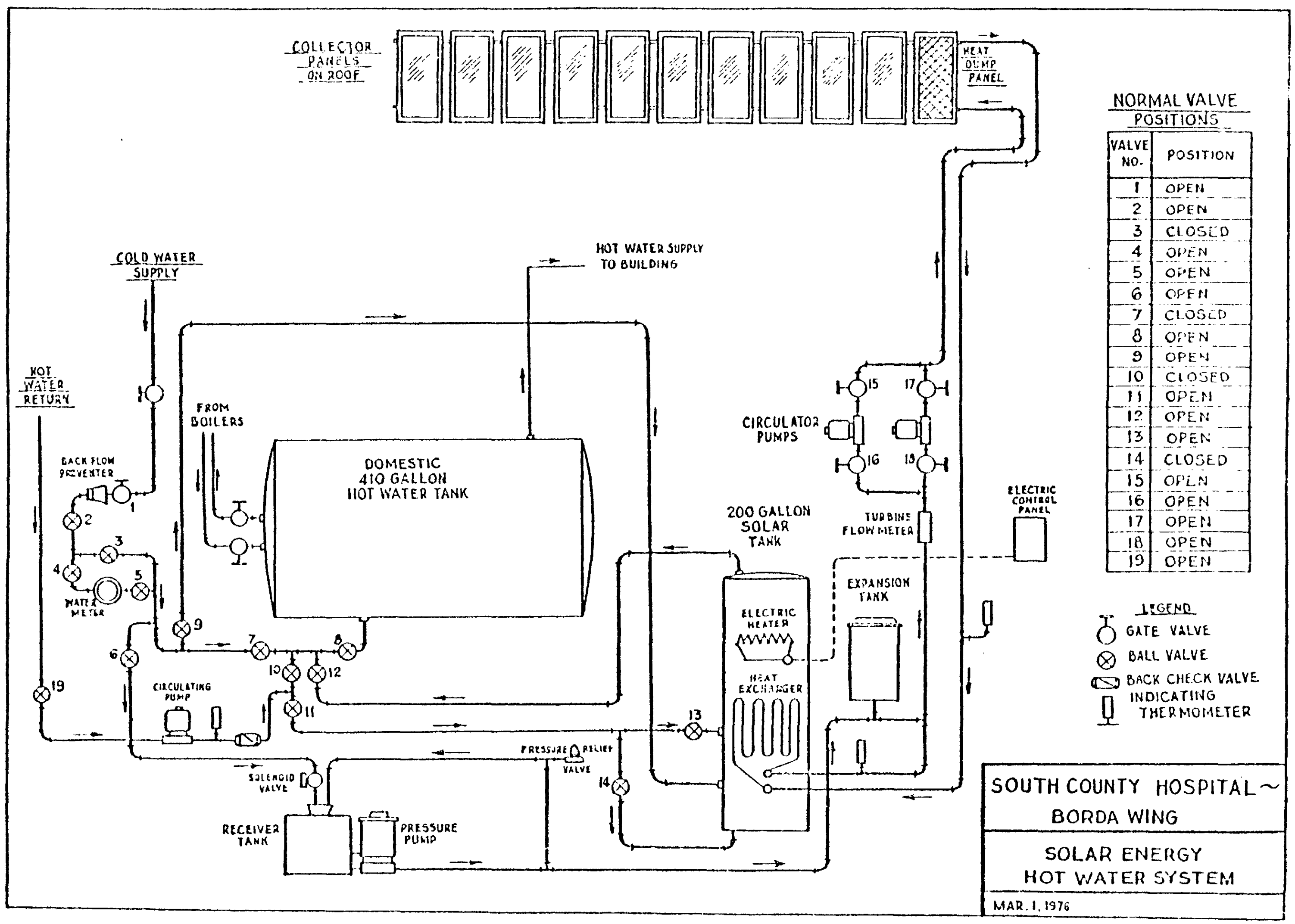
M. A Current Example of an Institutional Solar Water Heating System

The Narragansett Electric Company, an affiliate of the New England Electric System, has installed a solar research project at the South County Hospital in Wakefield, Rhode Island, as a supplementary source of heat for hot water used in the two-story, 30-bed Borda Wing. The system has been designed to supply most of the hot water for the Borda Wing. Hot water needed above that supplied by the solar system is heated electrically with 11.25 KW heater installed in the 200-gallon storage tank. The system is heavily instrumented to monitor system performance and to maintain system operation.

A schematic diagram of the complete system in show in Figure 20. The collector is made up on ten Daystar 20 panels, Figure 21. Because the system is designed to provide such a large fraction of the hot water by solar heat, a heat dump panel is necessary to avoid an overtemperature condition on those days when the available solar heat exceeds that needed for hot water.

The system is expected to supply an average of 60 million BTU's annually in the New England climate or just under 300,000 BTU's per square foot of effective aperture*. The installed cost of the system was \$30,000 or \$150 per square foot. A good portion of this cost was in instrumentation and recording equipment that would not be needed in most installations. Let us generously assume that half the cost was for instrumentation, making the square foot cost of a basic system \$75. If the system performs as expected each square foot of the system will collect annually the energy equivalent of 4.3 gallons of fuel oil utilized at 50% efficiency. If we put the cost of fuel oil at 50¢ per gallong, each square foot of collector returns \$2.15 in oil equivalent energy a year. When presently unknown operation and maintenance costs are deducted, the net return will be significantly less.

*We believe this estimate is optimistic.



VALVE NO.	POSITION
1	OPEN
2	OPEN
3	CLOSED
4	OPEN
5	OPEN
6	OPEN
7	CLOSED
8	OPEN
9	OPEN
10	CLOSED
11	OPEN
12	OPEN
13	OPEN
14	CLOSED
15	OPEN
16	OPEN
17	OPEN
18	OPEN
19	OPEN

Fig. 20

South County Hospital Solar System (NEES)

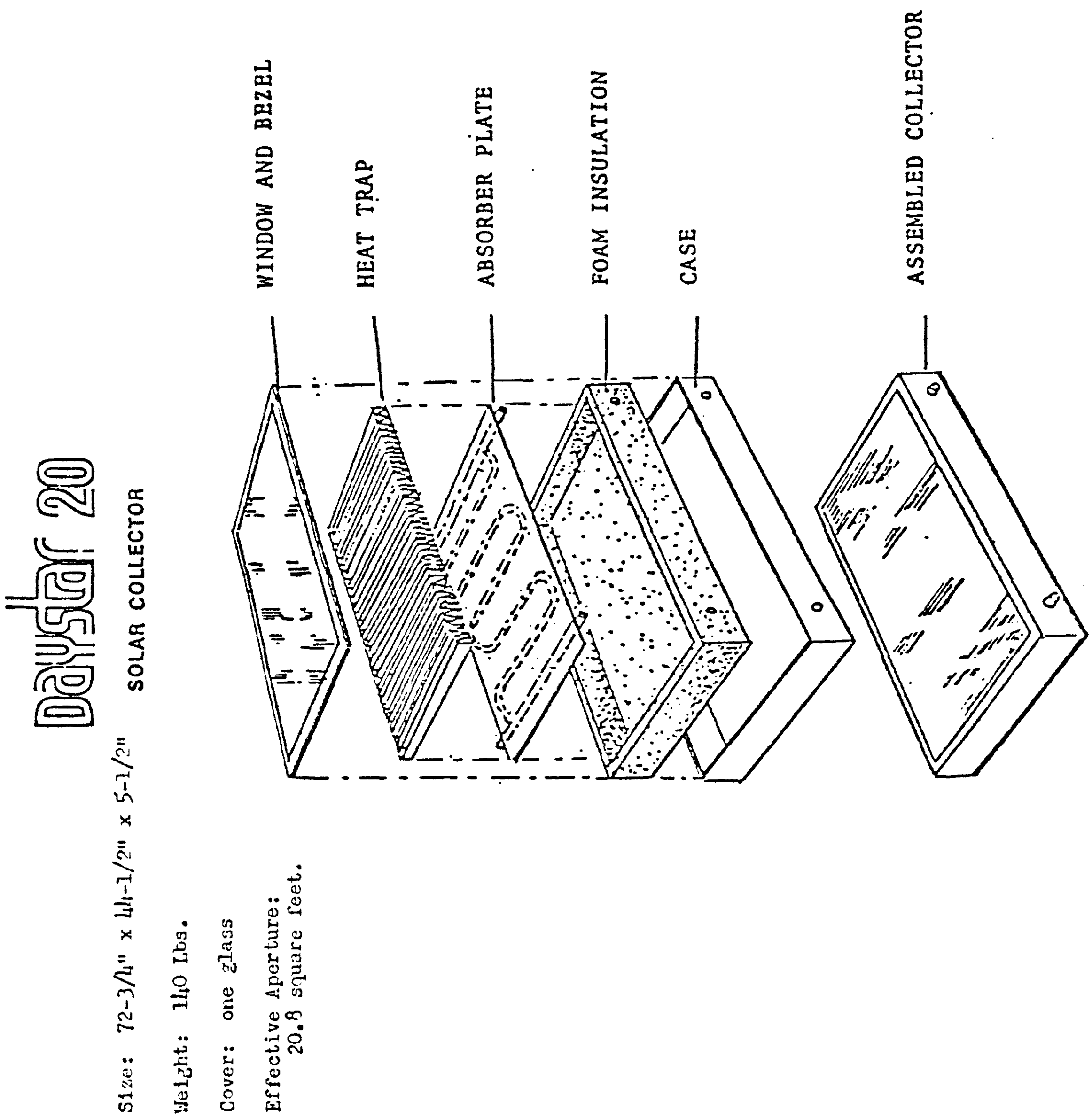


Fig. 21
Solar Collector
South County Hospital System

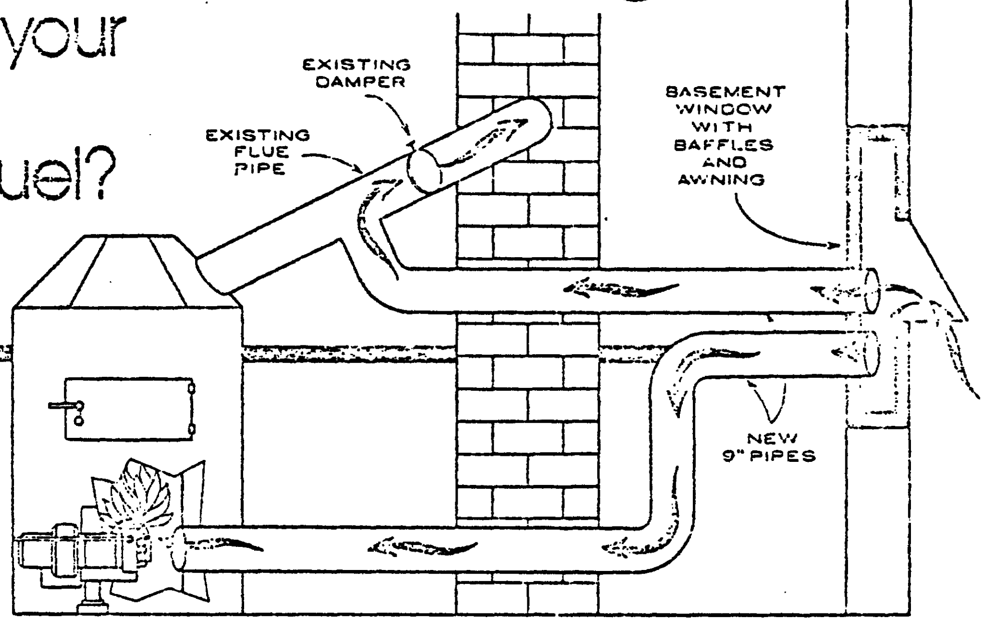
Appendices

Popular Science

February 1976

Outside venting:

Will it help your furnace burn less fuel?



Two readers share venting ideas that have trimmed their fuel bills—and a heating expert comments

By ARTHUR E. GEALT

By venting an existing oil-fired furnace to the outside, I was able to reduce considerably my furnace's oil consumption, raise the humidity to a more comfortable level, and reduce the drafts in the house.

We live in an older home—circa 1898—in Philadelphia. It's three stories high plus an attic, constructed of stone some 20 inches thick but with no insulation except in the attic floor. The heating system was originally a gravity warm-air system with a hand-fired coal furnace. Years before we bought the house, a gun-type oil-burner conversion had been made and the return air was brought back to the heater and a filter and air blower added.

The house has storm windows, and the windows have weather stripping. We have an outside vestibule protecting the front door, and the rear door is shielded.

Sound pretty good? The fact is the house had always been cold and drafty, and the humidity had varied between five and 10 percent in spite of using two humidifiers consuming about three gallons of water a day. In the coldest weather the humidity would drop clear out of sight, the burner would run almost all the time, and the house still would be cold.

We explored the various improvements possible. There wasn't space to add insulation to the stone walls. Storm windows could be added to the three windows (out of 20) that didn't already have them, for some possible improvement. Our weather stripping could stand some overhaul, but it was basically sound. We could lower the thermostat, but since we had been operating at 70 degrees—and were finding that chilly—to lower it even more would be intolerable. We could install a clock thermostat, but with our family's hours it could be set back for only about six hours a day. We had long since closed off all of our unused rooms.

Could we change to any other form of heating? Solar heating would call for major rebuilding. Gas or electric heating was impossible, for both utilities had suspended any additional installations in our area.

We looked again at the hot flue pipe running from the heater to the chimney. How could we keep more of those wasted Btu's? A fan blowing on the flue pipe would extract more heat and keep the basement warmer. Water piping through the flue pipe could preheat the water going into the hot-water heater. We could attempt to slow down the hot flue gases for less heat loss.

But what gases were flowing through the flue pipe? Obviously gases of combustion. But where do they come from and what are they? They don't just come from the oil. Oil is a mixture of different hydrocarbons, all of which burn to carbon dioxide and water. But this needs oxygen, lots of oxygen, and therefore lots of air. And where was all this air coming from? The cellar! And how was it getting into the cellar? There's a pair of windows in the cellar but they are about as tight as the other 30 windows in the house. So the air was coming in through all the windows and the doors, through the house and down to the cellar. By the time it got to the heater it had been warmed at least to cellar temperature. Also, the damper flapper was sucking a lot more warmed air into the chimney and out of the house.

What we did about it

First, we set out to measure how much air we were talking about. Armed with a toy telephone and a stop watch, we squirted some oil into the fire-pot and timed the puff of black smoke that came out of the chimney. This proved to be about three seconds. With a nine-inch flue pipe and chimney and a 40-foot travel distance, this calculated to some 10 cubic feet per second, or 36,000 cubic feet per hour.

Since the average person breathes about 18 cubic feet per hour, there was plenty of room for reduction without causing a ventilation problem. We closed off a portion of the flue exit at the heater with a fire brick and travel time was a little slower. We checked with cigarette smoke to make sure that air was being sucked in at the fire-box door, and then added a second fire brick. With this addition the travel time was doubled. Of course we again checked for a positive draft at the door. We ran the system for a month in this configuration and felt some improvement in comfort, but it was too short a time to measure a change in fuel consumption.

Then we tore down the existing flue pipe, opened a nearby window, and inserted a panel with two nine-inch openings (see drawing). We added a T ahead of the existing damper, and ran a nine-inch-diameter pipe to one opening in the window panel, a distance of about 10 feet. From the other opening we ran a similar duct about six feet to the fan of the burner. At this location the duct was open-ended, just pointing at the fan. On the outside of the window we installed a baffle to prevent direct wind entry, and an awning to keep out rain and snow. We fired up the system and again checked for positive draft at the fire-box door and at the flue-damper entrance. Next we felt both of the new ducts and they were cold as all outdoors. The smoke-pipe temperature had dropped enough to let us touch it, so we knew we had done some good.

Here are the results

One effect was immediate. The drafts around our upstairs windows almost completely disappeared and the house began to feel more comfortable. Although this was December, the furnace's "on" periods became shorter and less frequent.

The next effect we noticed was that the humidity rose to 20 percent in the first day. We shut off the water to the humidifiers, but the humidity continued upward and crept up to 25 percent. Previously, we had been fighting to maintain 10 percent. Since we were no longer sucking all the air we had just humidified right up the chimney, there was enough moisture from showers, damp towels, dish washing, and just people to build up the humidity without extra help.

The next effect took about two months to notice. Regular oil deliveries, scheduled automatically on a degree-day basis, were smaller than usual. Of course, with prices rising to 36 cents a gallon, the bills really weren't any lower.

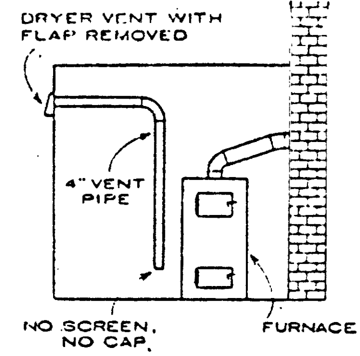
We went back to our files and dug out all the oil-delivery slips for the last five years and drew graphs of usage for each year, plotting accumulated usage to date, and we were startled by the results. By the end of the heating season we had used only 1460 gallons as compared with an average of 2455 gallons during the five previous years. It had been a mild winter, some nine-percent fewer degree days than normal. But our oil usage for the season was down 40 percent!

Will it work for you?

If you have an oil-heated house, every gallon of oil your furnace burns requires about 2000 cubic feet of air for combustion. Further, if your chimney is tall enough for a coal furnace it was designed to produce enough suction to pull all the air needed through a thick bed of coal and ashes, without the help of an electric blower. With an oil burner—or with gas for that matter—this resistance does not exist, and a much greater flow of air and gases occurs. In my own case it was drawing well over 10 times as much air as was needed.

About a dozen of my colleagues were intrigued enough by my success to build similar installations in their own homes for use during the current heating season. The reports to date have been unanimous with respect to the reduction of drafts and the improvement of humidity. The savings with oil have averaged about 25 percent and those with gas have been about 15 percent.

My savings have indeed been greater than the average user may expect. But all the people who have used this technique are exultant over the comfort improvement and more than satisfied with the fuel saving they have experienced.



Here's a simpler vent system you can try

Your articles last September, on insulation and energy conservation were interesting and gave good hints. Here's another:

Fuel can burn properly only when there's enough combustion air in the furnace to avoid the formation of carbon monoxide. A hot-air furnace burning 100 cubic feet of natural gas per hour requires 1000 cubic feet of air just to burn the gas, and an additional 250 cubic feet of air to assure complete combustion. In most homes, the furnace is located inside and the combustion air is taken from the area immediately surrounding the furnace.

With an outside temperature of zero, it requires 14,000 Btu per hour just to replace the combustion air. This burns up air that you have paid to heat and sends it out the chimney. Some homes are now so tightly sealed that a furnace has difficulty breathing, and actually starts making carbon monoxide. So air must be provided.

I installed a four-inch dryer vent through my basement wall and ran the vent piping to within a foot of the furnace combustion chamber. This allows cold fresh outside air to be sucked in and burned, and the heated air inside the house isn't consumed. I have noticed that there are now no cold drafts around doors and windows because the furnace is not pulling air through the house. My heating bills were reduced about 14 percent, enough to more than pay for installation of the vent in our first heating season.—*Allan E. Anderson, Marshall, Minn.*

We found the fuel savings these readers reported almost too good to be true, so we asked a heating authority to evaluate the benefits of venting furnaces to the outside. Dr. L. G. Austin, Professor of Materials Science at Penn State, comments:

"A better comfort level can be obtained if the furnace uses cold air from outside instead of sucking warm air from inside the house. But from a heat-balance point of view it is immaterial where the cold air enters—through a window crack or through a venting pipe. The real point is that *movement* of the cold air through the house causes drafts and prevents the build-up of humidity, which gives you an uncomfortable house for the same temperature and fuel input.

"I suspect that the excess air being sucked through Mr. Gealt's furnace was far greater than with an efficient modern furnace: A properly designed furnace loses less heat up the chimney with a small flow of hot gas than an unbalanced system passing huge quantities of colder noncombustion air. After *any* major modifications to the air feed to a modern furnace, it is advisable to have a trained furnace man reset the fuel-air balance to give correct CO_2 content (measured with an Orsat tester) of the flue gas."

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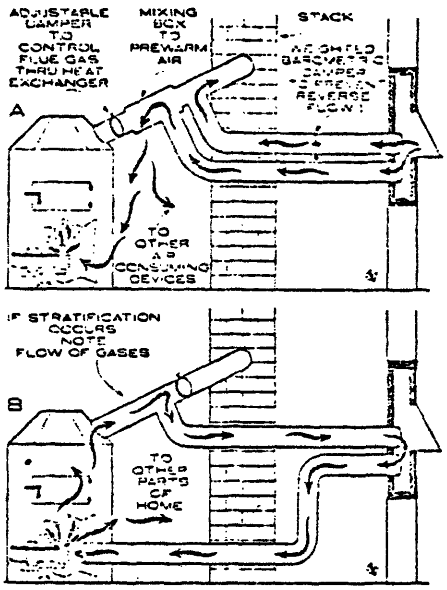
PS READERS TALK BACK

Outside venting

The first and most serious problem with Mr. Gealt's system is the failure to place a barometric (flapper) damper in the upper air supply to the smoke pipe. This omission will, under certain conditions, allow the introduction of flue gases into the home.

A smokestack operates because the



byproducts of combustion, when heated, are lighter than the cooler outside air. If, due to an oversized stack or the introduction of colder air, these byproducts are cooled to a temperature level equal to the outside air before they leave the stack, stratification can occur (see drawing B). The furnace will begin to feed on itself with a rapid buildup of carbon monoxide. Because the furnace is not the only device drawing air into the house, these fumes can be drawn into the living areas by other air-consuming devices such as clothes dryers, fireplaces, and exhaust fans. A weighted barometric damper (see drawing A) will prevent this reverse flow.

Another change I'd make in the system is the addition of a heat exchanger or mixing box to prewarm the air being brought in from outside (drawing A). I'd also put the existing damper between the furnace and the mixing box; this would allow a finer control of the flue gases passing through the prewarmer. The ideal setting for this damper will slow the flow of flue gases through the mixing box for maximum transfer of heat, while allowing complete combustion in the fire chamber. The setting should be made with the proper test equipment.

Prewarming outside air before it enters the gas or oil burner's air intake is necessary because with direct air intake it is almost impossible to obtain the correct air-fuel ratio over the wide range of outside air temperatures.

Ronald P. Knudsen, Park Ridge, Ill.

Adding a motorized damper in the fresh-air intake duct, which would open as soon as the blower starts, would improve the system by preventing cooling of the boiler water jacket during off periods.

Rene Van Der Spek,
Mississauga, Ont.

Cold air, continuously admitted to the vicinity of the burner fan intake, will sweep residual heat from furnace structures up the stack during burner off periods, thus depriving the house of same. Also, excessive amounts of cold outside air will have continuous entry to the cellar.

A better way to solve problems of cold drafts and humidity is to install a five-inch-diameter air duct from the outside to the return air duct of the furnace. Place a bird screen and damper in the duct. Once adjusted, this will give automatic ventilation since the makeup air entering is heated and humidified as it passes through the furnace and is distributed throughout the house. More information can be obtained from the National Research Council of Canada, Ottawa. Request Housing Note No. 13, reprint from *Canadian Builder*, vol. 13, no. 9, Sept. 1963.

E. T. W. Bailey, Hamilton, Ont.

With regard to Arthur E. Gealt's article, "Outside Venting, Will It Help Your Furnace Burn Less Fuel?" [PS, Feb.] I approve heartily of bringing in outside air for combustion. A word of warning about introducing cold air into the vent pipes of older homes, however:

If the products of combustion are cooled below the dew point, there can be problems of condensation. The water will react with other elements in the flue products and form various acids. If the chimney is not lined, these acids will attack the mortar. It is unlikely that the author's house—built in 1898—has a lined chimney.

Grover C. Lewis, Michigan City, Ind.

Appendix III INFRA-RED SURVEY

We were able to arrange for a limited infra-red survey of some of the buildings at St. Mark's.

An infra-red survey involves the use of a heat detector, television monitors and instant cameras.

The heat detector converts the temperature distribution over a surface into electric signals. These electrical signals are displayed on a television screen as varying levels of whiteness directly proportional to the surface temperature: the warmer the point on the surface, the whiter the display. The brightness level can be adjusted so that, at St. Mark's, for example, the sky was black and an open window, white.

A conventional television camera is pointed at the surface of interest at the same time and its television monitor presentation compared with the displayed picture of the infra-red (heat) camera.

If a building were perfectly insulated, the infra-red picture would be completely black. If a window were opened, the opening should appear white.

In the case of an imperfectly insulated building, the walls would appear as grey. Cracks around the windows would appear as white lines.

Figures 22 through 24 are paired photographs of the buildings and the infra-red camera presentation on a television monitor.

In the infra-red portion of Figure 22 we see the high heat loss through the wood studs and lower heat loss through the walls. The studs are whiter than the walls, illustrating a higher heat loss.

This is due to the fact that there is some insulation furnished by the wall materials, but the wood studs act as thermal "bridges" and conduct heat directly from the inside of the building to the outside. Insulation ought to be placed over the studs, window frames and other wood members to minimize these losses.

In Figs. 23, 24, we see the heat loss through large picture windows of other buildings on campus.

These illustrate a situation at St. Mark's. The older buildings are very poorly insulated. There is heat leakage through walls, roofs and windows.

The newer buildings apparently have adequate insulation in the walls and roofs, but overall efficiency is still low because of the large expanses of single pane windows which pass valuable heat. Thermopane could be substituted or another pane of glass, in appropriate mullions and frames, placed in the openings.

Fig. 22
Infra-red Survey (Wall of Older Building)

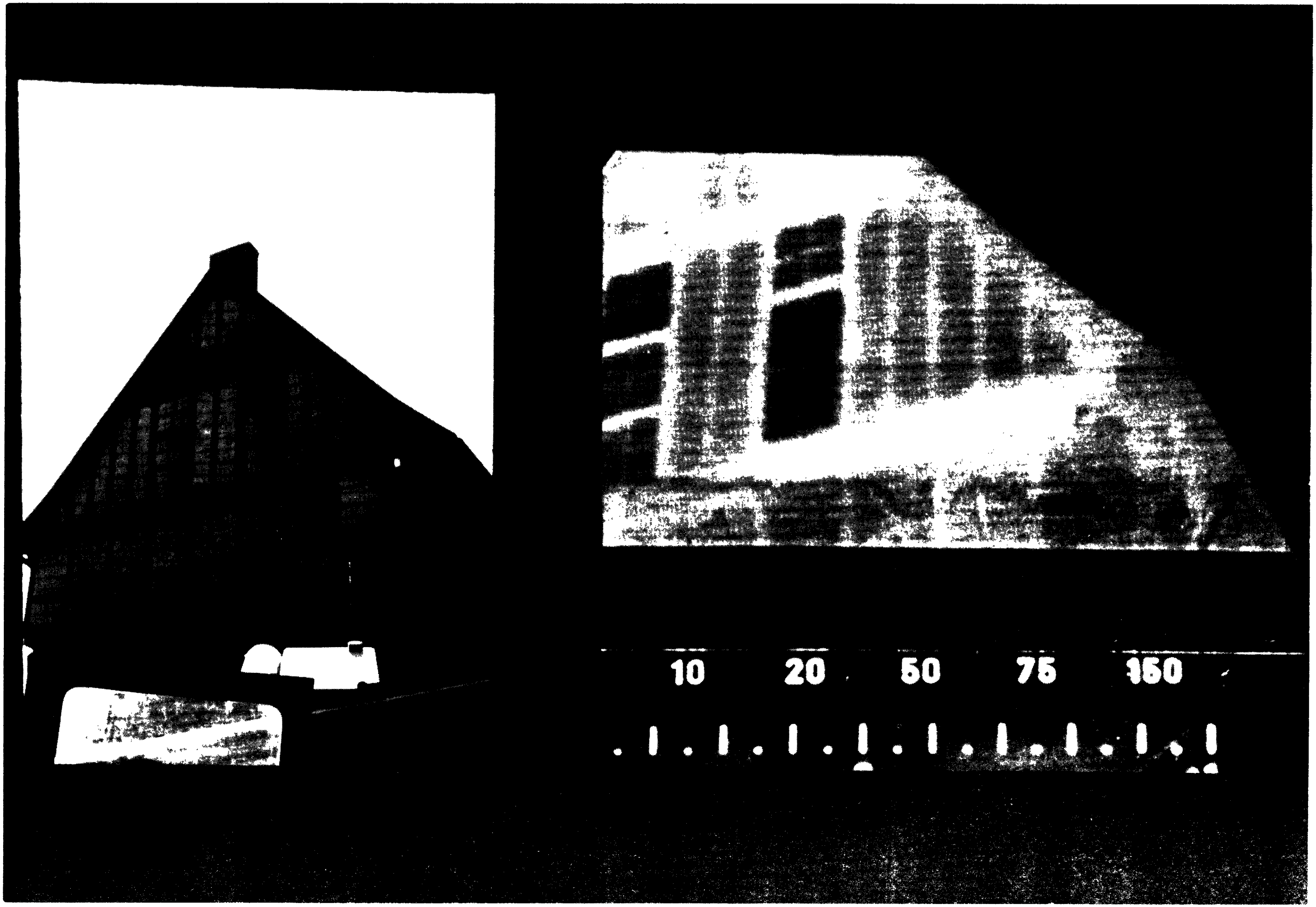


Fig. 23
Infra-red Survey (New Library)

Fig. 24
Infra-red Survey (New Arts Building

The discussions and guidelines reveal opportunities and options for lighting energy conservation which are in accord with the following principles and practices.

- Illuminate specific task areas to that level, for each area, which provides adequate visual acuity, to perform the required task satisfactorily and reduce illumination levels in adjacent areas.
- Provide artificial (electric) lighting only where and when it is required (to perform the task or for safety).
- Consider all available light sources, including daylight, and select the most efficient that suits the application (highest lumen output per input watt).
- Institute a thorough maintenance program to sustain the highest value of light loss factor (L.L.F.)

REDUCE ILLUMINATION LEVELS

Conserve energy for lighting by reducing illumination levels when they need not be high and eliminating illumination where it is not needed at all. Consult Table 8, "Types of Lighting Compared" for suggested levels in specific areas of the building. If several tasks requiring different levels of illumination occur within the same space, first consider their visual severity and then modify maintenance procedures, redecorate the area, and implement changes to the lighting system while reducing illumination levels to the appropriate level for each task. A uniform modular lighting pattern of general illumination, throwing light equally on all areas regardless of task may waste up to 50% of the energy used for lighting in the building. Orient lighting to suit the tasks to be performed.

If one task with a critical lighting requirement is confined to a specific work area, i.e., drafting table, typewriter, desk top - in the midst of a larger work area with less critical requirements, provide a lower general illumination level for the overall area and a portable light at each critical task to raise the level of illumination locally (less than $25/lamp). Use fluorescent portable lamps in preference to incandescent.

In many cases it is less costly to move tasks to suit an existing lighting pattern than to add or rearrange fixtures. If task areas are widely dispersed, more light spills into adjoining areas where it may not be needed. Group tasks requiring similar lighting levels to limit the spill of higher level illumination and to allow lower lighting levels at less critical work areas.

Light levels in standard footcandles can be determined with portable illumination meters such as a photovoltaic cell connected to a meter calibrated in footcandles. The light meter should be accurate to about ± 15 percent over a range of 30 to 500 footcandles and ± 20 percent from 15 to 30 footcandles. The meter should be color corrected (according to the CIE Spectral Luminous Efficiency curve) and cosine corrected. Generally, measurements refer to average maintained horizontal footcandles at the task or in a horizontal plane 30 inches above the floor.

Measurements should be made at many representative points between and under fixtures; an average of several readings may be necessary. Daylight should be excluded during illumination-level readings for a true determination of level without light contribution from daylight.

The suggested illumination levels for office buildings, listed in Table 8 agree closely with new standards recommended by the U.S. Government Services Administration for public office buildings. Keep in mind, however, that even lighting at lower intensities is very wasteful if lamps are burning when not needed.

Types of Lighting Compared

Table 8

	Type & Wattage	Lumens per Watt (L/W)	Life-time	Lumen Efficacy	Equip-ment Cost	Ope-rating Cost	Color Characteristics	Recommended Uses	Remarks
incandescent	Standard 15 25 40 60 75 100 250 500	 8 9 12 14 18 18 20 21	750–1000 hrs: shortest of all lamps	80% prior to failure	Low	High	· Nearest to natural daylight Skin tones heightened. Gives "warm" atmosphere where used	· Where lamps are burned fewer than 6 hrs a day · Where foot-candle requirements are under 50. · Where "warm" atmosphere is desired	· Efficiency is critically dependent on operating voltage. Do not burn lamps at voltages lower than the output of the electrical socket.
	Long-life 100		2, 3, or 5 years		High	High		· Only where maintenance is difficult or irregular	
	PAR 250	18.4		Reduced to 70% after 1,000 hrs.				· As narrowbeam floodlights · "Cool beam" lamps suitable for displaying food	
	Tungsten Halogen 45 100 150 200 250 Spot 500 Flood 1,000 Flood	 13 18 18 19 13 14 17	4,000 hrs. minimum for high-voltage lamps	90% after 3,000 hrs.	Low	Low	· Good color rendition: bright, white	· Where strong light is desired · Where good color is desired · General lighting for large rooms, production areas · In cornices and niches	· Low wattages available for single-purpose lamps · Not as flexible as standard incandescent · Significant savings in energy and costs over standard incandescent
	PAR 150			98% after 3,000 hrs.				· For floodlighting and outdoor decorative lighting	
fluorescent	40 60 75 110	66 68 73 72	20,000 hrs.	70% at 12,000–15,000 hrs.	Higher than incandescent	Lower than incandescent	· Warm white has the poorest color rendition; cool and deluxe warm white are better. Deluxe cool white most closely approximates natural daylight	· In production areas, kitchens, offices · As display lighting · Deluxe cool white, deluxe warm, and white can be usually used in place of incandescent bulbs	· Ballasts required for start-up reduce lamp efficiency · Color-corrected lamps are 30% less efficient than standard · Efficiency especially affected by ambient temperature · Cool and warm white have highest outputs, followed by deluxe and color-corrected lamps

Table 8 (cont.)

high-intensity discharge

Type & Wattage	Lumens per Watt (L/W)	Life-time	Lumen Efficacy	Equip-ment Cost	Opera-ting Cost	Color Characteristics	Recommended Uses	Remarks
Mercury 40 100 175 250 400	 29 41 42 46 51	24,000 hrs.	75% after 16,000 hrs.	Low	Medium	• Available in clear, white, color-corrected, and deluxe white. Deluxe white has best color rendition • Deluxe white is interchangeable with cool white fluorescent	• Indoors to light large spaces such as kitchen and production areas • Outdoors in parking areas and as merchandising or decorative lighting	• Cannot be dimmed; voltage requirements are precise • Not as sensitive to frequent start-ups as fluorescent
Special Mercury 40 75 100	 18 36 36	24,000 hrs.	75% after 16,000 hrs.	Low	Medium	• Excellent color; preferred alternative to cool white fluorescent • Second best color choice for "warm" atmosphere	• Can replace incandescent lamps in interior fixtures	• Limited number of sizes; strictly for interior fixtures • Higher wattages and longer life than standard mercury
Metal Halide 175 250 400	 70 64 80	7,500–15,000 hrs.	60% after 11,000 hrs.	Medium	Medium	• Better color than mercury; not as good as special mercury • Color-coated bulb has good, warm color; clear bulb less satisfactory • Best color rendition for outdoor lighting	• Parking areas • Large work spaces • Interior spaces lighted from above • Food displays	• Ballast required • Higher lumen output, lower lifetime than mercury
High-pressure Sodium 150 250 400	 89 80 106	12,000 hrs. 15,000 hrs. 20,000 hrs.	80% at end of lifetime	High	Low	• Poor color rendition: grays colors of red and blue objects. Similar to warm white fluorescent	• Outdoor, where color is unimportant: in parking spaces and security uses • If illumination of building is enhanced by yellow light	• The most efficient lamp currently on the market

NOTES: Neon lights have not been included because they are commonly used only as decorative lighting.
Fluorescent lamps described are all "rapid start."
Lumen efficiencies and numbers of lumens per watt are approximations.

SUGGESTED LIGHTING LEVELS*

With proper attention to quality the following levels should generally be adequate for tasks of good contrast:

Circulation Areas between Work Stations: 20 footcandles.

Background beyond Tasks at Circulation Area: 10 footcandles.

Waiting Rooms and Lounge Areas: 10-15 footcandles.

Conference Tables: 30 ESI footcandles with background lighting 10 footcandles.

Students/Faculty/Secretarial Desks: 50 ESI footcandles with auxiliary localized (lamp) task lighting directed at paper holder (for typing) as needed. In secretarial pools, 60 ESI footcandles.

Over Open Drawers of Filing Cabinets: 30 footcandles.

Kitchens: non-uniform lighting with an average of 50 footcandles.

Cafeterias: 20 footcandles.

Snack Bar: 20 footcandles.

Laboratories: As required by the task, (consider 2 levels, 1/2 and full). In computer areas, reduce general overall lighting levels to 30 footcandles and increase task lighting for critical areas for input. Too high a level of general lighting makes it difficult to read the self-illuminated indicators.

Drafting: Full-time, 80 ESI footcandles at work station, part-time, 60 footcandles at work stations.

Accounting Offices: 80 ESI footcandles at work stations.

Note: Where applicable, refer to health and safety codes and federal standards (OSHA) for minimum lighting specifications.

The goal of the above standards is to reduce class and office lighting energy usage to less than 2 watts/sq. ft. gross floor area, or 2.5 watts/sq. ft. net area and 1.5 watts/sq. ft. for religious buildings. To determine net area subtract from the gross building floor area, the corridors, storage rooms, lobbies, mechanical equipment rooms, stairwells, toilet rooms, and other unoccupied, or seldom occupied areas. Use the following as a guide:

Table 9

Indoor Lighting Survey with Light Meter

Room	No. of Bulbs	Average Wattage	Illumination footcandles	IES Recommended	
				Illumination in footcandles	Lamp Type
Overall					
Work Surface					
At Center					

N.B. 1. Check age of bulbs - new lamps will give different readings
2. Cleanliness of fixture
Photocell switches to outdoor lighting
3. Replace outside high press sodium lamps with high intensity discharge lamps with same lumen output and also inside deluxe mercury in special places.
4. Use fluorescent inside except for decorative.

*Unless otherwise noted, all levels are average.

We do not know the water consumption rate at St. Mark's. The supply is obtained from wells. Hot water is made at several localities by means of steam heat exchangers, the steam being supplied through the distribution system by the power plant.

We are aware that some attempts have been made to reduce hot water consumption in the showers. Reduction of water use at wash basins is also desirable and possible.

We recommend that hot and cold water flow restrictors be placed in all showers and at all wash basins.

The following, an excerpt from a paper by a government official and a calculation for a situation at St. Mark's serves to support this recommendation:

REDUCING ENERGY CONSUMPTION IN RESIDENTIAL WATER HEATING
THROUGH USE OF FLOW CONTROLS

From a Federal Energy Administration Report Prepared by Dr. John Muller

Residential water heating accounts for a fuel consumption of 1,100,000 BPD of oil equivalent or about 3% of all energy consumed in the United States. The National Bureau of Standards reports that bathing accounts for 42% of the total daily usage of hot water in a residence. Showers are perhaps the most popular form of bathing.

A sizeable energy savings can be obtained reducing the amount of hot water used in showers. The reduction in hot water use can be accomplished by urging citizens (a) to install a flow restrictor to limit the shower flow rate, and (b) to reduce the duration of the time spent in the shower.

In the Water Encyclopedia published by the Water Information Center, it is said that a shower bath requires 30-60 gallons of water. In the case of a showerhead flowing at 6 GPM, this quantity might be consumed in 5-10 minutes. By installing a flow control device in the showerhead, the flow can be cut to 3 GPM, and by educational programs most individuals can be taught to keep showers down to 5 minutes or less. Thus, for each shower the water usage can be reduced to 15 gallons rather than 30-50. To evaluate the reasonableness of this savings, a comparison with the only published data found on the subject is in order.

A year ago a test was run by the Washington Suburban Sanitary Commission on 25 single family homes fitted with 40 plastic flow restrictors which limited flow rate to 3.0 GPM. Duration of showers was not controlled. Sizeable water savings were observed. In December the average savings per household was 50 GPD, and in January, 30 GPD. More savings might be expected in warm weather seasons when people take more showers, the WSSC report observed.

The U.S. Department of the Interior - Federal Water Quality Administration published in December 1969 a report prepared by James R. Bailey, et al, of General Dynamics Electric Boat Division entitled "A Study of Flow Reduction and Treatment of Waste Water from Households." In this report limiting flow valves for showers were discussed. It noted that some claimed a 50-70% saving in shower water use. For their own calculations, the authors selected a figure of 6 GPD per capita, or a saving of 24 gallons per day in a 4 member household. Here again, the savings figure arrived at does not reflect reduced shower durations.

It is appropriate to evaluate the effects of a reduction in hot water usage for showers on a typical family and on the nation.

[End of excerpt]

Let us assume that:

(a) the average number of hot showers taken daily at St. Mark's is one per student
(b) for each shower a hot water saving of 15 gallons is achieved
(c) the annual average temperature of the cold water in the mains is 60°.
(d) the temperature of the water used in a hot shower by the average person is 105°

(e) the overall efficiency of gas or oil fired hot water is 50%

(f) oil costs 33¢/gallon

A few simple calculations then yield interesting results:

(a) for one person, a 15 gallon reduction in the amount of hot water used per shower means the duty of the water heater is reduced by:

$$1 \text{ shower/day} \times \frac{15 \text{ gallons saved}}{\text{shower}} \times \frac{8.33 \text{ lbs}}{\text{gallon}} \times 1.0 \times (105°\text{-}60°) = 11.2 \times 10^3 \text{ btu saved/day, or}$$

220 days*/year x 11.2 x 10^3 btu/day = 4.09 x 10^6 btu/year. (*school year)

(b) for a water heater fired by oil with an efficiency of 50%, the fuel savings are:

$$\frac{4.09 \times 20^6 \text{ btu/year}}{.50} = 8.2 \times 10^6 \text{ btu/year or } \underline{59.2 \text{ gallons of oil/year}}$$

CONCLUSION

If a flow restrictor were installed in all showers, and each hot shower were held to 5 minutes or less, the school's annual energy consumption would fall by 13,024 gallons of oil or $4298.00.

* * * * * * * * * *

REDUCING THE WATER WASTED BY HOTEL-MOTEL GUESTS WHILE TAKING A SHOWER

Prepared by Mr. Rudolph Bares, Vice President, Colonial Williamsburg

OBJECTIVE:
To conserve two natural resources, water and fuel, by reducing the amount of heated water used by hotel-motel guests while taking a shower. At the same time, reduce the volume of water which must be handled by sewage treatment plants.

METHOD:
Install a shower flow control between the water pipe (shower arm) and the existing shower head. In a local test installation, water volume used was reduced from about six gallons per minute (gpm) to about three gpm. In 100 guest rooms, over a one-year period, not one guest comment was received as to any inadequacy in the effectiveness of the shower. Measurements of water volume were made with a flow meter. The existing shower head is the Sloan Actomatic.

DEVICE:
Noland SFC-3 Shower Flow Control - available from your Sheraton Supply Company Customer Service Representative.

INSTALLATION:
Installation is easy and quick. Remove shower head, insert shower flow control in supply pipe and replace shower head.

RESULTS OF TEST:

Water Saving -	31	gallons per shower, 5 minute shower
	- 15	gallons per shower, 5 minute shower with shower flow control
	16	gallons per shower saved (52%)
	x 2.5	showers, per occupied room per day (assumes multiple occupancy)
	40	gallons saved per day
	x 256	days per year (70% annual occupancy)
	10,240	gallons saved per year, per room
	x 97¢	water cost 50¢ + sewer service cost 47¢ per 1000 gal.*
	$ 9.93	DOLLARS SAVED PER ROOM PER YEAR, WATER ONLY AT 70% OCCUPANCY

*City of Williamsburg, Virginia, rates as of July 1, 1973.

Fuel Saving-	10,240	gallons water saved per room, per year
	x66.6%	proportion of shower water which is heated
	6,820	gallons hot water saved
	x 4.5	gallons fuel oil required to heat 1000 gallons water
	30.7	gallons fuel oil saved per year
	x 32¢	cost per gallon oil (medium fuel oil)
	$ 9.82	COST OF FUEL OIL SAVED PER ROOM PER YEAR
Total Saving-	$ 19.75	WATER AND FUEL COST SAVED PER ROOM PER YEAR

A. Background

The amount of energy consumed in heating hot water is about 4% of the annual energy used in most large commercial buildings. In smaller commercial buildings, the percentage is smaller. However, in facilities which include restaurants, cafeterias and especially laundromats, the percentage of energy for hot water compared to other systems will be greater.

If domestic hot water is heated by the same boiler which heats the building, and if the load is only 10 or 20% of the total boiler load in those months when the building is heated, the energy used in the fall and in summer months for domestic hot water may be considerably higher than in the winter as the boiler will be operating at low part load efficiency. To determine the amount of energy used for domestic hot water follow the method described in Section 3, Figure 12.

The opportunities to conserve energy for heating domestic hot water can be summarized as follows:

Reduce the load.

- decrease the quantity of domestic hot water used
- lower the temperature of the domestic hot water

Reduce the system losses.

- repair leaks and insulate piping and tanks
- reduce recirculating pump operating time

Increase the efficiency of the domestic hot water generator.

B. Existing Conditions

1. Average Usage

Table 10

<u>Office Buildings</u>	
(Without kitchen or cafeteria services)	2 to 3 gallons per capita per day for hand washing and minor cleaning (based on an average permanent occupancy which includes daily visitors)
<u>Department Stores</u>	
(Without kitchen and cafeteria services)	1 gallon per customer per day
<u>Kitchen and Cafeterias for hand washing</u>	
Dishwashing, rinsing and hand washing	3 gallons per customer per day
<u>Schools</u>	
Boarding	25 gallons per capital per day
Day	3 gallons per capita per day (Does not include cafeteria or athletic facilities)
<u>Apartments</u>	
High rental	30 gallons per capita per day
Low rental	20 gallons per capita per day
<u>Hospitals</u>	
Medical	30 gallons per capita per day
Surgical	50 gallons per capita per day
Maternity	50 gallons per capita per day
Mental	25 gallons per capita per day
Hotels	30 gallons per capita per day

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2. Average Temperatures

The usual temperature at which hot water is supplied - from 120°F to 150°F - is too hot to use rectly and must be mixed with cold water at the tap. For dishwashing and sterilization the delivery temperature is generally 160°F or higher. Often hot water supplied to all faucets is at temperature required for the kitchen. Frequently, the hot water, generated and stored in tanks at 150°F to 160°F, loses heat by conduction and radiation from the tank and piping, even before the delivery at wasteful temperatures.

When hot water is supplied by a tankless heater, it is within 5° or 6°F of the boiler water temperature maintained to heat the building. A mixing valve is often used to control the delivery temperature, but frequently the temperature at which it is set is excessive. If the tankless heater, or tank heater, is installed inside the boiler, the losses from the doemstic heater may be considerable.

3. Methods of Generation and Storage

a) By a tankless heater from a hot water boiler used to heat the building, or by a below-the-water line tankless heater on a steam heating boiler.
b) By a tank heater and storage tank combination which is either a hot water or steam-heating boiler. The tank heater may be integral with the storage tank, or separately mounted and connected to the boiler and tank by piping.
c) By a separate oil, gas, coal or electric domestic hot water heater with integral storage tank.
d) By separate electric booster heaters without storage tanks.

4. Distribution

Hot water is distributed either by gravity circulation or by a recirculating hot water pump through separate piping to the fixtures. The recirculating hot water pump delivers hot water instantly at the faucets and reduces the total quantity of water used by saving the cold water which is usually drawn upon first opening the faucet. However, because the pump requires electrical power for operation, and because its piping system must always be filled with hot water and experience heat loss, the use of the recirculating pump could be energy-wasteful in systems where all faucets are close to the tank.

C. Energy Conservation Opportunities

REDUCE THE TEMPERATURE OF DOMESTIC HOT WATER SUPPLIED TO TAPS

Lowering the temeprature of the hot water reduces both the "building" domestic hot water load, as well as the distribution load. The building load for hot water heating is expressed by the following formula:

Yearly BTU's = $Q \times Td_B$, where Q = Quantity of domestic hot water used per year in pounds, and Td_B = Magnitude of the difference, in °F, between the temperature of cold water entering the heater, and the temperature of the hot water at the faucets.

The parasitic load is determined similarly, except:

Yearly BTU's = $Q \times Td_p$, where Td_p = Magnitude of the difference, in °F, between the generation temperature and the temperature of the water at the taps.

Ttoal load, then is calculated as follows:

Yearly BTU's = $(Q \times Td_B) = (Q \times Td_p)$.

Or, because:

$Td = Td_B + Td_p$

(that is, the difference between the temperature of the water as it enters the heater and the genera-

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tion temperature), it is calculated more simply as follows:

Yearly BTU's = Q x Td

Figure 25 indicates energy used for domestic hot water at various generation temperatures and usage rates. An incoming water temperature of 50°F and 251 days of occupancy per year are assumed.

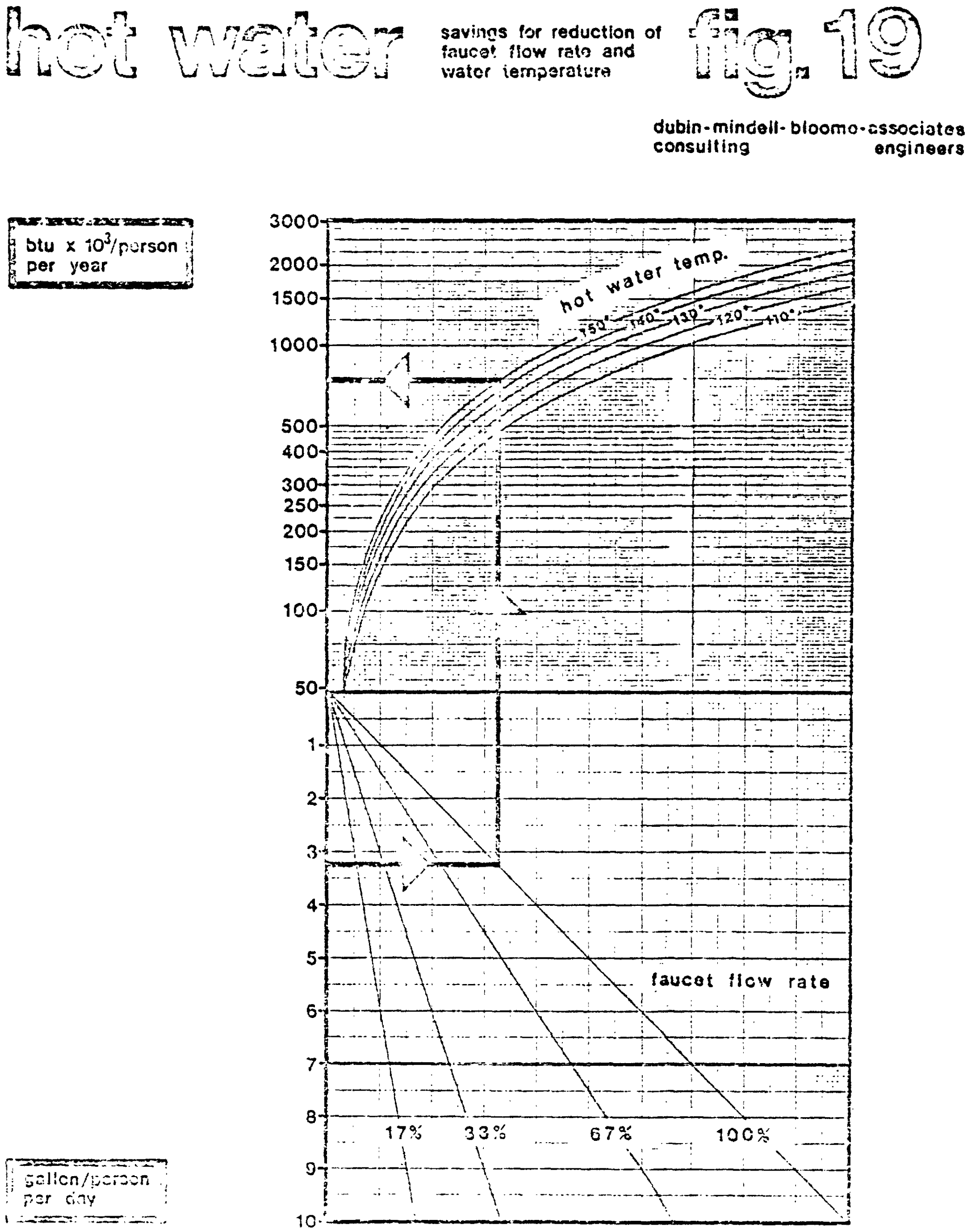

Figure 25

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Figure No. 25 Engineering Data:

Method: Straight heat transfer calculations

Assumption: Users open faucet for a set amount of time regardless of flow rate, i.e., washing hands is based on the time it takes rather than the water quantity.

The actual amount of energy required to supply the total load depends upon the seasonal efficiency of the heater, "E", which varies with the type of heater and the fuel used. On a seasonal basis, the following are average efficiencies:

a) Oil-fired heating boilers used year round, but with domestic hot water as the only summer load = .45.
b) Oil-fired heating boilers used year round with absorption cooling in the summer = .7.
c) Gas-fired heating boilers used year round, but with domestic hot water as the only summer load = .50.
d) Gas-fired heating boilers used year round with absorption cooling in the summer = .75.
e) Separate oil-fired hot water heaters = .70.
f) Separate gas-fired hot water heaters = .75.
g) Separate electric water heaters = .95.
h) Separate coal-fired water heaters = .45.

To determine actual energy consumption, divide the value obtained from Figure 29* by the appropriate efficiency or use the following formula:

$$\text{Yearly BTU's} = \frac{Q \times Td}{E}$$

Example:

An office building has 500 occupants, each of whom uses 3 gallons of hot water per day for 250 days each year. The temperature of the water as it enters the heater is 60°F. (an average for the year) and it must be heated to 150°F in order to compensate for a 20°F drop during storage and distribution, and still be delivered, at the tap, at 130°F. Hot water is generated by an oil-fired heating boiler, used year round with domestic hot water as the only summer load. The fuel is #2 oil, which contains 138,000 BTU's to a gallon.

Builidng load

Q = 500 occpt x 3 gal./day/occpt x 250 day/yr. = 375,000 gal./yr.

1 gal. = 8.3 pounds, therefore

Q = 390,000 gal./day x 8.3 lbs./gal. - 3,112,500 lbs/yr.

Td_B = 130°F - 60°F = 70°F.

Yearly BTU's - 3,112,500 lbs. x 70°F - 217,875,000.

Parasitic load

Td_p = 150°F - 130°F = 2-°F.

Yearly BTU's = 3,112,500 lbs. x 20°F - 62,250,000

Total load

Yearly BTU's = 217,875,000 + 62,250,000 = 280,125,000

Total energy used

E = .45

$$\text{Total BTU's} = \frac{622,500,000}{138,000 \text{ gal.}} \quad \text{BTU's} = 4,511$$

To calculate the amount of fuel needed at a reduced delivery temperature, 90°F, for example, perform the following procedure:

*If incoming temperature differs from 50°F, adjust valve before dividing. If incoming temperature is 60°F, for instance, at a generation temperature of 150°F, multiply value by (150 - 60)/(150 - 50).

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$$4{,}511 \text{ gal.} \times \frac{90°F}{130°F} = 3{,}123 \text{ gal.}$$

This is actually a conservative figure, as the total savings in heating, storing, and distributing the water would include reduced storage and distribution losses as well.

Table 10 indicates the yearly energy loss in BTU's for various sizes of tanks, located in a space with an ambient temperature of 65°F, and with fiberglass insulation.

Table 10

Insulation Thichness	Tank Size in Gallons	BTU's in millions/year. Lost at Hot Water Temperatures of: 100°F	120°F	160°F
1"	50	1.9	3.0	5.2
	100	3.0	4.7	8.2
2"	250	3.1	4.9	8.4
3"	500	3.1	4.9	8.4
	1000	5.2	8.2	14.1

Costs for insulating hot (or cold) water tanks with 3# density fiberglass - foil scrim craft facing, finished with pre-sized glass cloth jacket are as follows:

Material Thickness	Cost/sq. ft. of Surface Area
1"	$ 2.60
1-1/2"	$ 2.70
2"	$ 2.95
3"	$ 3.60

REDUCE THE QUANTITY OF DOMESTIC HOT WATER USED

A primary benefit of reducing the quantity of hot water used is that energy consumption will be decreased to the same extent as with an equal percentage reduction in temperature.

A secondary benefit is the reduction in raw source energy which occurs because less water needs to be treated in the water supply treatment and sewage treatment plants, whether on-site or off-site. For municipal facilities, the diminished energy requirements will result in lower operating costs than otherwise possible, which in turn will mean that less taxes will be needed to support the facility. In areas where there is a charge based on total water consumption flowing into the sewer, the reduction in consumption of water will result in direct savings as well. Water consumption can be lowered to 1-1/4 or 1-1/2 gallons per person per day in office buildings today without inconvenience to the occupants. Additional opportunities to reduce water consumption are summarized in the guidelines.

Example:

An office building has 500 occupants, each of whom uses 3.5 gallons of hot water per day for 250 days each year. The water, as it enters the heater, is at 40°F, and it is heated to 150°F. The separate gas-fired heater has an efficiency of 0.75.

Enter Figure 25 at 3.5 gal./person per day. Follow the example line intersection with the 100% flow rate and 150°F temperature lines and read yearly energy used of 800×10^3 BTU per person per year.

Re-enter Figure 19 intersection with the 33% and 120°F lines and read yearly energy used of 190×10^3 BTU/person/yr.

Savings: The energy saved equals 800-190 or 610×10^3 BTU/person/year and for 500 people, the total is $5 \times 610 \times 10^3$ or 305×10^6 BTU/year.

$$\frac{305 \times 10^6}{138{,}000 \times 0.75} = 2{,}947 \text{ gal.}$$

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Convert to cost: At $0.36/gal., the savings is 0.36 x 2,947 or $1,061 per year.

Results: Energy saved - 2,947 gallons/year

Dollars saved - $1,061/year

IMPROVE THE EFFICIENCY OF THE STORAGE AND DISTRIBUTION SYSTEMS

Repair and replace all torn insulation to reduce heat loss. All measures to improve the efficiency of both space heating and domestic hot water heaters are noted in Section 4, "Heating" and the measures to reduce heat loss from piping are detailed in Section 4, "HVAC Systems and Distribution".

GENERATE HOT WATER MORE EFFICIENTLY

All of the measures for improving combustion units for space heating apply equally well to hot water heaters. Keep in mind, however, that when more than one heater, be it boiler or hot water heater, is installed on a project, it is more efficient to operate one for the total load if it can carry it, rather than to operate all boilers at partial loads.

The greater opportunities for conserving energy by improving the efficiency of the hot water generator, after normal service operations and minor modifications have improved the existing equipment to the extent possible, will require major modifications or the replacement of the equipment.

ECM-2 details these opportunities which include the following:

- Provide a separate hot water heater for summer or year round use.
- Heat hot water by use of rejected heat from refrigeration system condenser water or hot gas heat exchangers.
- Heat hot water with recovered energy from incinerators, heat pipes, hot water heat exchangers, or heat pumps.
- Replace resistance electric hot water heaters with gas or oil heaters or heat pumps.
- Add separate booster heater for kitchen or laundry service.
- Heat hot water with condensate return to steam operated systems.
- Heat hot water with solar water heaters.

GUIDELINES TO REDUCE ENERGY USED FOR DOMESTIC HOT WATER

Reduce Domestic Hot Water Temperature:

- Where possible, use cold water only for hand washing in lavatories when cold water temperature is 75°F or above. This is most readily accepted in retail stores, religious buildings, owner-occupied small office buildings and in washrooms used primarily by the public on an infrequent basis.
- Where tenants insist upon hot water for hand washing, heat tap water to 90°F.
- Do not maintain an entire hot water system at the same temperature required for the most critical use.

Do not heat water for hand washing, rinsing or cleaning to the same temperature required for dishwashing sterilization.

- If the space heating boiler is also used to supply domestic hot water, lower the aquastat setting in the summer time to 100°F. The same setting should be used for storage tank temperature control, summer and winter.

- Where higher temperatures are required, at a dishwasher, for example, a small gas or electric booster used only as needed saves more energy than a large storage tank, piping and distribution system which heats all domestic hot water in the building to the most critical temperature.

- Use cold water detergents for laundries and laundromats and set water temperatures to 65°F - 70°F.

Conservation Paper No. 20, Guidelines for Saving Energy in Existing Buildings", Building Owners and Operators Manual, ECM-1, June 16, 1975, FEA/D-75/359, FEA, Washington, D.C.

- Refer to Health or Food Handling Codes, if applicable, for minimum temperature specifications.

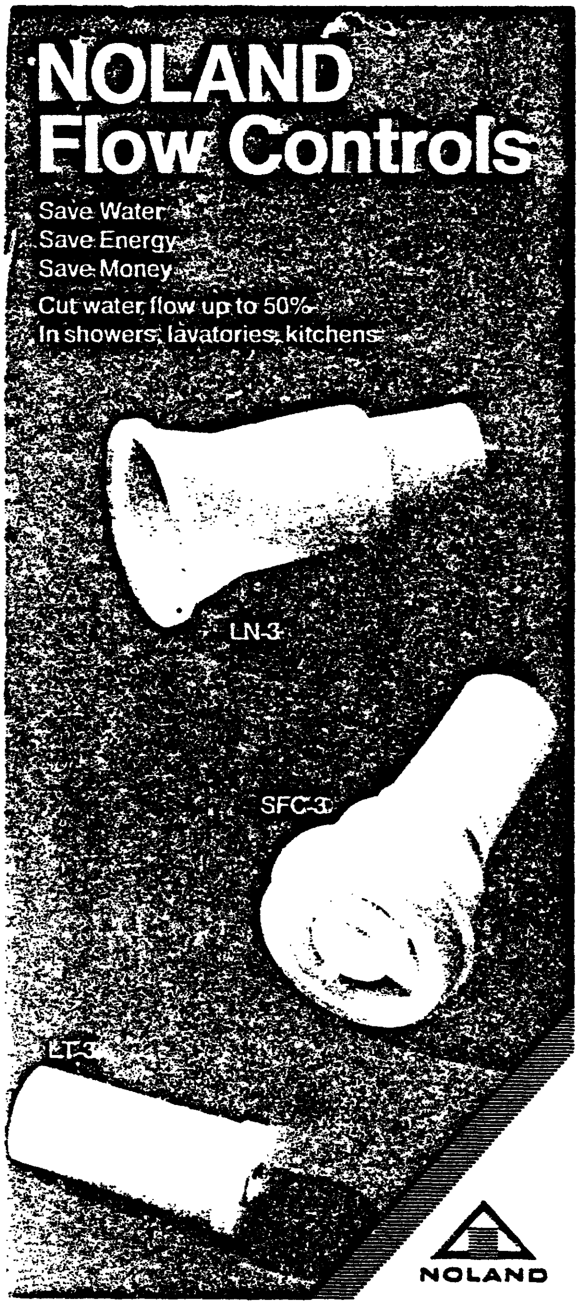
REDUCE HOT WATER CONSUMPTION

- Insert orifices in the hot water pipes to reduce flows.
- Install spray type faucets that use only 1/4 gallons per minute (gpm) instead of 2 or 3 gpm, at a cost of about $50 a unit.
- Install self-closing faucets on hot water taps.
- In buildings with cooking facilities that are used only periodically, such as meeting rooms in religious buildings, shut off the hot water heating system, inclding gas pilots where installed, when the facilities are not in use.
- Re-examine the need to heat entire tank of water when only a small quantity or no hot water is needed.
- Simplify menus to reduce the need for large pots and pans that require large amounts of hot water for cleaning. Where practical use short dishwashing cycles and fill machine fully befor use.
- Reduce the number of meals served and/or serve more cold meals to reduce the hot water requirements for dishwashing.
- In areas where water pressure is higher than a normal 40 to 50 lbs., restrict the amount of water that flows from the tap by intstalling pressure reducing valves on the main service. Do not reduce pressure below that required for fire protection or for maintaining adequate pressure on the top floor for flushing.
- Refer to Plumbing Codes, if applicable, for hot water supply requirements.

REDUCE SYSTEM LOSSES

- Repair insulation of hot water piping and tanks or install it where missing (unless piping and tanks are located in areas which require space heating or are air-cooled).
- Where forced circulation of hot water is used, shut off the pump when the building is unoccupied; when hot water usage is light consider using gravity circulation without the pump.
- Flush water heater during seasonal maintenance of heating systems.
- Repair leaky faucets.
- Repack pump packing glands of recirculation hot water heaters to reduce leaking of hot water.
- For boilers with immersion tankless domestic hot water coils, make sure boiler water covers coils.

Conservation Paper Number 20, "Guildelines for Saving Energy in Existing Buildings," Buildings Owners and Operators Manual, ECM-1, June 16, 1975, FEA/D-75/359, FEA, Washington, D.C.



Satisfied Users of NOLAND Flow Controls

Educational Institutions

Kern High School District	Bakersfield, California
Pennsylvania State University	State College, Pennsylvania
Princeton University	Princeton, New Jersey
University of Nebraska	Lincoln, Nebraska
University of Virginia	Charlottesville, Virginia

Hotels/Motels

Americana Hotels	Various Locations
Astroworld Hotel	Houston, Texas
Hilton Hotels	Various Locations
Holiday Inns	Various Locations
Howard Johnson Motor Lodges	Various Locations
Williamsburg Inn	Williamsburg, Virginia

Government

Cherry Point Marine Air Station	Cherry Point, North Carolina
Defense Construction Supply Center	Columbus, Ohio
Department of Environmental Resources	Harrisburg, Pennsylvania
Oceana Naval Air Station	Virginia Beach, Virginia

Property Management

Allen & O'Hara, Inc.	Memphis, Tennessee
Housing Authority of Milwaukee	Milwaukee, Wisconsin
Norfolk Redevelopment & Housing Authority	Norfolk, Virginia
Virgin Islands Housing Authority	St. Thomas, V. I.

Utilities

Monte Vista County Water District	Montclair, California
Muskingum Watershed Conservancy District	New Philadelphia, Ohio
North Tahoe Public Utility District	Tahoe, California
Washington Suburban Sanitary Commission	Hyattsville, Maryland

For More Information on NOLAND Flow Controls, Contact:

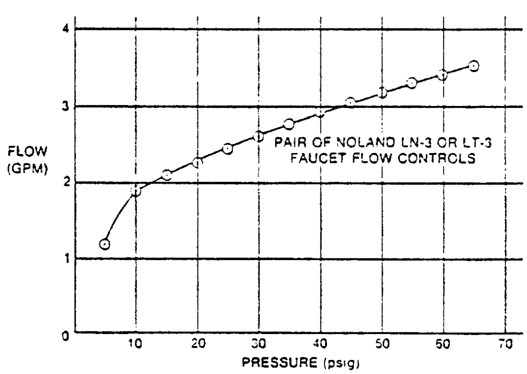
Noland Company
National Accounts Department
2700 Warwick Blvd.
Newport News, Va. 23607
(804) 247-0116

NOLAND LN-3 Flow Control
For Lavatory & Sink Faucets With Solid Shanks

Save Water and Energy in Bathrooms, Kitchens
A typical lavatory or kitchen faucet uses 5 to 7 gallons of water per minute. Noland LN-3 flow controls are specially engineered to reduce the flow through lavatory or kitchen faucets to 3 G.P.M., while maintaining a spray pattern that's sufficient for normal lavatory or kitchen sink uses. Since much of the water used in lavatory and kitchen faucets is hot water, you get a double saving—both in total water consumption and in energy used for heating the hot portion of the water saved.

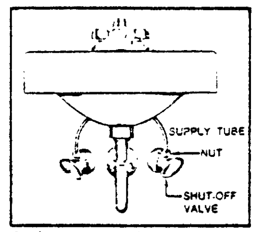
Improved Connection Between Supply Tube and Faucet
Noland LN-3 controls are designed to fit into the shanks of lavatory and kitchen faucets, one in the cold side and one in the hot side. They actually improve the connection between the supply tubes and the faucet shanks, because metal-to-metal contact is eliminated and proper alignment is assured by the shape of the flow control. The installer also has the option of using either straight supply tubes or supply tubes with formed nosepieces, as the LN-3 is designed to make a leak-proof connection with either type.

Pressure-Compensating Feature
As shown in the flow chart below, the Noland LN-3 compensates for fluctuations in pressure. A pair of LN-3s deliver 3 G.P.M. at a pressure of 45 PSI. As pressures rise above 45 PSI, the LN-3 controls compensate for these changes, and flow rate through the controls increases only very slightly.

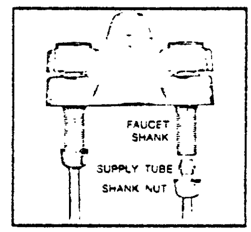


Installation Instructions
Install a pair of flow controls (one in hot side, one in cold side) using these simple steps:

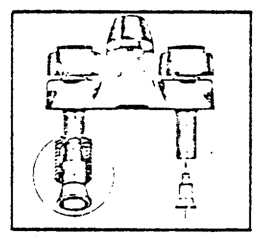
1. **SHUT OFF MAIN WATER SUPPLY**



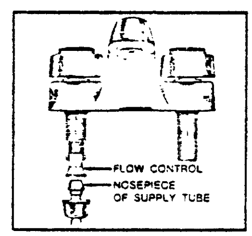
2. Loosen coupling nut on shut-off valve and disconnect bottom of supply tube from shut-off valve.



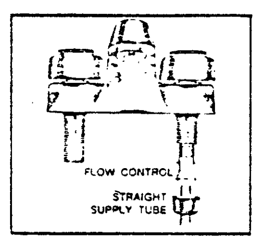
3. Loosen shank nut and disconnect top of supply tube from faucet shank.



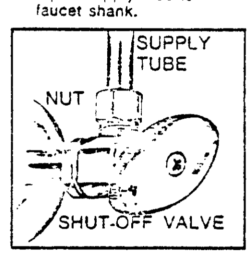
4. Insert narrow end of flow control into faucet shank.



5. **WHEN USING SUPPLY TUBE WITH FORMED NOSEPIECE:** Insert nosepiece of supply tube into flared end of flow control. Tighten shank nut to reconnect top of supply tube to faucet shank.



6. **WHEN USING STRAIGHT SUPPLY TUBE:** Insert top of supply tube as far as possible into narrow section of flow control. Tighten shank nut to reconnect top of supply tube to faucet shank.



7. Reconnect bottom of supply tube to shut-off valve and turn on water supply.

NOLAND'S SFC-3 Shower Flow Control

A Low-Cost, Pressure-Compensating Flow Control

Noland's SFC-3 is a simple, but highly engineered, three-chambered Celcon cylinder with no moving parts. Non-clogging, it regulates the flow of water at a predetermined rate and automatically compensates for varying pressures.

Cuts Water Flow by 50% or More

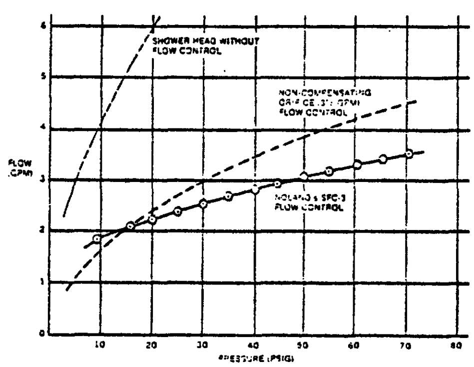
Noland's SFC-3 reduces the maximum flow of water through a ½" I.D. shower arm from the normal 7 to 10 G.P.M. to 3, conforming to latest plumbing code restrictions. While the volume of water is substantially reduced, the output quality of the shower head is maintained. The SFC-3 will operate effectively at any temperature above the freezing point of water and below its boiling point.

Thoroughly Tested by Virginia Tech

The graph below shows the results of performance tests conducted by the Virginia Polytechnic Institute & State University Industry Center. It compares flow rates through a shower head:

- with no flow control
- equipped with Noland's SFC-3
- equipped with a non-compensating (orifice) flow control.

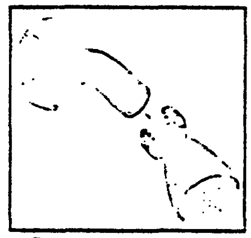
VPI stated, "As a result of our tests, we have concluded that the modified nozzle (Noland's SFC-3) is a definite improvement over the orifice type. We believe that it is a simple and effective method of reducing the flow rate to conserve energy and reduce the sewage problem."



Easily & Quickly Installed

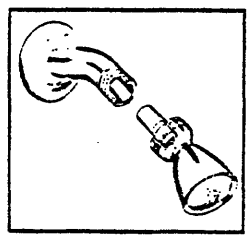
Inserts smoothly into either the upstream or downstream end of ½" I.D. shower arm. The standard installation can be made by either a plumber or homeowner in a matter of minutes.

Standard Installation Instructions

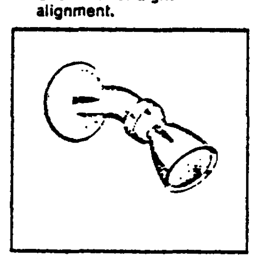


1. Remove shower head from threaded shower arm.

2. Insert flanged end of flow control into shower head. Check for straight alignment.



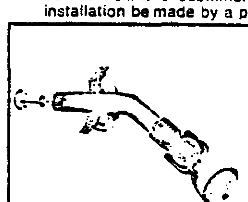
3. Insert narrow end of flow control into shower arm until shower head threads engage shower arm threads.



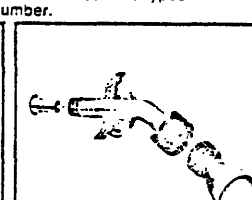
4. Thread shower head onto shower arm by hand, then tighten with an adjustable wrench.

Vandal Proof or Integral Ball Joint Installation

Insert unit into the upstream end of shower arm as shown behind wall. It is recommended that these two types of installation be made by a plumber.



Vandal Proof



Ball Joint

NOLAND LT-3 Flow Control For Lavatory & Sink Faucets With Copper Tube Inlets

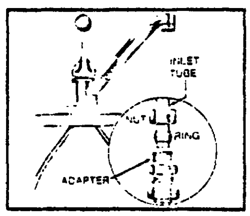
LT-3 Controls Specially Designed for Copper Tube Inlets

Noland LT-3 flow controls are specially designed to fit faucets with copper tube inlets and provide the same great water savings that the LN-3 controls do. Flow rate through a faucet equipped with a pair of LT-3 controls is 3 G.P.M. at 45 PSI, as shown in the chart on page 4.

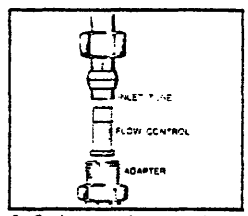
Installation Instructions

Install a pair of flow controls (one in hot side, one in cold side) using these simple steps:

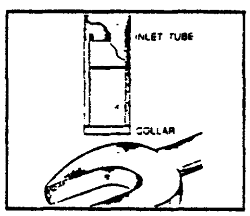
1. **SHUT OFF MAIN WATER SUPPLY.**



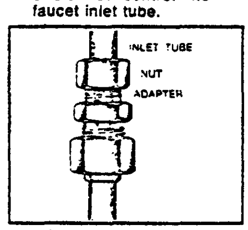
2. Loosen compression nut from top of adapter and slide nut and ring up faucet inlet tube.



3. Spring top of adapter free from bottom of faucet inlet tube. Insert narrow end of flow control into faucet inlet tube.



4. Press or lightly tap flow control until bottom of faucet inlet tube is flush with collar of flow control.



5. Slide compression nut and ring down to bottom of faucet inlet tube, insert inlet tube into top of adapter, and tighten compression nut. Turn on water supply.

Alternate Installation Method

As an alternative to installation in the faucet inlet tubes, a pair of LT-3 controls can be installed in the bottom of the **supply tubes** using these simple steps:

1. **SHUT OFF MAIN WATER SUPPLY.**
2. Loosen compression nut on shut-off valve and disconnect bottom of supply tube from shut-off valve.
3. Insert narrow end of flow control into bottom of supply tube. Press or lightly tap flow control until bottom of supply tube is flush with collar of flow control.
4. Reconnect bottom of supply tube to shut-off valve and turn on water supply.

Figure 26

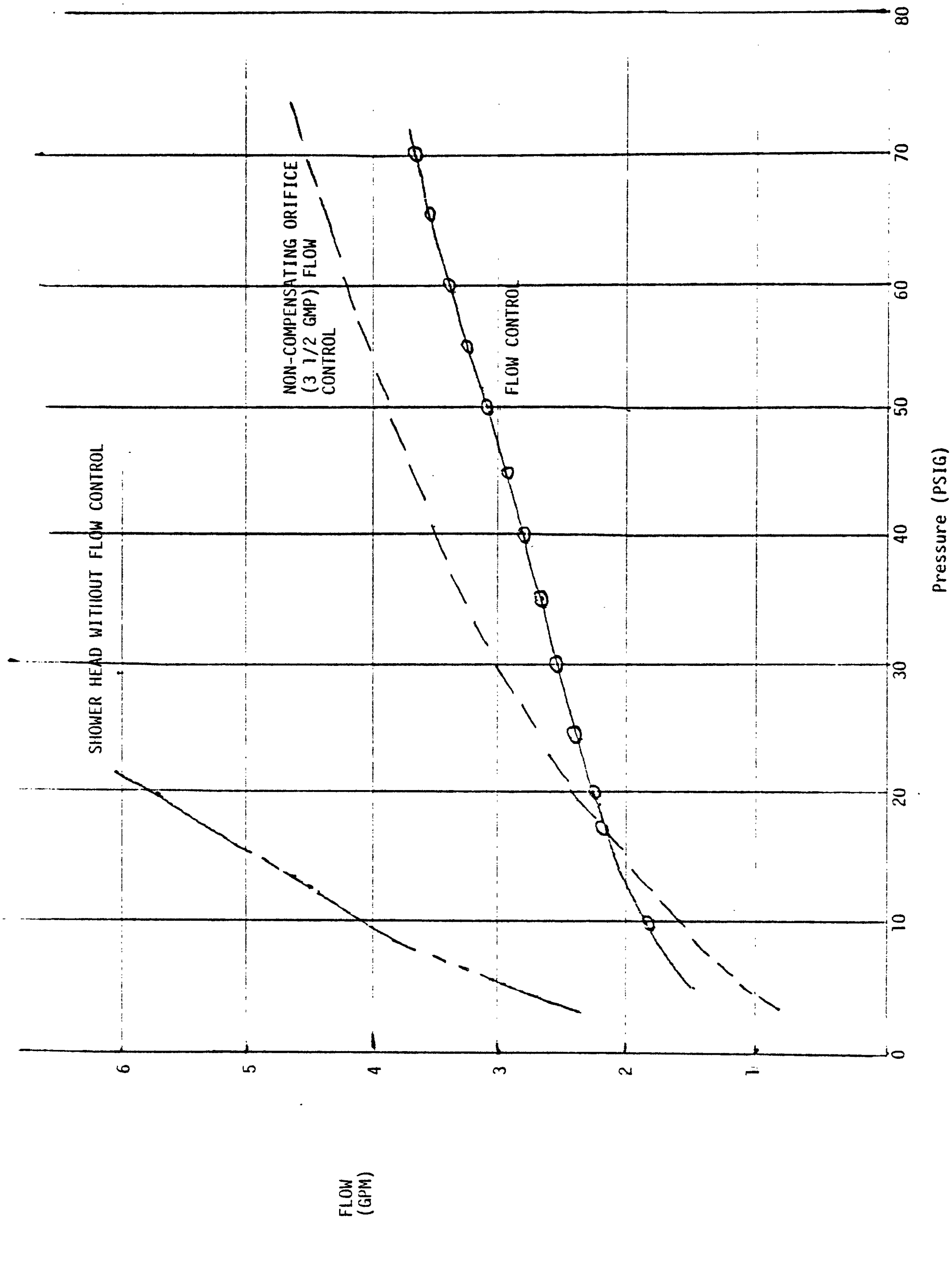


Figure 26 Change in Water Flow with Control Inserted

M. D. P. U. NO. 343
CANCELLING M. D. P. U. NO. 325

MASSACHUSETTS ELECTRIC COMPANY

GENERAL RATE C-22

AVAILABILITY

Service under this rate is available for all purposes.

No service will be be furnished hereunder to a Customer for resale in whole or in part within the territory of the Company, except to a Customer who was engaged in reselling electricity furnished by the Company on April 21, 1958 who may continue to resell, but only under the same circumstances or conditions, in the same location and to the same extent as such Customer was reselling on said date.

MONTHLY CHARGE

$1.82 for the first 20 kilowatt-hours or less of electricity delivered each month,
5.796 cents per kilowatt-hour for the next 80 kilowatt-hours,
5.196 cents per kilowatt-hour for the next 200 kilowatt-hours,
4.086 cents per kilowatt-hour for the next 1700 kilowatt-hours,
2.896 cents per kilowatt-hour for the excess over 2000 kilowatt-hours.

PURCHASED POWER COST ADJUSTMENT

The prices under this rate as set forth under "Monthly Charge" may be adjusted from time to time in the manner provided in the Company's Purchased Power Cost Adjustment Provisions to reflect changes occurring on or after January 1, 1971 in the Primary Service for Resale Rate of the Company's supplier, New England Power Company.

ADJUSTMENT FOR COST OF FUEL

The amount determined under the preceding provisions shall be adjusted in accordance with the Company's Standard Fuel Clause as from time to time effective in accordance with law.

MINIMUM CHARGE

$1.82 per month.

However, if the KVA transformer capacity needed to serve a customer exceeds 25 KVA, the minimum charge will be increased by $1.75 for each KVA in excess of 25 KVA.

MASSACHUSETTS ELECTRIC COMPANY

GENERAL RATE C-22

BIMONTHLY BILLING

The Company reserves the right to read meters and render bills on a bimonthly basis. When bills are rendered bimonthly, the charge for the initial block, the kilowatt-hours stated in each block and the Minimum Charge shall be muliplied by two.

TERMS AND CONDITIONS

The Company's Terms and Conditions in effect from time to time, where not inconsistent with any specific provisions hereof, are a part of this rate.

Effective October 21, 1974.

MASSACHUSETTS ELECTRIC COMPANY

General Rate C-22
M.D.P.U. No. 343

Purchased Power Cost Adjustment No. 5

Effective March 1, 1976

Monthly Charge as Adjusted

$1.96		First	20	KWH or less per month
6.473¢	per KWH	Next	80	KWH per month
5.873¢	per KWH	Next	200	" " "
4.763¢	per KWH	Next	1700	" " "
3.573¢	per KWH	Xcs of	2000	" " "

Minimum Charge

Zero Use = $1.82

Use 1-20 KWH = $1.96

However, if the KVA transformer capacity needed to serve a customer exceeds 25 KVA, the minimum charge will be increased by $1.75 for each KVA in excess of 25 KVA.

Other Rate Clauses apply as usual.

M. D. P. U. NO. 342
CANCELLING M. D. P. U. NO. 324

MASSACHUSETTS ELECTRIC COMPANY

ALL-PURPOSE ELECTRIC SCHOOL RATE B-2

AVAILABILITY

Service under this rate is available for all purposes to public and private schools, including adjacent buildings owned and operated by such schools and used principally for educational purposes, and subject to the conditions hereinafter stated. If delivery is through more than one meter except at the Company's option, the Monthly Charge for service through each meter shall be computed separately under this rate.

CONDITIONS

1. Electricity must be the sole source of energy for space heating and water heating, and be supplied only under this rate.
2. All electric space heating equipment must be permanently installed. It is recommended that insulation be permanently installed and conform to the Company's standards.
3. The Company may require that electric water heaters, space heating equipment and other major electrical loads be time controlled to restrict operation during peak periods. Electric facilities for the purpose of such control will be provided by the Company.
4. This rate is not available for resale and any violation shall terminate the availability of this rate.

MONTHLY CHARGE

$4.88 for the first 120 kilowatt-hours or less per month,
2.396 cents per kilowatt-hour for the next 280 kilowatt-hours,
1.696 cents per kilowatt-hour for the next 49,600 kilowatt-hours,
1.346 cents per kilowatt-hour for the excess over 50,000 kilowatt-hours.

All Customers having a connected load of 5,000 KW or greater will be supplied and metered at a single delivery point and will be at the Company's available nominal primary voltage of not less than 12,500 volts. All electric facilities beyond the delivery point must be owned and maintained by the Customer. The Company reserves the

M. D. P. U. NO. 343
CANCELLING M. D. P. U. NO. 325

MASSACHUSETTS ELECTRIC COMPANY

GENERAL RATE C-22

AVAILABILITY

Service under this rate is available for all purposes.

No service will be be furnished hereunder to a Customer for resale in whole or in part within the territory of the Company, except to a Customer who was engaged in reselling electricity furnished by the Company on April 21, 1958 who may continue to resell, but only under the same circumstances or conditions, in the same location and to the same extent as such Customer was reselling on said date.

MONTHLY CHARGE

$1.82 for the first 20 kilowatt-hours or less of electricity delivered each month,
5.796 cents per kilowatt-hour for the next 80 kilowatt-hours,
5.196 cents per kilowatt-hour for the next 200 kilowatt-hours,
4.086 cents per kilowatt-hour for the next 1700 kilowatt-hours,
2.896 cents per kilowatt-hour for the excess over 2000 kilowatt-hours.

PURCHASED POWER COST ADJUSTMENT

The prices under this rate as set forth under "Monthly Charge" may be adjusted from time to time in the manner provided in the Company's Purchased Power Cost Adjustment Provisions to reflect changes occurring on or after January 1, 1971 in the Primary Service for Resale Rate of the Company's supplier, New England Power Company.

ADJUSTMENT FOR COST OF FUEL

The amount determined under the preceding provisions shall be adjusted in accordance with the Company's Standard Fuel Clause as from time to time effective in accordance with law.

MINIMUM CHARGE

$1.82 per month.

However, if the KVA transformer capacity needed to serve a customer exceeds 25 KVA, the minimum charge will be increased by $1.75 for each KVA in excess of 25 KVA.

MASSACHUSETTS ELECTRIC COMPANY

All-Purpose Electric School Rate B-2
M.D.P.U. No. 342

Purchased Power Cost Adjustment No. 5

Effective March 1, 1976

Monthly Charge as Adjusted

\$5.69		First	120	KWH or less per month
3.073¢	per KWH	Next	280	KWH per month
2.373¢	per KWH	Next	49,600	" " "
2.023¢	per KWH	Xcs of	50,000	" " "
1.773¢	per KWH	Xcs of	200,000	" " "

*Where the customer has a connected load of 5,000 KW or more and takes delivery at a nominal primary voltage of not less than 12,500 volts.

Minimum Charge

Zero Use = \$4.88

Use 1-120 KWH = \$5.69

Other Rate Clauses apply as usual.

Appendix VII

Project Conserve

IMPORTANT! Open immediately.
Free energy analysis of your home.

Federal Energy Administration Washington D.C. 20461

Postage and Fees Paid
Federal Energy Administration
FEA 350

Third Class Bulk Rate

U.S. MAIL

Official Business
Penalty for Private Use $300

AMERICAN REVOLUTION BICENTENNIAL 1776-1976

FEDERAL ENERGY ADMINISTRATION

WASHINGTON, D.C. 20461

OFFICE OF THE ADMINISTRATOR

Dear Homeowner:

In the last two years heating and cooling costs for most homeowners have increased. Even the availability of fuel, which we have long taken for granted, has become uncertain.

You can do something about these higher prices by making simple changes in your home. Unless your home is properly insulated you will continue to pay higher utility bills.

To help you evaluate your home energy use and to determine if your home is adequately protected, the Federal Energy Administration has developed a program called Project Conserve. By completing the enclosed questionnaire, you can obtain a FREE analysis of your home and specific recommendations for relatively inexpensive improvements that will help you save money and energy. You will also receive a range of cost estimates (contractor and do-it-yourself) based on rates in your area and an estimate of your potential energy and dollar savings.

Saving energy is in your and the Nation's best interest. We hope you will take a few minutes to fill out the Project Conserve questionnaire.

Frank G. Zarb
Administrator

Michael S. Dukakis
Governor

DETACH HERE

What Is It?

Project Conserve is a free, voluntary program developed by the Federal Energy Administration to help you save money, conserve energy in your home, and make you more comfortable, too. It works for all dwellings except for apartments and mobile homes.

What Do I Have To Do?

Just complete the questionnaire and return it to us in the envelope provided. The enclosed booklet, "How To Save Money By Insulating Your Home," will be helpful in answering the questions and in making the recommended home improvements. The sooner you send in your questionnaire, the faster you'll receive your personal recommendations.

What Happens To The Information I Provide?

The information will be received and processed by computer. The processing involves calculating estimates of costs and savings for your home if you install storm windows, storm doors, ceiling insulation, caulking, and weatherstripping, or if you adjust your thermostat setting. Following this processing, the system destroys your name and address except for your ZIP code.

What Will It Cost For Me To Participate?

Nothing. It's FREE!

The only cost is a few minutes of your time to complete and return the questionnaire. In fact, the results that are returned to you could show you a way to save money.

What If I Don't Answer All The Questions?

You can probably answer most of the questions easily. Each unanswered question affects the accuracy of the results you receive. If too many questions are unanswered, your results will represent a "typical" home rather than the home where you live.

What Will I Get?

You will receive specific suggestions for simple, relatively inexpensive steps which could conserve energy and make your home a more comfortable place to live.

How Accurate Will The Results Be That I Receive?

The results will be estimates of what you may expect things to cost and what you may expect to save. Don't be surprised if material costs or contractor estimates differ slightly. These differences will likely be caused by varying material types and qualities as well as the way your home is constructed. The estimates of savings, in particular, will vary from your actual savings since fuel prices and weather differ from winter to winter.

Regardless of these things, the results will allow you to see the approximate costs and the approximate savings for simple energy-conserving home improvements. You can then make those improvements that could save you the most money.

Project Conserve

Approved by GAO
B-181-254(R0150)
Expires 6-30-78

FEA-H593-S1

Name ______

Address ______

City ______ State ______ Zip Code ______

My Response

General Information

1. When was your home built?
   - ☐prior to 1920
   - ☐1921-1945
   - ☐1946-1965
   - ☐1966 to present

2. What type is your home?
   - ☐one-story
   - ☐split-level
   - ☐two-story
   - ☐three or more stories

3. When was your heating system last cleaned or serviced?
   - ☐less than 6 months ago
   - ☐6 months to 1 year ago
   - ☐1 to 2 years ago
   - ☐more than 2 years ago
   - ☐not serviced

4. What indoor temperature do you attempt to maintain in your home in the winter during:

   daytime:
   - ☐65° or less
   - ☐66°-68°
   - ☐69°-71°
   - ☐72°-75°
   - ☐above 75°

   night:
   - ☐65° or less
   - ☐66°-68°
   - ☐69°-71°
   - ☐72°-75°
   - ☐above 75°

   evening:
   - ☐65° or less
   - ☐66°-68°
   - ☐69°-71°
   - ☐72°-75°
   - ☐above 75°

5. Approximately, what is the total square footage of heated living area in your home? (To estimate living area, multiply the length and width of your home by the number of heated and utilized stories.
   - ☐800 or less
   - ☐800-1,000
   - ☐1,001-1,200
   - ☐1,201-1,400
   - ☐1,401-1,600
   - ☐1,601-1,800
   - ☐1,801-2,000
   - ☐2,001-2,200
   - ☐2,201-2400
   - ☐2,401 or more

Attics

16. Do you have an attic or crawl space under your roof?
   - ☐yes
   - ☐no

   If you have no attic or crawl space under your roof, go on to Question No. 23.

17. Is your attic area heated?
   - ☐yes
   - ☐no

18. Do you have permanent flooring installed in your attic?
   - ☐yes
   - ☐no

19. Does your attic have vents or windows that provide ventilation?
   - ☐yes
   - ☐no

20. Is your attic equipped with an exhaust fan?
   - ☐yes
   - ☐no

21. How much insulation is in the floor of your attic?
   - ☐1-2 inches
   - ☐3-4 inches
   - ☐5-6 inches
   - ☐7-8 inches
   - ☐9 or more inches
   - ☐none
   - ☐unknown

22. What does the insulation in your attic look like?
   - ☐loose particles
   - ☐blankets or batts
   - ☐none present
   - ☐unknown

FALCONI BROS. INC.
29 Boston Road, Southboro, Mass.
Tel. 485-0377

May 13, 197[illegible]

St. Marks School K Factors

#10 ---- 5.081
#14 ---- 4.443
#15 ---- 3.291
#16 ---- 4.475
#20 ---- 4.055
#21 ---- 3.160
#22 ---- 2.442
#23 ---- 2.111
#24N --- 2.515
#24S --- 2.564
#25 ---- 2.313
#26 ---- 2.339
#27 ---- 3.419
#28HT -- 0.559
#29 ---- 1.109
#31 ---- 3.731

FALCONI BROS. INC.
29 Boston Road, Southboro, Mass.
Tel. 485-0377

Cont.

#37 ---- 3.324
#38 ---- 3.163
#39 ---- 6.841
#40 ---- 3.458
#41 ---- 3.415
#42 ---- 5.176
#43 ---- 3.339
#44 ---- 6.216
Sears Rd. - 4.290

The above K Factors are based upon the last 3 oil deliveries.

OIL BURNER SERVICE

Appendix IX

36 WEBB STREET
SALEM, MASS. 01970

Boilers, Furnaces, Oil Burners Installed
24 Hour Service, 365 Days a Year

Pleasing You Pleases Us

Telephones: 745-3638
468-1583

March 16, 1976

Massachusetts Institute of Technology
Room E40 155
Cambridge, Massachusetts 02139

Attn: Mr. William Jones

Re: St. Mark's School, 25 Marlboro Rd., Southboro, Mass.

<u>Barber House - Chamaro side</u>
H. B. Smith - Steam boiler. Rated at 1.80 gph, fired at 1.20 gph (60°H). #1 smoke, 9½% CO_2, stack temp. 460°F gross, 400°F net, draft in breech -.03, draft overfire -.01, 81% eff. Unit running fine.

<u>Barber House - other side</u>
H. B. Smith - Steam boiler. Rated at 1.80 gph, fired at 1.35 gph (80°H). 0 smoke, 9% CO_2, stack temp. 540°F gross, 475°F net, draft in breech -.02, draft overfire -.01, 78% eff. Unit running fine.

<u>Large House</u>
H. B. Smith - Hot water unit. Rated at 1.80 gph, fired at 1.50 gph (45°H). #8 smoke, 5½% CO_2, stack temp. 540°F gross, 475°F net, draft in breech -.05, draft overfire -.01, 71½% eff. Needs minor air adjustments and baffling to reduce stack temp. and a swap to 60° or 80° nozzle and maybe a reduction to 1.35 gph.

<u>Clark House</u>
Burnham boiler 180,900 BTU. Rated at 2.00 gph, fired at 1.50 gph (80°H). #4 smoke, 8½% CO_2, stack temp. 720°F gross, 650°F net, draft in breech -.05, draft overfire -.01, 71½% eff. Needs minor air adjustments and work to lower stack temp.

<u>Choate Mansion</u>
H. B. Smith - 1330 ft. steam. Fired at 8 gph. 0 smoke, 7½% CO_2, stack temp. 440°F gross, 375°F net, draft in breech -.03, draft overfire 0, 79½% eff. Runs very well.

<u>Gardner House</u>
H. B. Smith - Hot water 116,300 BTU. Rated at 1.55 gph, fired at 1.00 gph (60°H). #3 smoke, 4½% CO_2, stack temp. 590°F gross, 525°F net, draft in breech -.08, draft overfire -.05, 67% eff. Needs minor air adjustments and draft regulator adjustments to lower stack temp. Burner questionable.

Tea House

H. B. Smith - Hot water. 116,300 BTU. Rated at 1.55 gph, fired at 1.00 gph (45°H). #1 smoke, 4% CO_2, stack temp. 530°F gross, 475°F net, draft in breech -.06, draft overfire -.02, 61% eff. Needs larger nozzle, change to 60° or 80° spray angle. Burner air adjustments. Burner questionable.

Wales House

American Standard - 1250 ft. steam. Rated at 3.00 gph, fired at 1.65 gph (60°H). 0 smoke, 6½% CO_2, stack temp. 530°F gross, 475°F net, draft in breech -.02, draft overfire -0, 72% eff. Unit runs well, needs new nozzle.

Choate Barn

Cleghorn - approx. 1000 ft. steam. Fired at 5.00 gph, (2-45°PLP). 0 smoke, 5% CO_2, stack temp. 510°F gross, 450°F net, draft in breech -.07, draft overfire -.05, 69% eff. Needs minor air adjustments to bring up CO_2.

Perkins House

H. B. Smith - Hot water, 116,300 BTU. Rated at 1.55 gph, fired at 1.20 gph (60°H). 0 smoke, 6% CO_2, stack temp. 470°F gross, 400°F net, draft in breech -.04, draft overfire -.01, 75% eff. Runs well.

APPENDIX X

House #	Deg. Days/gal. K Factor	Design Temp.	FR_T gph	(FR_C) gph	FR_R gph
10	6	0°F	0.5		
14	4.4	0°F	0.65		
15	3.3	0°F	0.8		
16	4.5	0°F	0.6		
20	4.1	0°F	0.65	(1.2)	1.2
21	3.2	0°F	0.85	(1.65)	1.2
22	2.4	0°F	1.1	(1.5)	1.2
23	2.1	0°F	1.3	(1.5)	1.2
24N	2.5	0°F	1.1	(1.35)	1.2
24S	2.6	0°F	1.0	(1.2)	1.2
25	2.8	0°F	0.95		
26	2.9	0°F	0.9	(1.0)	1.0
27	3.4	0°F	0.8		
28HT	0.56	0°F	6	(8)	6.0
29	1.1	0°F	2.5	(5)	2.5
31	3.7	0°F	0.75		
37	3.3	0°F	0.8		
38	3.2	0°F	0.8		
39	6.8	0°F	0.5		
40	3.5	0°F	0.8		
41	3.4	0°F	0.8		
42	5.2	0°F	0.5		
43	3.9	0°F	0.7	(1.0)	
44	6.2	0°F	0.5		
Sears Rd.	4.3	0°F	0.65		

25 installations

FR_T: Calculated nozzle size based on K factors and a 0°F design temperature. (no hot water)

(FR_C): Firing rate currently found in burners insepcted.

FR_R: Recommended firing rate. Minimum size nozzle for quick recovery of domestic hot water is 1.2 gallons per hour.

<u>MIT Energy Laboratory calculation of nozzle sizes at St. Mark's.</u>

APPENDIX XI

OIL FIRED FURNACES IN MASTERS DWELLINGS AT ST. MARK'S

FURNACE TYPE: H.B. SMITH HOT WATER 116,300 Btu/hr @ 1.55 gph.*

Dwelling	Annual Oil	Nozzle/Angle	Smoke	CO_2	Stack T.	Draft Breech	Draft O.F.	Eff.	% Oil Loss	K Factor**
#20 Perkins	2000 gal	1.20/60°H	0	6%	400°F	.04	.01	75%	17.2%	4.1
#26 Lee House	2500 gal.	1.00/45°H	1	4%	475°F	.06	.02	61%	23%	2.9
#43 Gardner House	2000 gal.	1.00/60°H	3	4.5%	525°F	.08	.05	67%	25%	3.9

To burn one gallon of oil requires 1450 cubic feet of air.

Oil fired heating boilers with domestic hot water as the only summer load have seasonal efficiencies of only 45-50%.

*140,000 x 1.55 = 217,000 $\frac{116,300}{217,000} = 0.54$

**Falconi Bros, Inc.

APPENDIX XII

[COPY]

From Bill Hanley 8/31/76

Sheet No. 1 of 2

M.D.P.U. No. 46

Cancels M.D.P.U. No. 36

COMMONWEALTH GAS COMPANY

SERVICE CLASSIFICATION NO. 6

PRIME MOVER RATE

AVAILABILITY:

To non-domestic customers using gas for one of the following uses:

(a) Prime mover use

(b) Total energy requirements on the premises supplied

(c) No other uses of gas will be permitted on this Service Classification

CHARACTER OF SERVICE:

Gas containing not less than 1,000 BTU per cubic foot.

RATE: (per month)

Demand Charge:

$7.00 per 1,000 cubic feet of fraction thereof of the daily demand

- plus -

Energy Charge:

7.0¢ per 100 cubic feet of gas use.

TERMS OF PAYMENT:

Ratesare net and bills are payable on presentation.

PRICE ADJUSTMENT:

As provided in Service Classification No. 18.

MINIMUM CHARGE:

The demand charge plus the energy charge for 200,000 cubic feet per month minimum use of gas, adjusted for the price adjustment.

DETERMINATION OF DEMAND:

The demand for billing purposes shall be the highest 24-hour demand established during the billing month, or the preceding 11 months as measured on a suitable meter or as determined by equipment input, tests or any other accepted method, at the option of the Company, but shall not be less than 10,000 cubic feet (10 MCF) per day.

The Company may, at its option, disregard excess demand occurring during the billing months of May to September, inclusive.

Date issued	Filed by	Date Effective
December 8, 1972	J.C. Stoneman Executive Vice President 25 Quingsigamond Avenue Worcester, Massachusetts	January 1, 1973

[COPY]

[COPY]

M.D.P.U. No. 46
Cancels M.D.P.U. No. 36

COMMONWEALTH GAS COMPANY

SERVICE CLASSIFICATION No. 6
PRIME MOVER RATE (Continued)

TERM:

The contract between the Company and the customer shall continue for a fixed period of one or more years to be agreed upon between the customer and the Company, and from year to year thereafter, subject to the right of either party to terminate the contract at the end of such agreed period or of any such year to year extension thereof by written notice to the other, given not less than 30 days prior to the date of such intended termination.

Approved By
Massachusetts Department of Public Utilities
December 12, 1972 (D.P.U. 17007-B)

Date issued	Filed by	Date Effective
December 8, 1972	J.C. Stoneman Executive Vice President 25 Quinsigamond Avenue Worcester, Massachusetts	January 1, 1973

[COPY]

Appendix XIII

Fuel Choice in the Power Plant
(based on an actual reading)

Data for one and one-half hours of operation of operation of the system were obtained on one school day during May 1976.* The existing meters were the ones used. Twenty-five hundred cubic feet of natural gas were consumed to produce 165 kilowatt hours of electricity.

The number two Cleaver-Brooks boiler was operating. Ordinarily one may assume that the demand for steam exceeded that which was being obtained by recovery of waste heat from the diesel engine.

(165 kilowatt hours) (3025) = 5×10^3 btu of electrical energy being generated.

Since the gas is being purchased by volume, we take the low heat value of 995 btu per cubic foot for the input energy

$$(995)(2.5)(10^3) = 2500 \times 10^3 \text{ btu}$$

$$\frac{500}{2500} \times \frac{10^3}{10^3} = \frac{1}{5} = 20\% \text{ efficiency}$$

Twenty percent efficiency in the generation of electricity at low load on the diesel is not unreasonable.

In telephone conversations with engineers at the Caterpillar offices, it was stated that one could assume the following distribution of input energy for this case:

22% mech (shaft/electricity)	-	550×10^3 btu
34% jacket cooling	-	850×10^3 btu
34% exhaust gases	-	850×10^3 btu
10% random radiation	-	250×10^3 btu

One hundred percent of jacket heat can be recovered and about 50% of the exhaust heat. Under full load conditions the recoverable exhaust heat runs between 50-60% of that available.

100% of jacket heat	=	850×10^3 btu
50% of exhaust gas	=	425×10^3 btu
		1275×10^3 btu

$$\frac{1275 \times 10^3 \text{ btu}}{2500 \times 10^3 \text{ btu}} = 50\% \text{ thermal efficiency}$$

Table 12

	Conventional System (Purchase electricity and on-site steam/hot water)	St. Mark's TE System (Diesel Oil)	St. Mark's TE System (Gas)	
Purchased Electricity	$13.46	-	-	
Fuel Cost on-site steam gen.	$ 2.68	-	-	
TE diesel fuel (oil)	-	$ 5.94	-	
TE System diesel fuel (gas)	-	-	$ 4.25	
Demand Charge	-	-	$ 1.05*	
TOTAL	$16.14	$ 5.94	$ 5.25	

It appears that the TE system at St. Mark's is cost effective. We repeat here, operating, maintenance and capital costs are not included in the calculations. One thing is apparent though, there are savings to be enjoyed if one uses the gas diesels.

*The demand charge of $7.00 per day per 1000 cubic feet has been prorated.

Appendix XIV UPDATE OF APPENDIX XIII

Fuel Choice in the Power Plant

As this report was being typed in final form, the price of fuels increased. It was not possible to alter the main body of the report. This Appendix contains data based on natural gas prices as of 10 December 1976. The new prices are noted. The old rate is added to this Appendix.

a. First 210 thousand cubic feet of gas is $210

b. All over 210 thousand @ $0.80 per 1000 cubic feet

c. Adjustment charge $1.494 per 1000 cubic feet

d. Demand charge of $8.50 per 1000 cubic feet or fraction thereof of the daily demand.

We discussed fuel costs for the operation of the several diesel engines for 1976 with Peter Dirkin, a sales engineer of the Commonwealth Gas Company, Worcester, Massachusetts. Commonwealth Gas supplies the natural gas to the power plant.

In January 1976 a demand of 49 thousand cubic feet was established. Demand at St. Mark's varies between 45 and 50 thousand. We then assumed that in any billing period 100% load factor would be the demand (49 thousand) times the number of days in the billing period. As an example, for a 30-day period the total gas fuel consumed would be 1,470 thousand cubic feet.

It is conceded that the following is not the exact way the calculations should be made, but the data required for the correct way are not available. It is obvious that for the months of May, June July and August the errors would be too large so these months therefore were not considered.

For the remaining billing periods we calculated the gas consumption for 100% load factor and compared that with the actual gas consumption to obtain the actual load factor. This is described in Table 9.

The price of gas per thousand cubic feet and the equivalent and normalized price one would have to pay for oil were calculated for three load factors, 38%, 70% and 100%, Table 6.

The cost of gas at the most recent rate (December 1976) to deliver a given amount of electricity (and recovered steam) for three engine load factors is tabulated in column 2.

In column 3 are listed the equivalent prices that one would pay for oil to deliver the same amount of energy using the liquid (diesel oil) fuel engine.

The posted price for diesel fuel during December 1976 was 44.9¢ per gallon. The actual price paid by St. Mark's is subject to negotiation. This fact underlines the argument that the choice of fuel for electric power generation is derived from a calculation which the Business Office must perform from time to time as its bargaining position and fuel prices alter.

TABLE 13

Period		No. of Days	MCF (100% Load Factor)	Actual MCF	Load Factor %
From	To				
4 Dec 75	5 Jan 76	32	1568	949	60
5 Jan 76	3 Feb 76	29	1421	676	48
3 Feb 76	2 Mar 76	26	1274	845	67
2 Mar 76	1 Apr 76	30	1470	635	43
1 Sept 76	5 Oct 76	34	1666	887	53
5 Oct 76	2 Nov 76	28	1372	672	49
2 Nov 76	2 Dec 76	30	1470	1004	68

APPENDIX XV RATIONALE OF A TOTAL ENERGY SYSTEM

a. A well operated steam of hot water heat boiler/burner system can operate at about 75% efficiency. That is, for every four gallons of oil consumed, the heat energy delivered to the facility is equivalent to that in three gallons of oil. One cannot do much better than that; 80% is about the theoretical maximum. The heat energy equivalent of the one gallon is not obtainable for use. It is lost in the gases that go up the chimney.

b. In the generation of electricity at either a commercial utility plant or by a diesel at St. Mark's, the conversion efficiency is about 33%. That is, for every three gallons of oil consumed, electrical energy with the equivalent of the energy in one gallon of oil is delivered to the consumer. The energy of the two gallons of oil has to be discarded as "waste heat". This is not an engineering or economic limitation. It is a function of the laws of nature.

At a utility the efficiency of a boiler turbine unit can be increased to about 39% but requires highly skilled operation and special equipment.

In a diesel system one third of the input energy goes to the shaft that turns the electric generator, another third goes into the jacket cooling water, a third goes out the exhaust as hot gases and the remaining 10% radiates into the surrounding air.

c. If St. Mark's were to purchase electricity and to make its own heat (hot water, steam), it could be paying for a total of seven (7) gallons of oil or gas to obtain a total of four (4) energy units of electricity, hot water and heat.

The electrical utility must buy 3 gallons of fuel in order to supply the one unit of electricity and St. Mark's must purchase directly 4 gallons of fuel in order to obtain 3 units of heat energy.

d. The St. Mark's "total energy" power plant, designed so as to maximize the extraction and use of energy in each gallon of oil (and thus reduce the number of gallons of fuel that must be purchased) required only five and two-thirds (5 2/3) - instead of 7 - gallons of oil for the 4 units of energy. This can be explained as follows:

1. Three gallons of fuel are needed by the diesel engine/generator to produce the one unit of electricity. The energy of two gallons normally is rejected as "waste heat" and is discharged to the air.
2. However, we capture this waste heat and make some steam from it. We can do this at about 50% efficiency. We can obtain the equivalent of one unit of energy as steam.
3. We now have two units of useful energy from three gallons of fuel, one in the form of electricity, one as steam.
4. In the on-site boilers we burn two and two-thirds gallons of fuel at 75% efficiency and obtain two units of steam.
5. A total of five and two-thirds gallons of oil instead of seven gallons for the same amount of useful energy, a savings of one and one-third gallons of fuel or about 20%.

e. Annual data must be derived by performing at least two calculations.

1. for the winter conditions in which all recoverable waste heat of the diesel can be used for space heating and hot water. Under these conditions a figure of about 20% (in practice closer to 16%) in fuel savings is correct.
2. for fall and spring conditions, when the demand for heat and hot water averaged for a 24-hour day, 7-day week can be less than the available recoverable heat. For these (spring/fall) conditions, the fuel savings decrease to an average of 5 percent.

On an annual basis, the fuel savings range between 5 and 14 percent depending upon climate, operation, etc.

Appendix XVI

The Power Plant

I. Boilers

There are two low pressure steam boilers. They burn #6 oil. The specifications are as follows:

Mfg: Cleaver-Brooks Co., 3707 N. Richards Street, Milwaukee, WI 53212, (414) 962-0100

Type: Model 08663X-350 (4 pass) (350 means 350 horsepower)

Consumption: 97.6 gallons of #6 oil per hour or 14,645,000 btu/hr

Output: (@ 8 lb. psi) 12,000 lbs per hour or 11,716,250 btu/hr . This is about 34.5 lb steam/hr/ boiler hp when the feed water is 200°F.

Stack temp: 260°F

The third boiler was originally a high pressure unit. During the study it was converted to low pressure operation and coupled to the system. It is not known how the conversion was made and if any operating data were taken. (Figure 27).

As manufactured by Cleaver-Brooks it was rated at 115 psi steam at an output of 150 hp.

Cleaver-Brooks boilers, under full load, when the tubes are clean, filter clear, air-fuel mixtures optimized and fuel and air preheats proper, operate at about 84% efficiency. Allowing for the age of the equipment, average heat transfer characteristics (mid-point between boiler tube cleaning), etc. a reasonable number is 80% efficiency in the conversion of the energy content of the fuel into steam at the top of the boiler.

Our observations of the operating procedures, maintenance schedules, record keeping and ability of the power plant personnel indicate that this portion of the system is being operated very well.

Now that the high pressure system has been converted to low pressure and the present engineer approaches retirement, there is the hazard that a less competent or thorough person may be put in charge and the system performance will deteriorate.

We feel that all of the action being presently taken, all records that are kept, are vital to the continuation of excellence.

II. Diesel Engines

Mfg.: Caterpillar Tractor Company, 100 N.E. Adams Street, Peoria, IL 61602 (309) 578-6997
att: Roger Jarman

There are two types of diesel/electric sets. One is a Type D353TA that operates from liquid, diesel fuel. Two Type G353TAs operate from natural gas. They are 6-cylinder units; each engine is rated at 330 hp.

The rule of thumb that applies to these units is: of the input energy (fuel) the output is as follows:

30% mechanical (shaft rotation)
30% jacket cooling
30% exhaust gases
30% random radiation and lubricating oil heating

Figures 28 and 29 illustrate the characteristics of engine/generators. A more detailed description of the engine/generators is contained in Appendices XIII and XIV.

The natural gas engines should cost less to operate. Natural gas is generally a cleaner fuel and, in addition, there is no problem of lubricating oil dilution as there is with liquid-fueled engines.

III. Electric Generators

Mfg: Electric Machine Co., 1800 Central Avenue, Minneapolis, MN 55413 (612) 378-8000

Serial No.: 271909031

Rating: at 1200 rpm: Output - 312 KVA, 250 kilowatts; 208 volts, 866 amps; 240 volts, 750 amps.

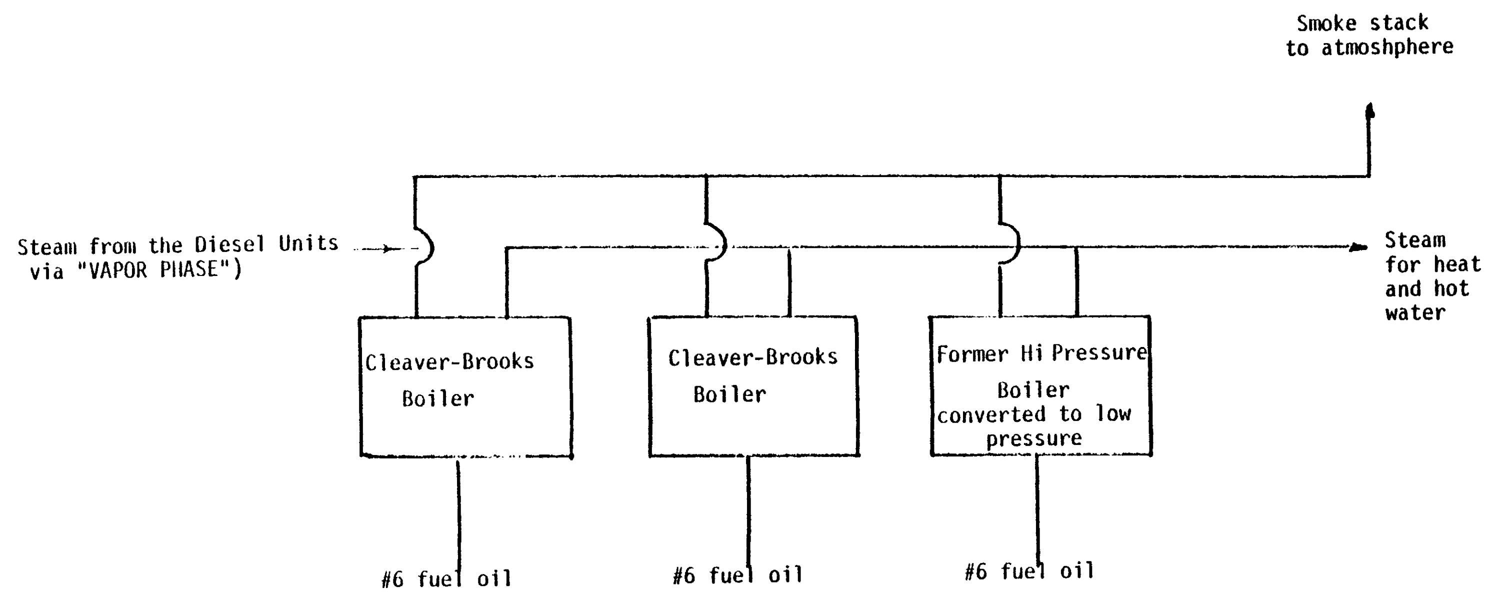


Figure 27

Coupling of Steam from Diesel Units to Output of the Cleaver Brooks Boilers

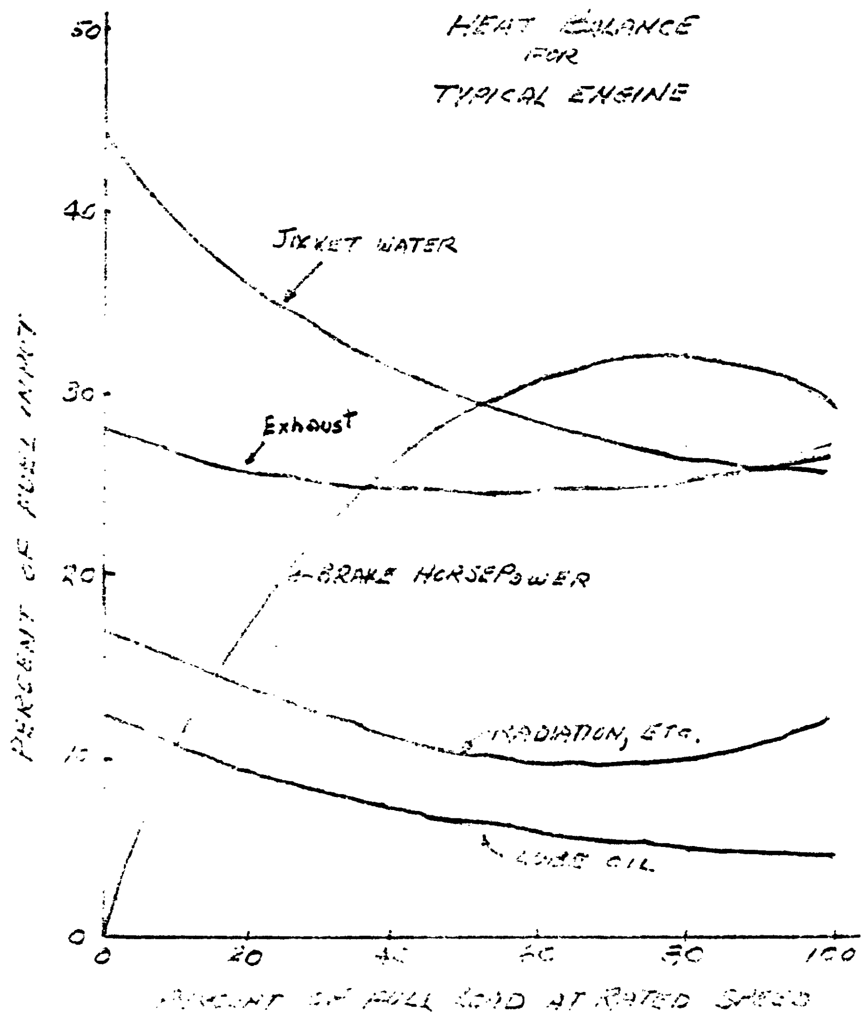


Fig. 28
Diesel Engine Characteristics

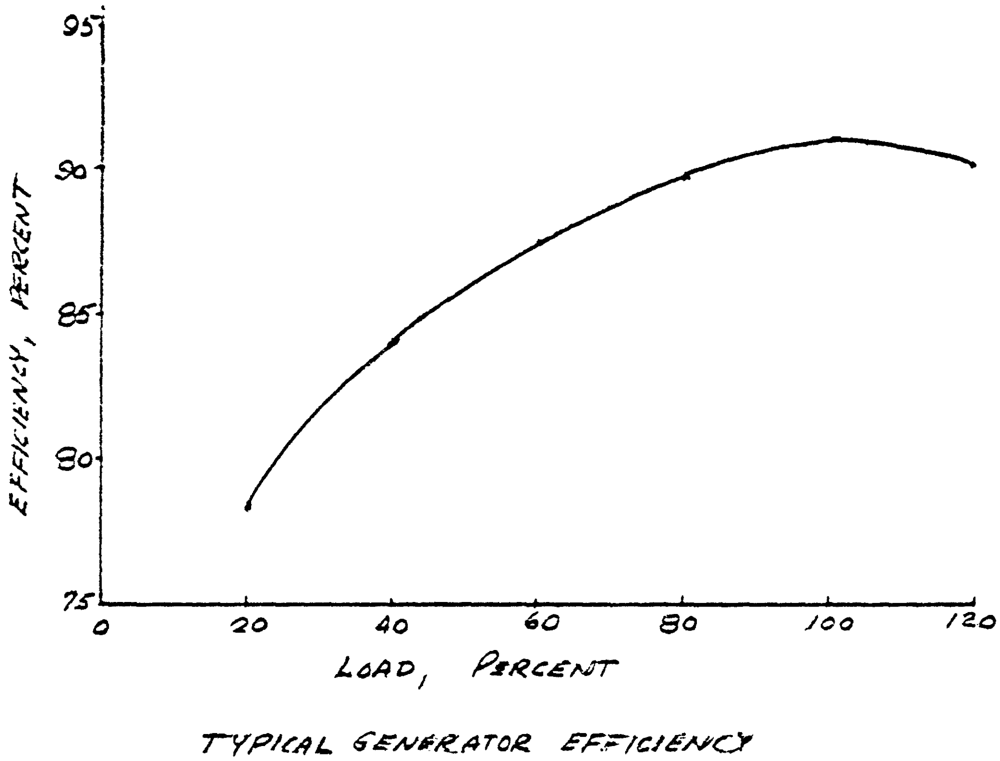


Fig. 29

Diesel Engine Characteristics

IV. Heat Recovery Unit

The heat recovery units were manufactured by Engineering Controls under the trade name "Vapor Phase."

Mfg: Vapor Phase, Engineering Controls, Inc., Division of Pott Industries, 611 East Marceau Street, St. Louis, MO 63111 (314) 638-4000, att: Warner Bauer.

Local Dealer: Clifford E. Ford, Witt-Armstrong Equipment Co., P.O. Box 101, Hopkinton, MA 01748, (617) 435-6321.

A more complete description is contained in Appendix XIX. An outline of the St. Mark's installation is shown in Figure 30.

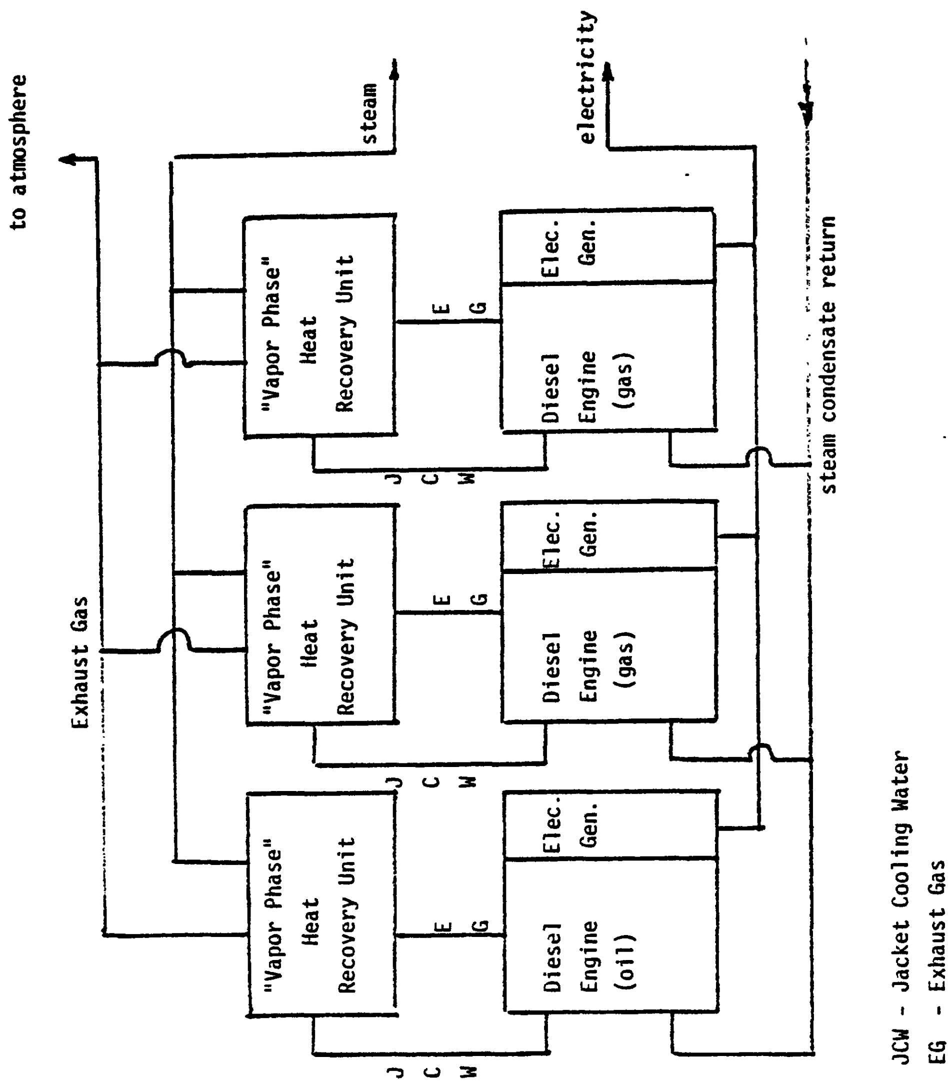


Fig. 30
Basic One-line Diagram of Total Energy Portion of the Power Plant at St. Mark's School

APPENDIX XVII

Preface

The following "Total Energy Handbook" is a publication of the Caterpillar Tractor Company of Peoria, Illinois 61602, and has been reproduced with its permission.

TOTAL ENERGY HANDBOOK

Contents

Revised August, 1969

INDEX OF TABLES

INDEX OF CHARTS AND DIAGRAMS

INTRODUCTION

On-Site power generation using internal combustion engines has gained economic feasibility and attractiveness in recent years largely by virtue of the advances made in the art of recovery and use of rejected heat. Broadly summarizing, the thermal efficiency of these engines, combined with the cost of a suitable fuel has, in the past, imposed limitations upon the competitive capability of on-site power except when reliability or remoteness of location were prime factors. However, when the thermal efficiency of the complete energy system is improved materially, the situation changes — sometimes dramatically.

In the operation of reciprocating, internal combustion engines, approximately 32% of the heat energy in the fuel is converted into work or shaft horsepower when operating at or near rated load. The remaining energy in the fuel is rejected in the form of heat.

To improve the thermal efficiency of an on-site energy system, part of the rejected heat must be recovered and put to useful purposes. The most convenient source of recoverable heat is the heat rejected to the jacket water or cooling system. Essentially 100% recovery of this normally-wasted heat is feasible. The second source of recoverable heat is the exhaust, approximately 60% of which is economically recoverable. Further heat recovery, while possible, is seldom economically attractive.

How much does heat recovery affect the efficiency of on-site energy systems? The overall or plant efficiency can reach, by utilizing heat recovery, 70% or more as opposed to 25% to 30% without heat recovery. This increased efficiency then enables on-site power to successfully compete with utility power on an economic basis in many instances.

Shaft horsepower may be used to generate electricity, drive a compressor for air conditioning, refrigeration, or industrial compressed air, drive a pump, or for any other normal engine load. The recovered heat may be utilized in absorption air conditioning, industrial heating processes, or to heat the building or domestic hot water supply.

Two prime factors affect the economics of any Total Energy application. These are (1) the plant load factor and (2) the relationship of fuel cost to the cost of purchased energy. Considering these factors, the ideal application would be one having a high load factor for electric power usage and a favorable steam or heat utilization factor along with a relatively low fuel cost as compared to purchased electric power. One factor being very favorable can compensate for the other being something less than favorable. A manufacturing plant working three shifts per day would generally represent a very favorable load factor, while a school or office building operating five days a week, eight hours per day, might not present an especially favorable load factor. Each, however, could very well be economically feasible for Total Energy application should the cost of fuel be low compared to the cost of purchased electric power.

The market opportunities for Total Energy application are practically unlimited. Shopping centers, apartment complexes, schools, office buildings, hospitals and industrial facilities all offer excellent potential for Total Energy application. The economic advantage to be realized — the return on invested capital — is the outstanding sales feature of the concept. Tax exempt institutions especially offer ideal economics as a rule. The need, however, for a reliable source of power becomes of prime importance in many instances. Hospitals, airports, and many manufacturing concerns must have a reliable source of power. Thus, some of the initial first cost of a Total Energy plant can be "written off" against the cost of this requirement, that is, the cost of standby power when utility power is used.

Acceptance of the Total Energy concept has been substantially accelerated by the performance record of the early or "pioneer" installations, which have demonstrated quite clearly that on-site power, when properly applied, can yield very attractive savings over purchased utility power. Other contributing factors to the growth and progress of this movement are (1) the development of compact, dependable heat recovery equipment, (2) greatly improved prime mover governors assuring precise frequency regulation, (3) the widespread and increasing demand for year round "climate control", (4) the availability of good quality, attractively priced fuel, and (5) the availability of dependable and efficient prime movers in a wide range of sizes, and (6) improved knowledge of where and how to utilize this system.

It shall not be the purpose of this publication to explore all of the design and application possibilities of the Total Energy concept nor to design such a plant. The material and data presented on the pages that follow have been assembled simply to call attention to a number of basic requirements associated with the design of Total Energy systems and to provide, to the extent possible, performance data to assist the designer.

FUELS

Few performance features of a prime mover approach in importance that of fuel economy. Since fuel cost is usually the largest expense item associated with the production of power, an understanding of the chemistry of combustion and a working knowledge of the terms and methods used to define and express performance of internal combustion engines is highly desirable for anyone attempting an appraisal of power costs. This is especially true where the cost of utility electric power must be compared with the cost of power generated by internal combustion engines when using natural gas as fuel.

Not the least important of the expressions used in connection with gas engine performance are two terms associated with all hydrocarbon fuels and especially with natural gas, namely high heat value (HHV) and low heat value (LHV). An understanding of heat value is an absolute essential when calculating or determining fuel consumption of gas engines.

When natural gas is used as fuel in an internal combustion engine, one of the products of combustion is water. The amount of water formed during combustion varies with different gases, depending upon the kind and mixture of hydrocarbons which constitute the gas. The water so formed obviously is converted into steam before leaving the engine and thus carries with it the quantity of heat used to convert the water into steam. This quantity of heat which is absorbed in changing water at a given temperature to steam or vapor at the same temperature, called the "latent heat of vaporization" is, of course, lost to the engine, since the exhaust temperature is always above the dew point and the engine, therefore, has no opportunity to convert this heat into work.

The total heat generated by the combustion of a given quantity of gas, usually one cubic foot, is known as the high heat value (HHV). The low heat value (LHV) of a gas is the high heat value less the heat used to vaporize the water formed by combustion.

Since the amount of heat (per cu. ft. of gas) lost in vaporizing the water is different for different gases, the only choice the engine manufacturer has if he is to provide reliable fuel consumption data, is to eliminate this variable and use only the low heat value as a basis for published fuel consumption data. Only the low heat value of a fuel can be utilized by the engine to produce work. This explains why all engine manufacturers use the low heat value for gaseous fuels.

A brief examination of the combustion equation using, for example, pure methane (CH_4), the main constituent of natural gas, will illustrate this point further. The equation for combustion of methane is as follows:

$$CH_4 + 2\,O_2 = 2\,H_2O + CO_2$$

To determine the amount of water formed, first determine the molecular weight of each gas as noted here:

$$CH_4 + 2\,O_2 = 2\,H_2O + CO_2$$

$$16 + 64 = 36 + 44$$

The molecular weight of a substance expressed in pounds is known as a mol. Thus, 1 mol of methane (16 lb.) when combined during combustion with 2 mols of oxygen (64 lbs.) will form 2 mols of water (36 lbs.) plus 1 mol of CO_2 (44 lbs.). Therefore, for each pound of CH_4 burned, $36 \div 16 = 2.25$ lb. of water are formed.

To determine the amount of water formed per cubic foot of CH_4 burned, divide 2.25 lbs. by the cu. ft. per lb. of gas at standard conditions of temperature and pressure. For methane, one lb. = 23.61 cu. ft. Therefore, $2.25 \div 23.61 = .09529$ lb. of water is formed per cu. ft. of methane burned. Then, the difference between high and low heat value for CH_4 is the heat required to convert .09529 lbs. of water to vapor at standard conditions of 14.696 psi and 60° F. The latent heat of vaporization per pound of water at 60° F. is 1059.9 BTU. Therefore, the difference between HHV and LHV for CH_4 is: $.09529 \times 1059.9 = 101$ BTU. For commercial pipeline gas, the low heat value, if not known, can be calculated with acceptable accuracy by multiplying the heat value by 0.90.

If we are to equate gas engine performance and operating costs with the cost of power from other sources, it follows that we must acquaint ourselves with the methods and practices employed in the industry to determine fuel consumption and cost as related to load. It is customary to express fuel consumption for gas engines in terms of BTU (low heat value) per brake horsepower hour. This is known as specific fuel consumption and is usually published or presented graphically — as illustrated by Figure 1. Such curves are referred to as "Part load" curves since they provide fuel consumption data for loads less than rated output and usually at several speeds, as well as at rated output and speed.

To determine total fuel consumption per hour for a known load and speed, first determine the specific fuel consumption in BTU (LHV) per unit of output such as BHP hour or KWH. For example, using Figure 1, assume a 200 hp load at 1200 rpm. Locating 200 hp on the abscissa and following it vertically to the 1200 rpm curve, we find the two intersecting on the horizontal line corresponding to 7,750 BTU. This is the specific fuel consumption expressed in BTU (LHV) per BHP hour. Then for a 200 hp load at 1200 rpm, the total BTU consumption per hour is 7,750 x 200 = 1,550,000 BTU (LHV). Since gas is sold on the basis of high heat value, either by the therm (100,000 BTU) or by volume (1,000 cu. ft.) it is desirable to convert the total BTU consumption per hour (LHV) to the units of measurement used by the seller. Assuming, for the purpose of illustration, that the gas to be used in this case has a high heat value of 1050 BTU per cu. ft. and a low heat value of 955, the total BTU consumption (LHV) per hour (1,550,000) may be converted to cubic feet by dividing this figure by the low heat value of the gas (955): $1{,}550{,}000 \div 955 = 1{,}623$ cu. ft. per hour.

For convenience, these operations can be combined into one equation as follows:

Cu. ft. per hr. = Specific fuel consumption in BTU (LHV) x HP Load ÷ LHV of Fuel to be Used.

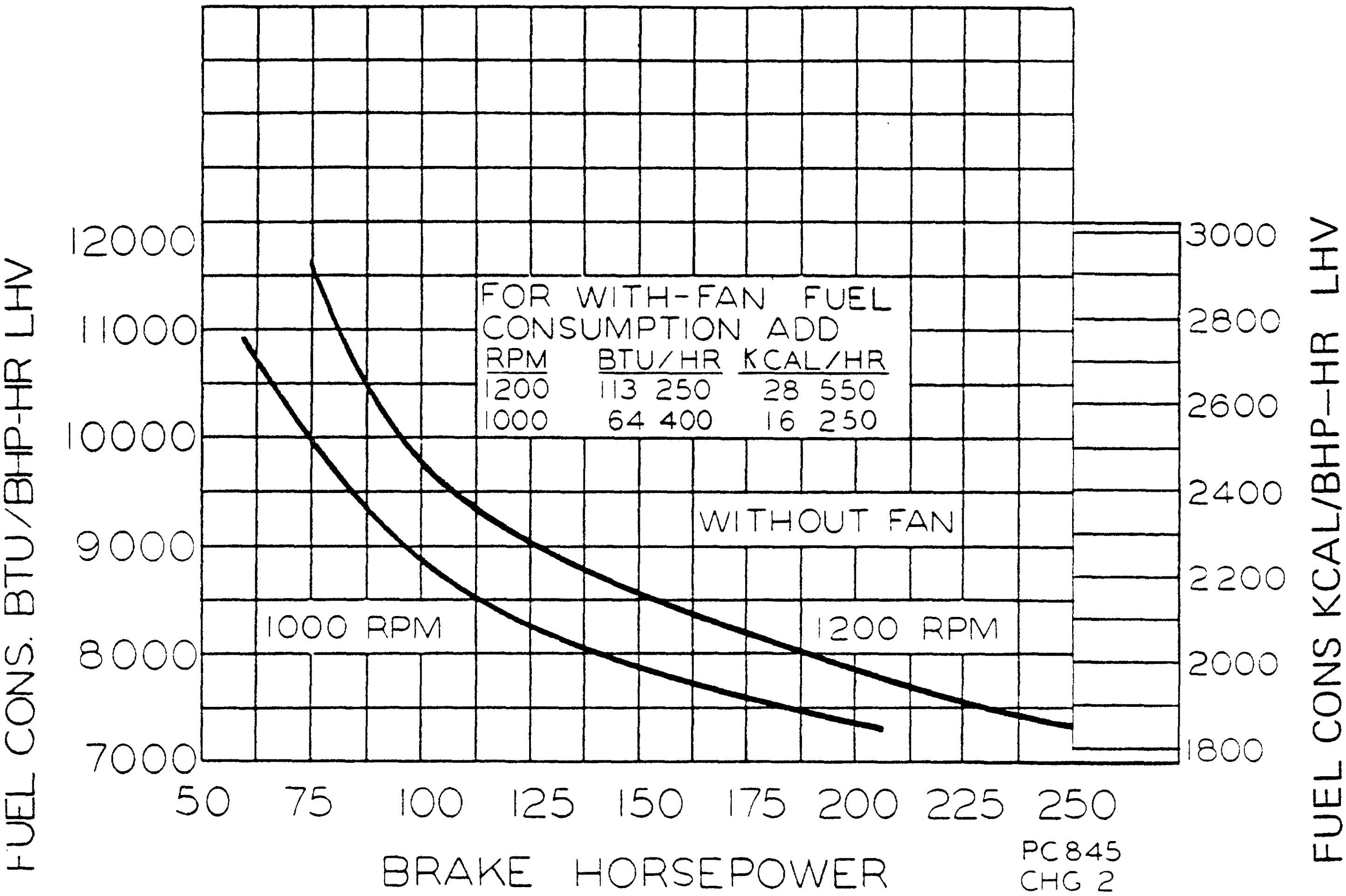


FIGURE 1.

TYPICAL SPECIFIC FUEL CONSUMPTION CURVE FOR NATURAL GAS ENGINE

If the gas is to be purchased by the therm, multiply the 1,623 cu. ft. by the high heat value (1,050) to get:

1,050 x 1,623 = 1,704,150 BTU Hr. (HHV)

Then divide by 100,000 to get:

1,704,150 ÷ 100,000 = 17.0415 Therms Per Hour (HHV)

These operations also may be combined as follows:

Fuel Used per Hr. in Therms = Cu. Ft. used per Hr. x HHV of Fuel ÷ 100,000

PROPANE

Since some gas engine installations will use propane as fuel, comparative power cost studies will often require fuel consumption and cost data for operation on propane. The same fuel consumption curves used for natural gas can be used for propane, however, since propane is sold by the gallon, the fuel consumption must ultimately be expressed in gallons. This may be easily done. It is only necessary to determine the total BTU (LHV) required by the engine per hour for a given load, then divide this figure by the number of BTU (LHV) per gallon of propane (84,190). Thus, for example, a load requiring 1,500,000 BTUH (LHV) would require:

1,550,000 ÷ 84,190 = 18.41 gal. Propane per hour.

DIESEL FUEL

Determining the fuel consumption for diesel engines is a very similar operation to that for gas engines except that it is less complex since all specific fuel consumption data for diesel engines are based on high heat value. Only the high heat value need be considered when diesel fuels are used. All hydrocarbon fuels, whether gaseous, liquid, or solid, or any other fuels which produce water as one of the products of combustion, have their respective high and low heat values. However, in the case of diesel fuel, there is little variation in the amount of water formed per unit of fuel burned for fuels of like gravity, regardless of the source or area of origin. Thus, the difference between high and low heat value is a fairly constant percentage. It has, therefore, become standard practice in the engine industry to publish fuel consumption data for diesel engines based on high heat value, usually expressed in pounds per brake horsepower-hour or pounds per KWH for diesel generator sets, for a given specific gravity fuel.

TABLE 1.

N.G.P.A. LIQUEFIED PETROLEUM GAS DEFINITIONS AND SPECIFICATIONS

(EFFECTIVE NOT LATER THAN JANUARY 1, 1963)

COMMERCIAL PROPANE

Commercial Propane shall be a hydrocarbon product composed predominantly of propane and/or propylene and shall conform to the following specifications:

Vapor Pressure

The vapor pressure at 100 F as determined my NGPA LPG Vapor Pressure Test shall not be more than 200 pounds per square inch gage pressure.

95 Per Cent Boiling Point

The temperature at which 95 per cent of volume of the product has evaporated shall be −37 F or lower when corrected to a barometric pressure of 760 mm Hg., as determined by the NGPA Weathering Test for Liquefied Petroleum Gases.

Residue

The product shall pass the non-volatile residue test and shall pass the oil ring test—each as determined by the NGPA Method for Determining Residues in Liquefied Petroleum Gases.

Volatile Sulfur

The unstenched product shall not contain volatile sulfur in excess of fifteen grains per hundred cubic feet as determined by NGPA Volatile Sulfur Test.

Corrosive Compounds

The product shall cause no more discoloration to a polished copper test strip when such product is subjected to the NGPA LPG Corrosion Test than the discoloration of Standard copper strip Classification 1, as described in ASTM Method D 130-56, Table I, Copper Strip Corrosion by Petroleum Products.

Dryness

The product shall be dry as determined by the NGPA Propane Dryness Test (Cobalt Bromide Test).

COMMERCIAL BUTANE

Commercial Butane shall be a hydrocarbon product composed predominantly of butanes and/or butylenes and shall conform to the following specifications:

Vapor Pressure

The vapor pressure at 100 F as determined by NGPA LPG Vapor Pressure Test shall not be more than 70 pounds per square inch gage pressure.

95 Per Cent Boiling Point

The temperature at which 95 per cent of volume of the product has evaporated shall be 36F or lower when corrected to a barometric pressure of 760 mm Hg., as determined by the NGPA Weathering Test for Liquefied Petroleum Gases.

Volatile Sulfur

The unstenched product shall not contain volatile sulfur in excess of fifteen grains per hundred cubic feet as determined by NGPA volatile Sulfur Test.

Corrosive Compounds

The product shall cause no more discoloration to a polished copper test strip when such product is subjected to the NGPA LPG Corrosion Test than the discoloration of Standard copper strip Classification 1, as described in ASTM Method D 130-56, Table I, Copper Strip Corrosion by Petroleum Products.

Dryness

The product shall not contain free, entrained water.

BUTANE-PROPANE MIXTURES

Butane-Propane mixtures shall be hydrocarbon products composed predominantly of mixtures of butanes and/or butylenes with propane and/or propylene and shall conform to the following specifications:

Vapor Pressures

The vapor pressure at 100 F as determined by NGPA LPG Vapor Pressure Test shall not be more than 200 pounds per square inch gage pressure.

95 Per Cent Boiling Point

The temperature at which 95 per cent of volume of the product has evaporated shall be 36F or lower when corrected to a barometric pressure of 760 mm Hg., as determined by the NGPA Weathering Test for Liquefied Petroleum Gases.

Volatile Sulfur

The unstenched product shall not contain volatile sulfur in excess of fifteen grains per hundred cubic feet as determined by NGPA Volatile Sulfur Test.

Corrosive Compounds

The product shall cause no more discoloration to a polished copper test strip when such product is subjected to the NGPA LPG Corrosion Test than the discoloration of Standard copper strip Classification 1, as described in ASTM Method D 130-56, Table I, Copper Strip Corrosion by Petroleum Products.

Dryness

The product shall not contain free, entrained water.

Product Designation

Butane-Propane mixtures shall be designated by the vapor pressure at 100 F in pounds per square inch gage. To comply with the designation the vapor pressure of mixtures shall be within + 0 lbs. − 5 lbs. of the vapor pressure specified. For example: A product specified as 95 pound LPG shall have a vapor pressure of at least 90 lbs. but not more than 95 lbs., at 100 F.

PROPANE HD 5

Propane HD 5 shall be a special grade of propane for motor fuel and other uses requiring more restrictive specifications than Commercial Propane and shall conform to the following specifications:

Vapor Pressure

The vapor pressure at 100 F as determined by NGPA LPG Vapor Pressure Test shall not be more than 200 pounds per square inch gage pressure.

95 Percent Boiling Point

The temperature at which 95 per-cent of volume of the product has evaporated shall be −37 F or lower when corrected to a barometric pressure of 760 mm Hg., as determined by NGPA Weathering Test for Liquefied Petroleum Gases.

Residue

The Product shall pass the non-volatile residue test and shall pass the oil ring test—each as determined by the NGPA Method for Determining Residues in Liquefied Petroleum Gases.

Volatile Sulfur

The unstenched product shall not contain volatile sulfur in excess of ten grains per hundred cubic feet as determined by the NGPA Volatile Sulfur Test.

Corrosive Compounds

The product shall cause no more discoloration to a polished copper test strip when such product is subjected to the NGPA LPG Corrosion Test than the discoloration of Standard copper strip Classification 1, as described in ASTM Method D-130-56, Table I, Copper Strip Corrosion by Petroleum Products.

Dryness

The product shall be dry as determined by the NGPA Propane Dryness Test (Cobalt Bromide Test).

Composition

The propylene content of the product shall not exceed five liquid volume percent and the product shall contain a minimum of ninety liquid volume percent of propane.

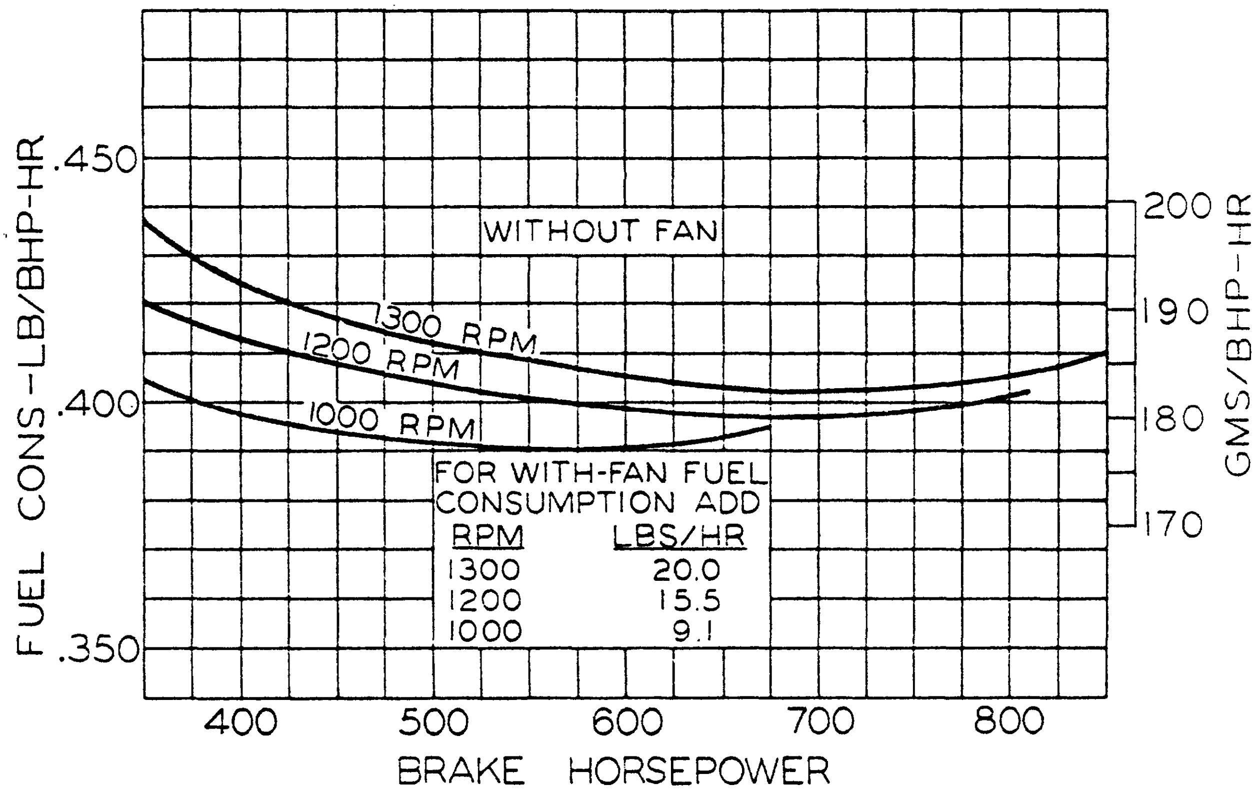


FIGURE 2.
TYPICAL SPECIFIC FUEL CONSUMPTION CURVE FOR DIESEL ENGINE

Figure 2 illustrates a typical family of specific fuel consumption curves for a diesel engine.

To use the curves, simply locate the horsepower load on the abscissa, follow this line vertically till it intersects the fuel curve corresponding to the operating speed, then horizontally to the left and read the specific fuel consumption in lbs. per BHP/Hr. on the vertical ordinate.

Multiplying this specific fuel consumption by the horsepower load will provide the total fuel consumption per hour in pounds, of a given gravity fuel, for the respective load. American Petroleum Institute's (A.P.I.) standard for gravity is usually used for petroleum products. To convert pounds to gallons it is only necessary to divide the total pounds used per hour by the number of pounds per gallon corresponding to the given fuel.

The standard unit for merchandising and pricing liquid fuels is the gallon, while the real value of diesel fuel is dependent upon its weight. The "work content" of a gallon of diesel fuel, the BTU content per gallon, is proportional to the weight of the fuel. Heavier and less expensive fuels contain more BTU's for a given volume than lighter fuels. Table 4 lists the density, heat value specific gravity, and the API gravity of several typical fuels. Instead of stating the fuel weight as a given number of pounds per gallon, at a given temperature, the weight is usually indicated by specific gravity or API gravity. The latter has an arbitrary relationship to the specific gravity. The specific gravity of a fuel is the ratio of its weight to the weight of an equal volume of water at a given temperature. Thus specific gravity increases as the weight per gallon increases. API gravity, however, decreases numerically as the weight increases.

PHYSICAL CHARACTERISTICS OF DIESEL FUELS
TABLE 2

Weight Fuel Lb/Gal	Heat Value BTU/Gal	Sp Gravity at 60° F.	Gravity Deg. API
6.79*	134,700	.816	42
6.95	137,000	.835	38
7.29**	141,800	.876	30
7.48	144,300	.898	26

* Typical No. 1 Diesel Fuel
** Typical No. 2 Diesel Fuel or Furnace Oil

NOTE: Caterpillar diesel fuel consumption figures are based on fuel oil having a gross heat value of 19,500 BTU per pound and weighing 7.12 pounds per U.S. gallon.

COMPRESSION RATIO (GAS ENGINES)

A wide variety of gaseous fuels can be used with Cat gas engines since each model is offered in two different compression ratios. The respective ratios are generally referred to as "high" and "low" and each has its advantages. The variety or range of gaseous fuels which can be used with the high compression ratio units is somewhat limited, however, the specific fuel consumption of these units is very favorable.

While the specific fuel consumption of low compression units is considerably higher, and thus less favorable, they have the advantage of being able to burn a much broader range of fuels.

The high compression ratio units are intended primarily for use with fuels that have high anti-knock qualities such as dry or processed natural gas (commercial pipeline gas) and sewage gas which is primarily methane. The low compression ratio units are used for other fuels which are known to be more prone to detonate. Of course, pipeline gas and sewage gas can be used with either high or low compression engines. Fuels which contain more than approximately 5% (by volume) hydrocarbons heavier than propane should be used only in low compression engines in order to avoid serious detonation. Also, since detonation increases with high air-fuel charge temperatures, the aftercooler water temperature for any turbocharged gas engine should be maintained at, or below, the temperature specified by the manufacturer for the particular engine. For example, Caterpillar high compression, turbocharged engines operating on natural gas require aftercooler water at 90° F. or less. For low compression, turbocharged engines, the aftercooler water should be 130° F. or less. See Table 3 for additional data on fuels.

GASEOUS FUELS FOR USE IN CAT GAS ENGINES:

The following paragraphs describe several fuels along with the suggested types of engine configuration suitable for each.

DRY, PROCESSED NATURAL GAS — 1000 BTU PER CU. FT. (HHV)

Commercial pipeline natural gas is composed primarily of methane and ethane. Any liquids present are removed prior to pipeline transmission. It can be used in all types of engines. The required aftercooler water temperatures are given in Table 3.

PROPANE HD5 OR EQUIVALENT — 2500 BTU PER CU. FT. (HHV)

Propane of HD5 or equivalent quality can be used in all natural gas engines when necessary adjustments are made; but high compression ratio engines, both naturally aspirated and turbocharged-aftercooled, are limited to non-lug applications. The fuel should not contain more than five percent (by volume) hydrocarbons heavier than propane. The required aftercooler water temperatures are given in Table 3.

BUTANE — 3200 BTU PER CU. FT. (HHV)

This fuel is recommended only for low compression ratio, naturally aspirated engines. The timing should be retarded from the timing recommended for natural gas, the exact setting being determined by "trial and error" until detonation is eliminated.

NATURAL GAS WITH PROPANE-AIR ADDED — 1000 BTU PER CU. FT. (HHV)

Many gas utilities add a mixture of propane-air to the natural gas during peak demand periods. This "modified" natural gas can be used in *naturally aspirated* engines with either compression ratio without any limitation. If aftercooler water at 130° F. or less is available, the low compression ratio, turbocharged-aftercooled engine can be used. If the amount of propane-air added does not exceed 35 percent of the mixture volume, the high compression ratio, turbocharged and aftercooled engine can be used with 90° F. water to the aftercooler. Should the proportion of propane-air mixture exceed 35% of the total volume, the high compression, turbocharged engines would require aftercooler water at a temperature of 70° F. or less to operate satisfactorily and the timing should be retarded until no audible detonation could be detected.

SEWAGE GAS — 600 BTU PER CU. FT. HHV (AVE.)

Sewage or "sludge" gas consists primarily of methane, air, and inert gases. Its HHV is lower than the HHV of natural gas because of the presence of the inert gases. Cat engines must be equipped with a digester gas carburetor to utilize low BTU (500-800 BTU/Ft^3 HHV) sewage gas as a fuel. It is necessary to derate the standard high compression ratio naturally aspirated engine by approximately 10% and turbocharged engines by 5% when equipped with the digester gas (DG) carburetors. Standard high compression ratio natural gas engines also require approximately a 5° timing advance from the standard natural gas engine timing.

NATURAL GAS WITH HYDROGEN ADDED — 800 BTU PER CU. FT. AVE. (HHV)

"Manufactured gas" is sometimes added to natural gas during peak demand periods resulting in hydrogen being mixed with the natural gas. When the hydrogen content is less than 50 percent by volume, the proper engine configuration can be found from Table 3. If the hydrogen content is more than 50 percent by volume, the fuel is not recommended for use in any type of Caterpillar gas engine.

FIELD GAS

This fuel comes directly from the gas well (unprocessed) and usually contains "heavy ends," butane and heavier, in excess of 5 percent by volume. If any liquids are present, they should be removed in a scrubber. A scrubber will prevent heavy ends from reaching the carburetor in the liquid form; however, it will not remove the vapor from these liquids from the gas stream. This fuel can be burned in low compression ratio engines, naturally aspirated or turbocharged-aftercooled; however, the timing must be retarded sufficiently to eliminate detonation.

STANDBY FUELS FOR NATURAL GAS ENGINES

When the possibility exists that the natural gas fuel supply will be interrupted, provisions can be made to operate the engines on standby propane. Digester gas engines can also be equipped to operate alternately on natural gas when necessary. For this combination, natural gas is supplied to the carburetor at a positive pressure by the regulator. Propane, in the vapor form, must be supplied to the carburetor with a negative gauge pressure. Therefore, a separate regulator and fuel piping system is required for the propane fuel. Propane should always be supplied to the engine in vapor form when the engine is located in a building or structure. For engines operating outdoors, a propane vaporizer can be located at the engine.

Propane fueled engines require that the standard natural gas engine timing be retarded. This operation involves rotating the magneto to adjust the timing. For this reason, the switch-over from natural gas to propane cannot be done automatically. However, when natural gas is used as a standby fuel for sewage gas engines, no change of timing is required although for long periods of operation, some adjustment is usually desirable to insure best fuel economy.

TABLE 3

SUMMARY—FUELS VS. ENGINE SPECIFICATIONS

Fuel	NATURALLY ASPIRATED		TURBOCHARGED-AFTERCOOLED	
	High Comp. Ratio	**Low Comp. Ratio**	**High Comp. Ratio**	**Low Comp. Ratio**
Dry, Processed, Natural Gas	X	X	X (1)	X (2)
Propane	X (3 & 5)	X	X (1, 3 & 5)	X (2 & 3)
Butane		X (3)		
Natural Gas W/Propane-Air	X (3)	X	X (1, 3 & 4)	X (1 or 2 & 3)
Sewage Gas	X (6)	X (6)	X (1 & 6)	X (2 & 6)
Natural Gas W/Hydrogen, Where:				
H_2 Greater than 50%	Not Recommended			
H_2 = 50%		X (3)		
H_2 = 30%	X (3)	X (3)		
H_2 = 20%	X (3)	X (3)		X (1 & 3)
H_2 = 10%	X (3)	X (3)	X (1 &3)	X (1 & 3)
Field Gas		X (3)		X (2 & 3)
Sour Field Gas	Consult Manufacturer			

Note 1—Temperature of water to aftercooler not to exceed 90° F.
Note 2—Temperature of water to aftercooler not to exceed 130° F.
Note 3—Retarded timing required.
Note 4—The propane-air added should not exceed 35% of the mixture volume.
Note 5—For non-lug, standby applications only.
Note 6—Advance timing. Consult manufacturer for rating.

*Turbocharged engines demand at least 12 PSI gas.

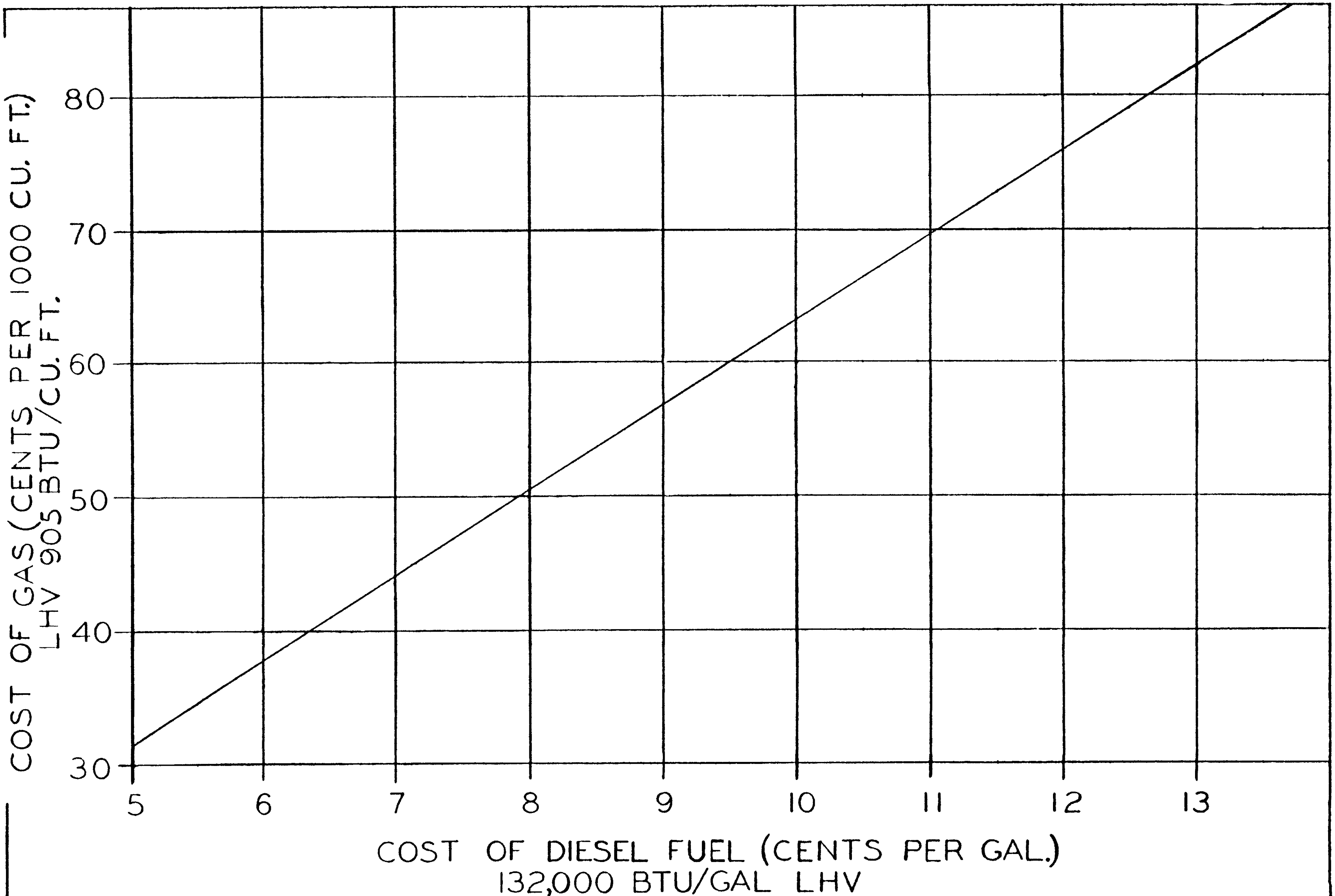


FIGURE 3.

COMPARATIVE COST OF NATURAL GAS AND DIESEL FUEL

ENGINE MAINTENANCE COSTS

Engine maintenance costs are not as easily computed or estimated as fuel consumption, recoverable heat, or initial cost; they are, however, not entirely elusive. The increasing use of guaranteed maintenance and service contracts has eliminated much of the estimating formerly required in feasibility studies. Maintenance contracts vary from complete maintenance and service, including all parts, supplies, and labor, to contracts that provide only a guaranteed cost for engine rebuild. For this reason, a maintenance cost figure is meaningless unless well defined. Complete maintenance costs are composed of three basic items:

1. The miscellaneous maintenance and service cost, including service manual recommendations plus make-up oil (excluding labor to perform this routine duty).
2. The overhaul maintenance cost, usually expressed in terms of cost per engine operating hour. This item should cover all labor and parts necessary to perform major and minor overhauls at the recommended intervals.
3. The third item is the labor cost necessary to perform the miscellaneous service for Item 1.

Items 1 and 2 will vary considerably with the severity of service the engine must perform. For On-Site Power installations, the conditions under which the engines operate, the quality of fuel, and the routine maintenance the engine receives, are all usually considered to be good. Item 3 will vary with labor costs and the location of the engine plant with respect to the point from which service personnel must be dispatched. Because of the many variables, it is difficult to provide realistic figures that would be useful for all applications. Maintenance costs should be based on past experiences in the area being considered.

HEAT RECOVERY SYSTEMS

Heat may be recovered from engines by use of a multitude of different systems. The nature of the heat requirements of a facility, however, will usually be the determining factor that makes one system of heat recovery more attractive than another for a particular job.

In its simplest form, heat recovery may amount to nothing more than utilization of the heat transferred from an engine radiator to a flow of air. The temperature of such air is usually rather low (100° F to 150° F). Air so heated can be delivered essentially free from contaminants and thus is quite suitable for pre-heating boiler combustion air, grain and cereal drying, space heating, etc. The cost of such a system is minimal and, under optimum operating conditions, the effect is a relatively efficient system, converting approximately 32% of input fuel energy into work, or power, and 30% into recovered heat energy for an overall efficiency of approximately 62%. This total percentage figure can be further increased by approximately 17% by recovering a portion of the exhaust heat. To do so would, of course, add something to the cost except in processes where the exhaust can be used directly.

One of the more popular heat recovery systems in use today for reciprocating engines employs the principle of ebullient cooling for the engine. This system, shown in Figures 7 and 8, has gained its popularity largely because of its simplicity, low operating and maintenance cost, and its capability to produce steam at pressures suitable for conventional absorption air conditioning chillers (12-15 psig). This system is obviously more costly and requires more initial capital investment than the simpler systems, however, it also has greater application flexibility.

Because an ebullient cooled system incorporates most of the considerations of a heat recovery system, it will be used as an example:

Primary responsibility of the heat recovery equipment is to cool the engine. Secondary functions are to recover heat and to silence engine exhaust. Individual units for each engine will offer maximum reliability and flexibility. These units include a heat recovery muffler, steam separator, and safety devices necessary to protect the entire cooling system. These units are constructed either as water tube (water inside tube) or fire tube units. The water tube unit generally provides excellent silencing and the highest BTU recovery at the lowest cost, weight and space requirements. The fire tube unit exhibits good life and, because of an integral steam separator, installation piping is simplified.

Either of these units should incorporate the equipment necessary to protect the system. These include:

Low water level switch
Minimum water level switch
High water level switch
Liquid level make-up valve — float type
Float and thermostatic trap
Vacuum breaker
Pressure control valve
High steam pressure switch
Safety steam valve
Gauge glass
Pressure gauge

Sizing: When sizing the heat recovery unit to the engine, both water and gas side pressure drops must be considered. On the gas side, pressures should be calculated with the assumption that the unit is operating dry. This will avoid excessive exhaust back pressures.

Between these two extremes in heat recovery system design, lie a host of other systems and combinations of systems. As stated earlier, it is not the purpose of this discussion to explore all of the possible systems nor to design the perfect system, it is rather to call attention to a number of basic requirements associated with the design of such systems and to provide performance data, to the extent possible, to assist the designer.

The gas turbine also offers some latitude in heat recovery system design; however, the most commonly used system likewise generates low pressure steam. Since economics should be the determining factor in practically all on-site power plant design decisions, no simple rule or equation can be given for evaluating heat recovery of turbines versus reciprocating type engines. It can be pointed out, however, that differences in fuel economy and rejected heat are appreciable for the two types of prime movers and thus justify a thorough examination before making a decision on the question of which type of prime mover to use.

Heat recovery systems are in use today around the world. Some typical application examples are:

1. Meat packing plants — hot water for processing
2. Hotels and motels — hot water, heated swimming pools, space heating, domestic hot water, steam absorption air conditioning.
3. Schools — hot water and steam, heating and air conditioning
4. Apartments — steam (same as hotels and motels)
5. Brick plants — steam, heat mix, exhaust drying
6. Carpet plant — steam process, exhaust gas drying
7. Mica Reduction — exhaust gas — increases energy of compressed air for reduction process.
8. Feed mill — hot water, boiler feed, water heating, steam
9. Dairy — steam and hot water
10. Heavy manufacturing — steam, air conditioning, space heating and hot water.
11. Warehouses — (same as heavy manufacturing)
12. Office buildings — (same as hotels and motels)
13. Ice rinks — hot water, space heating
14. Car wash — hot water, washing, drying
15. Municipal pumping plants — hot water, space heating and water treatment
16. Hospitals — steam, (same as hotels and motels)
17. Sewage plant — hot water, sludge heating
18. Printing plants — steam, (same as hotels and motels), humidity control
19. Ice plants — hot water, cleaning, treating
20. Power generation — steam, binary cycle

BASIC HEAT RECOVERY SYSTEMS

Heat Recovery Systems can be divided into four basic design classifications, as follows:

1. HOT WATER SYSTEM — NORMAL TEMPERATURE*
2. HOT WATER SYSTEM — HIGH TEMPERATURE*
3. HOT WATER AND STEAM SYSTEM WITH FLASH BOILER
4. EBULLIENT SYSTEM

* The temperature classifications used in this discussion evolve from internal combustion engine operating practices and have no relationship to similar classifications used in the building heating industry.

HOT WATER SYSTEM — NORMAL TEMPERATURE

This system utilizes normal jacket water temperature (approx. 190° F. - 210° F. recorded at engine outlet) and a shell and tube heat exchanger to transfer rejected engine heat to a secondary circuit — usually water. An exhaust heat boiler may also be included in the system. The primary coolant circuit which serves the engine jacket must be a "closed" system. Figure 4 illustrates a flow diagram for this system.

Critical Design Features

a. Provide adequate flow of coolant through engine. If standard engine jacket water pump is used, keep friction and static head on jacket water circuit beyond the engine to a minimum.
b. Controls must assure flow through muffler, if used, when engine is in operation.
c. Temperature differential between "coolant in" and "coolant out" of engine should not exceed 20° F. and should not be less than 10° F. A 15° F. differential is desirable.

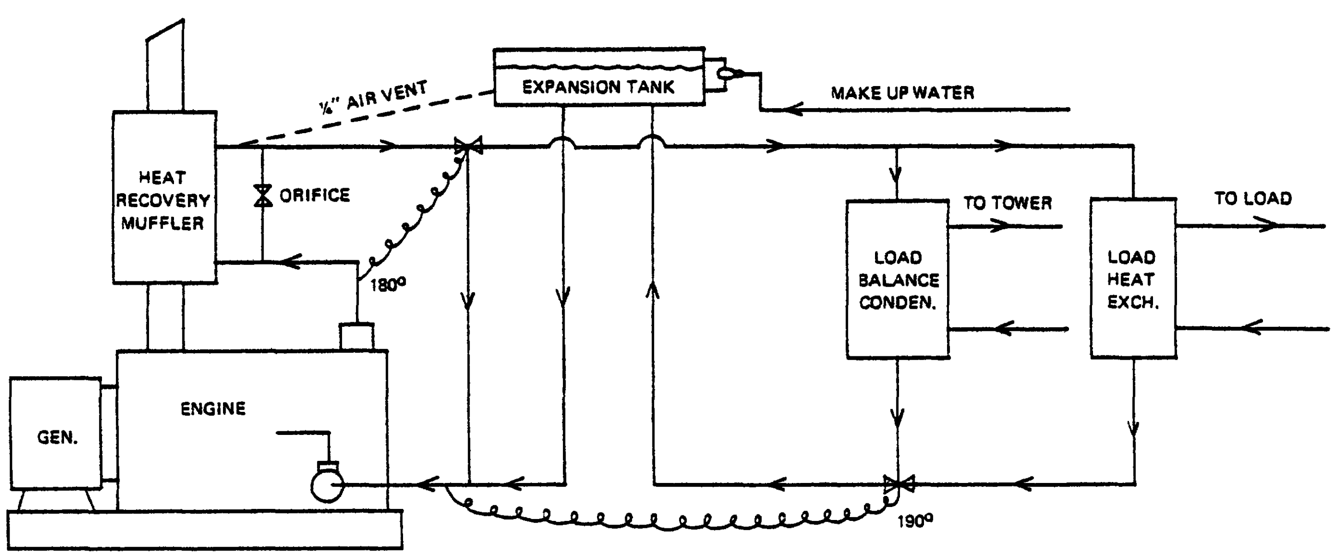


FIGURE 4

FLOW DIAGRAM, HOT WATER SYSTEM — NORMAL TEMPERATURE

d. Expansion tank in engine coolant circuit must be at highest point in the primary circuit.
e. Heat exchanger location must be at lower level than expansion tank.
f. Proper venting to expansion tank of all piping in the primary circuit which might develop either steam or air "pockets."
g. Temperature control of engine coolant to avoid excessively high temperature (210° F. max.).

HOT WATER SYSTEM — HIGH TEMPERATURE

This system utilizes elevated jacket coolant temperatures (220° F. to 250° F., recorded at engine outlet) and functions essentially the same as the normal temperature hot water system except for the pressure required in the circulating systems, especially in the engine coolant circuit. In this system a pressure control must be provided in the engine coolant circuit that will assure a pressure, at all times during operation, of several PSIG, preferably 4 or 5, above the pressure at which steam will form. The source of this pressure may be a static head imposed by an elevated expansion tank or controlled air pressure in the expansion tank. For 250° F. water temperature, this pressure should be approximately 20 PSIG at the engine. Also, all water circulating pumps, primary and secondary, must be suitable for use with the elevated temperatures and pressures. Conventional engine jacket water pumps are not suitable for this service. Figure 5 illustrates a flow diagram for this system.

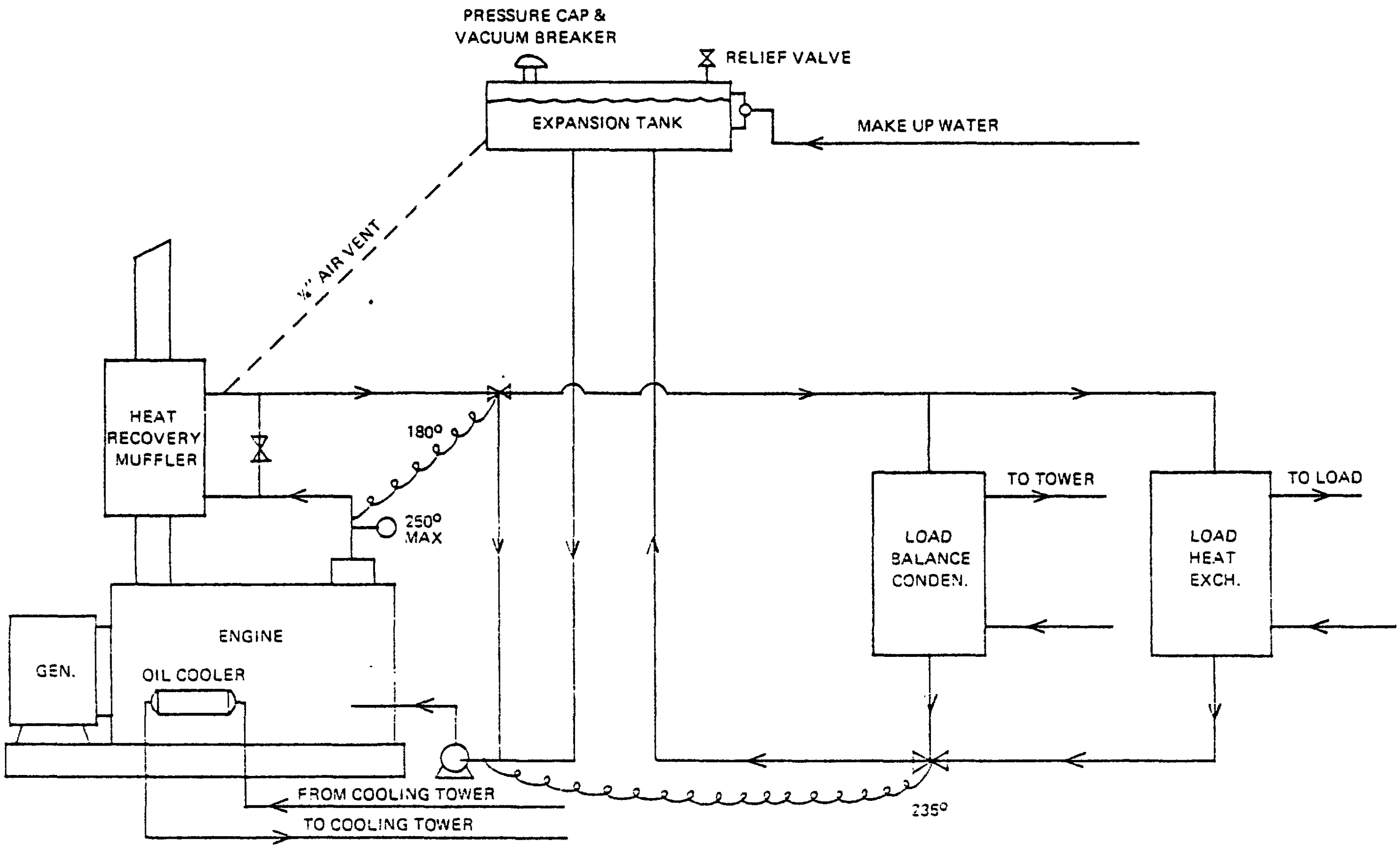


FIGURE 5
FLOW DIAGRAM, HOT WATER SYSTEM — HIGH TEMPERATURE
(primary circuit through heat recovery muffler)

Critical Design Features

a. Items B, C, D, E, and F of Normal Temperature Hot Water System
b. Requires pressure control for engine coolant circuit.
c. Water pump must be suitable for high temperature operation and capable of maintaining adequate flow.
d. Temperature control of engine coolant required to avoid temperatures exceeding 250° F.
e. Engine oil cooler (heat exchanger) and/or aftercooler requires cooling water circuit separate from engine jacket water circuit. Temperature of oil leaving cooler should not exceed 190° F. See Section on installation. Thermostatic control for oil flow is available for some models of Cat engines and should be used to satisfy the above requirements.
f. Use only treated water in engine coolant circuit.

g. Controls must assure flow through heat recovery muffler, if used, when engine is in operation.
h. Remove engine thermostats and eliminate the by-pass circuit.

HOT WATER AND STEAM SYSTEM WITH FLASH BOILER

This system incorporates many of the features of the high temperature hot water system plus a "flash boiler" for generating low pressure steam. Steam is generated in the flash boiler, and in the piping to the boiler, simply because of the pressure differential which exists by design between the engine outlet and the boiler. A lower pressure obviously prevails in the boiler than at the engine outlet, thus, as the high temperature water from the engine approaches the boiler, the static head is reduced and, as the "heat of the liquid" adjusts to the lower pressure, some heat is released and serves as heat of vaporization to convert part of the water to steam. In the process the temperature of both, the steam and the remaining water, adjust to the temperature corresponding to the controlled pressure prevailing in the boiler. The steam so formed is delivered to the load while the water, at the reduced temperature returns to the engine to repeat the process.

This type of system is usually designed to operate at steam pressure ranging from 2 to 8 PSIG. For any predetermined or maximum design engine coolant temperature, the total pressure imposed upon the engine cooling circuit by the combined steam pressure and static head must be adequate to prevent boiling or "flashing" within the engine. When 250° F. water temperature (leaving the engine) is used, the required total pressure at the engine is approximately 20 PSIG. The additional 5 PSIG over the pressure corresponding to 250° F. will allow a 3 to 4 PSIG pressure drop in the flash boiler without danger of "flashing" in the engine. For controlled boiler pressures less than 8 PSIG, the static head required may be reduced but should always be adequate to prevent "flashing" in the engine when normal pressure fluctuations occur. Figure 6 illustrates a flow diagram for this type of system.

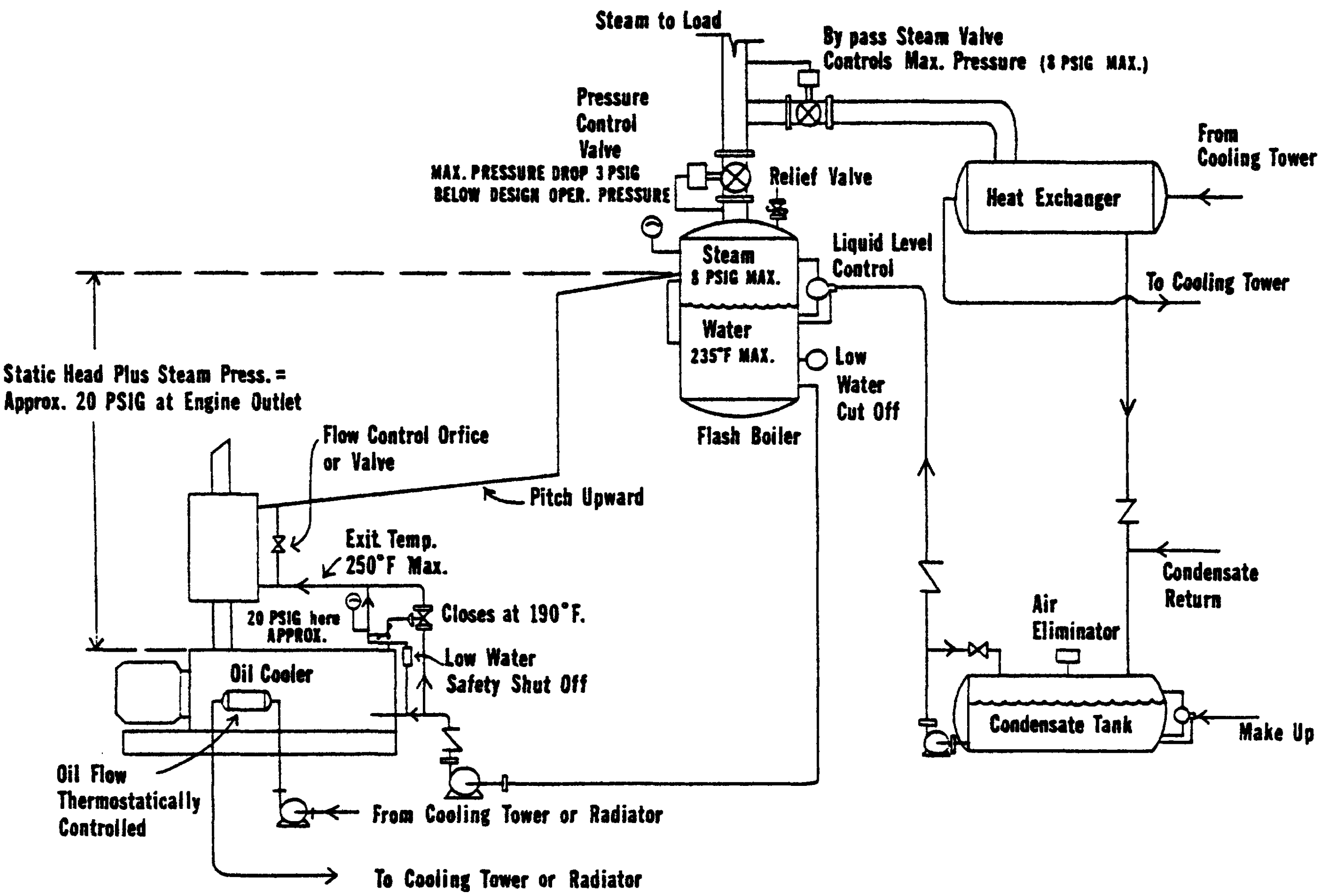


FIGURE 6
FLOW DIAGRAM, HOT WATER and STEAM SYSTEM WITH FLASH BOILER

Some flash boiler systems call for a pressure reducing valve or orifice at the inlet to the boiler instead of the static head and controlled steam pressure. While such a system, properly installed and carefully operated, can be made to function, it is not recommended because of the danger of pressure unbalance in the system causing steam to form in the engine jacket water pump and in the engine (because of circulation failure) with disastrous results.

Critical Design Features

a. Provide adequate coolant flow through engine. Remove standard engine thermostats and eliminate the bypass circuit.
b. The temperature differential of "coolant in" and "coolant out" of the engine should not exceed 20° F. and should not be less than 10° F. A 15° F. differential is desirable.
c. Controls must be provided to assure flow through heat recovery muffler, if used, at all times during engine operation.
d. Water pumps must be suitable for high temperature operation.
e. Adequate "make up" water supply and control to accommodate the inherent variations in steam demand peculiar to the particular installation. Make up water should be supplied almost entirely from the condensate return.
f. Use only treated water to supplement condensate for make up water.
g. Flash boiler must be elevated above engine to provide static head. Total pressure at engine outlet must be adequate to prevent "flashing" within engine when pressure variations occur in the boiler.
h. Boiler must be equipped with a pressure control valve located in the steam outlet line to limit pressure drops in the boiler to approximately 3 PSIG below design operating pressure.
i. All piping from engine to boiler must be pitched upward.
j. Engine oil cooler/(heat exchanger) and/or after-cooler, requires cooling water circuit separate from engine jacket water circuit. Temperature of oil leaving cooler should not exceed 190° F. Thermostatic control for oil flow is available for some models of Cat engines and should be used when available.

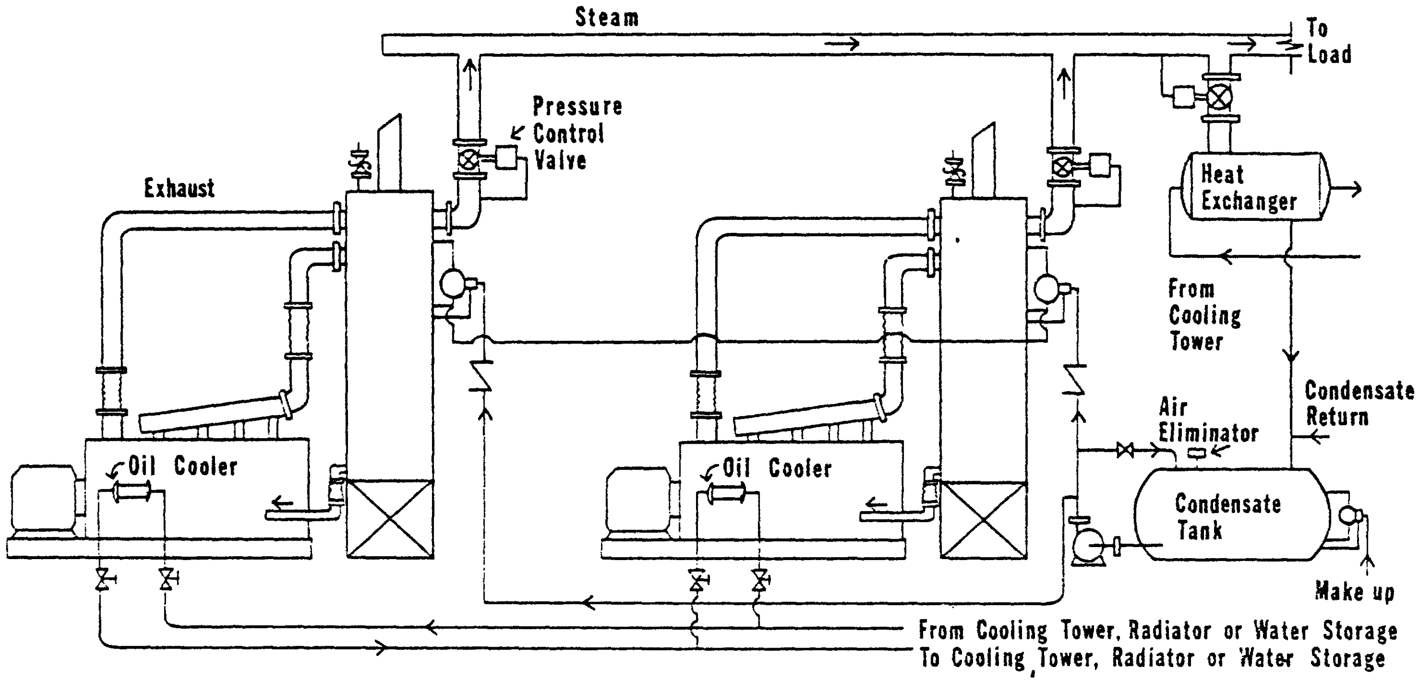


FIGURE 7
FLOW DIAGRAM, EBULLIENT SYSTEM, PACKAGE UNITS

EBULLIENT SYSTEM

This system utilizes the "heat of vaporization" to remove rejected heat from the engine. Steam, as such, however, is not allowed to collect within the engine but is moved through the water passages, along with the high temperature water by thermal action, to a steam separator located at an elevation somewhat above that of the engine. No jacket water pump is required with this system. While the temperature differential between "water in" and "water out" of the engine in this system is usually quite low (2° F. to 3° F.), flow through the engine is assured by virtue of the change in coolant density as it gains heat from the engine. The higher temperature coolant being lighter creates a pressure differential between the water inlet and water outlet connections to the engine. Almost all of the heat gain in the coolant is added in the form of heat of vaporization. Figures 7 and 8 illustrate the basic elements of an ebullient system. Obviously, any number of arrangements are possible. In some instances the exhaust gas boiler, or muffler, and the steam separator are combined into a single "packaged" unit — one packaged unit being used for each engine as illustrated by Figure 7. Other heat recovery equipment available (not illustrated) combines the exhaust gas boiler and the steam separator in a single unit and in addition includes a direct fired section in the exhaust boiler which serves to eliminate the need for an auxiliary boiler. Such units can be designed to serve two engines each; however, to do so requires a more complex exhaust piping system. Also, to serve as a steam separator the unit must be located well above the engines.

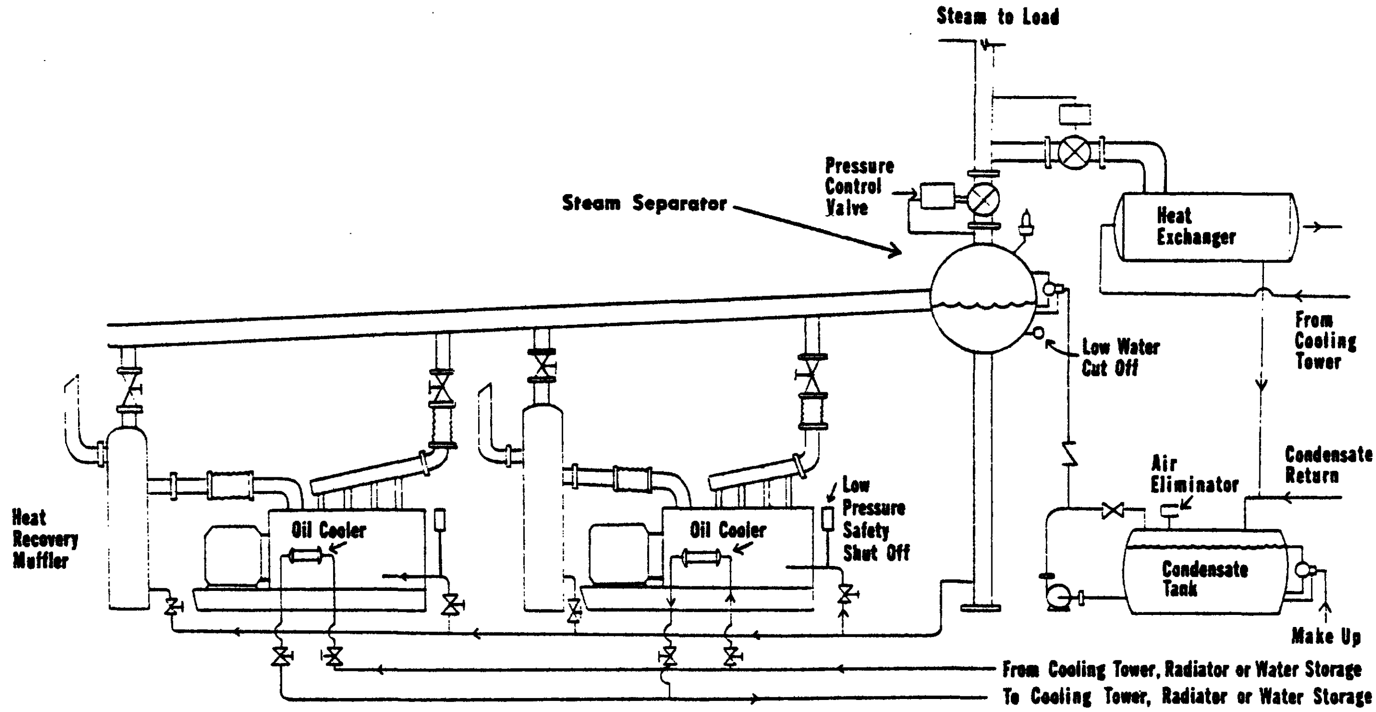


FIGURE 8
FLOW DIAGRAM, EBULLIENT SYSTEM, MULTIPLE UNITS, SINGLE STEAM SEPARATOR

Critical Design Features

a. To avoid excessive boiling within the engine and subsequent formation of steam pockets in the water passages, the liquid in the engine must at all times be under a static head of not less than one PSIG recorded at the coolant outlet of the engine. When measured in feet of water, the static head should be measured from the highest water passage in the engine where heat transfer from the engine or exhaust manifold to the coolant occurs. On some engines this may be the cylinder head while on others it might be the water cooled exhaust manifold.
b. Oil cooler (engine) requires cooling water circuit separate from the engine jacket circuit. Temperature of oil leaving cooler should not exceed 190° F. Thermostatic control of oil flow is provided with Cat ebullient cooled engines.
c. For turbocharged and aftercooled gas engines, the aftercooler requires a cooling water circuit separate from the engine. For gas engines the aftercooler water temperature should not exceed 90° F. It is common practice to place the oil cooler and aftercooler in the same cooling water circuit.
d. The engine cooling system must be protected against sudden loss of pressure. Controls must be provided between separator and load which will function to limit the pressure drop to not more than 3 PSIG. A greater sudden pressure loss will cause "flashing" in the engine which can result in serious damage to the equipment.
e. System pressure should not exceed 15 PSIG
f. Pipe size (for coolant) to and from the engine must be in accordance with the engine manufacturer's recommendations, or larger.
g. Coolant piping between engine and steam separator must be so installed that the flow of coolant (a mixture of water and steam) will always be pitched upward — never downward.
h. Make-up water should be provided to compensate for any loss in the system. This water is generally fed into the condensate tank and should always be treated.

PERFORMANCE OF HEAT RECOVERY SYSTEMS

REJECTED HEAT AVAILABLE FROM ENGINE

The amount of heat rejected by any direct-fired prime mover is directly proportional to the load and inversely proportional to the thermal efficiency. Heat rejection information is listed on the engine specification sheets. Calculation of recoverable heat, however, is not an exact science. While the heat rejected to the jacket coolant can be measured quite accurately and to the exhaust gas not quite so accurately, there are other areas, such as lubricating oil and radiation, where measurements and calculations become more in the category of close approximations.

HEAT REJECTED TO COOLANT

For liquid cooled engines, essentially all of the heat rejected to the engine coolant is recoverable. The quantity of heat available from this source is listed on each specification sheet.

HEAT REJECTED TO LUBRICATING OIL

When recovering heat from naturally aspirated or turbocharged-aftercooled engines using any of the high temperature cooling systems, it may also be worthwhile to utilize the heat rejected to the lubricating oil. This is especially so when an auxiliary boiler is used since this heat can be applied to pre-heat the boiler feed water. It can also be used for domestic hot water or other low temperature requirements. The heat removed by the lubricating oil from engines operating with coolant temperatures above 220° F is always rejected to a cooling medium other than the jacket water. The rate of heat rejection to the oil cooling circuit for Caterpillar Engines is approximately 5.5 BTU/hp/min (7.9 BTU/KW/min) for gas engines, 8.5 BTU/hp/min (12.2 BTU/KW/min) for diesel engines. This figure may be used when calculating the total heat removed by the lubricating oil circuit. See installation section for auxiliary water flow and temperature requirements.

HEAT RECOVERABLE FROM EXHAUST

The heat recoverable from engine exhaust gas can be calculated by application of the equation: $Q = C_p M (T_1 T_2)$ where Q = BTU per hour, C_p = the average specific heat of exhaust gas (.258 BTU/lb./degree F.), M = the mass or weight of exhaust gas flow in pounds per hour $\frac{(CFM \times 60 \times 41.13)}{(\text{Gas Temp.} + 460^\circ)}$ and T_1 and T_2 represent exhaust gas temperature in and out respectively. Heat recovery mufflers or boilers should be so sized and applied that, when operating at full load, the temperature of the exhaust gas leaving the unit will not be less than 325° F., ± 25° F. to eliminate possibility of water vapor in exhaust condensing.

Example: Heat recovery calculation

Given conditions: One G398 turbocharged and aftercooled Electric Set, ebulliently cooled, operating at rated prime power output, (500 KW), using 1000 BTU (HHV), 905 (LHV) gas; exhaust gas temperature leaving muffler, 325° F.

Required: Determine amount of recoverable heat per hour from jacket coolant and exhaust gas.

Solution:

Heat rejected to jacket coolant and lubricating oil, BTU/Hr	1,614,000
(26,900 x 60 = 1,614,000) (See specification sheet)	
Heat rejected to lubricating oil only, BTU/Hr	237,000
(500 KW x 7.9 x 60 = 237,000 BTU/Hr.)	
Heat rejected to jacket coolant only, BTU/Hr	1,377,000
Heat recoverable from exhaust	
$Q = C_p M (T_1 - T_2)$	
$Q = .258 \times 54.3 \times 60 \ (985 - 325) =$	554,000 BTU/Hr
Total recoverable heat, BTU/Hr	1,931,000

CONVERSION TO OTHER UNITS

The recoverable heat from prime movers can also be expressed in boiler horsepower, a unit sometimes used in rating the output of small boilers.

Example:

Conditions: G398 TA Industrial Engine operating at 700 HP, ebullient cooled, exhaust temperature leaving muffler 325° F.

Required: Equivalent Boiler HP of recovered heat (as steam)

Solution:

Heat rejected to jacket coolant and lubricating oil, BTU/Hr (28,300 x 60 = 1,698,000) (See specification sheet)	1,698,000
Heat rejected to lubricating oil only, BTU/Hr (700 x 5.5 x 60 = 231,000)	231,000
Heat rejected to jacket coolant only, BTU/Hr	1,467,000
Heat recoverable from exhaust, BTU/Hr ((Q = .258 x 75.0 x 60 (1,075 — 325) = 870,000))	870,000
Total Heat Recoverable, (as steam), BTU/Hr	2,337,000
Equivalent Boiler HP (2,337,000 ÷ 33,475 = 70)	70

It is likewise desirable at times to relate recoverable heat to equivalent tons of air conditioning when using an absorption chiller. Assuming heat input to the chiller per ton of air conditioning to average 19,000 BTU/Hr. and using the recoverable heat at rated load from the previous example:

Air Conditioning = 2,337,000 ÷ 19,000 = 123 tons

Ratio of HP output to tons of air conditioning from recovered heat = 5.7 HP per ton

Since thermal efficiency decreases as the load decreases and more heat is recoverable per HP output, this ratio (HP load per ton) improves as the load is reduced. Thus, since load factors of operating units seldom exceed 75%, it is common practice to use a ratio of one ton per 5.5 HP or per 3.75 KW on the switchboard when estimating the amount of air conditioning available from recovered heat.

STEAM GENERATION

It is often desirable to express heat recovery performance in terms of pounds of steam generated per hour when using either the flash boiler or the ebullient system. The procedure for determining the amount of steam available involves nothing more than calculating the total heat recoverable from the exhaust gas and the jacket coolant, then dividing this total by the heat required to generate a pound of steam under the prevailing conditions. The heat required per pound of steam may be determined by adding to the heat of vaporization for the prevailing pressure, one BTU for each degree F. difference between the steam temperature and the temperature of the make up water to the flash boiler or steam separator. Table 4 lists the enthalpy, or heat of vaporization, corresponding to the popularly used pressures and temperatures for Total Energy plants.

TABLE 4

ENTHALPY OF STEAM

PSIA	Temp. ° F.	Enthalpy of Vaporization, BTU/lb.
14.696	212	970.3
15	213.03	969.7
16	216.32	967.6
17	219.44	965.5
18	222.41	963.6
19	225.24	961.9
20	227.96	960.1
21	230.37	958.4
22	233.07	956.8
23	235.49	955.2
24	237.82	953.7
25	240.07	952.1
26	242.25	950.7
27	244.36	949.3
28	246.41	947.9
29	248.40	946.5
30	250.33	945.3

Example:

One G398 TA operating @ 700 HP and 12.3 PSIG steam pressure. Make up water temperature @ 200° F.
Recoverable heat, BTU/hr. = 2,337,000 (see previous example)
Heat of vaporization @ 12.3 PSIG (27 PSIA) = 949.3 BTU/lb.
Temperature difference, steam and feed water (244.36-200) = 44.36 F. (each degree difference represents 1 BTU per lb.)
Total heat required per lb. of steam (949.3 + 44.36) = 993.66 BTU
Pounds of steam per hour = 2,337,000 ÷ 993.66 = 2,352

BINARY CIRCUITS

Another method of using rejected heat, common with gas turbine applications, and much less common but sometimes feasible with reciprocating engines, is the use of this energy in a condensing steam turbine for additional power production. Initial review of the application indicates that for a plant operating full load, year round, with average fuel costs, the discounted cash flow payout on the steam turbine and associated hardware would be less than one year. Operation at a less favorable load factor would, of course, lengthen the payout time. This application requires an adequate source of cooling water, preferably river, lake, or sea. Each 6 KW of the reciprocating engine output will produce 1 KW in a steam turbine operating with a discharge pressure of 3 in. Hg absolute pressure.

BOILER COST REDUCTION

The ability to recover heat from a prime mover often has a favorable effect on first cost as well as on the operating cost since installation of engines will usually displace some other boiler room equipment.

The installed cost listed in Table 5 indicates owner's cost of a typical package boiler plant which might be replaced.

TABLE 5

APPROXIMATE COST OF SMALL BOILERS

	Boiler & Installation
20 HP	$9,300
40 HP	11,400
60 HP	14,700
100 HP	18,900

The total cost of boiler capacity replaced or reduced by the On-Site Power plant should be subtracted from the total cost of the On-Site Power plant when considering rate of return on investment. This is also true for all the other services which are replaced, such as electrical substations, domestic water heating equipment, etc.

SWITCHGEAR AND CONTROLS

The type of switchgear and controls used with On-Site Power generating plants, like heat recovery equipment, can and does vary widely in the degree of sophistication — and in cost. The type of facility and load served by the plant usually dictates the basic design requirements for the switchgear.

When viewed from the standpoint of switchgear and control design, total energy plants can be grouped into the following basic categories:

1. MANUALLY CONTROLLED PRIME POWER PLANTS (ATTENDED)
2. TOTALLY AUTOMATIC PRIME POWER PLANTS (UNATTENDED)

MANUALLY CONTROLLED PRIME POWER PLANTS (ATTENDED)

In this type of system, the operator places units on or off the line as the load profile demands. The units are paralleled and the load is divided manually. Generally one unit is designated the master and this unit is set to operate at zero droop, with the load limited, and controls the system speed. Its speed control is used to set the system speed and automatic clock accuracy can be applied if it is desirable to hold clock accuracy. In this type of plant, the speed adjustment is usually made manually by comparing a system electric clock to a master clock. Circulating currents are held to a minimum, as in all parallel systems, by cross current compensation but requires manual adjustment occasionally. Load sharing is also controlled by manual adjustment. This type of system requires minimum engine safety shutdown controls, however, it should have reverse current trips along with low oil pressure, high oil temperature, and overspeed shutdown devices. Water level and inlet air temperature alarms are also very desirable. See Table 6 for recommended safety devices.

The attractive features of switchgear for this type of plant are simplicity, relatively low initial cost, and low maintenance cost.

AUTOMATIC PRIME POWER PLANTS (UNATTENDED)

The totally automatic system has been made practical by the introduction of the electric governor. By maintaining stable and precise control, these governors allow the units to be automatically paralleled, and to divide load proportionally after being paralleled. The only other device necessary is a signal which will place units on the line or remove them as the load profile demands. Another feature offered by the electric governor is the ability to allow a large number of engine driven electric sets to be paralleled with reliability and ease.

Since the units in the system are automatic, they can be operated unattended if they have adequate safety and condition read-out devices to notify when other than routine servicing is required.

Also, as is true in all power systems, standby capacity must be available in order to provide reliable power. This available standby power should be equivalent to the essential load.

Reliability can be improved by designating a portion of the load, which includes the more critical operations, as "essential" and serving this load with a separate circuit. Then by allowing the remainder, or non-essential load, to be temporarily dropped in the event of an overload condition or unit malfunction, the essential load can be served without interruption. The essential load should not be greater than 90% of the output capability of the unit, or units, assigned to the base load.

If a system is to be totally automatic it must incorporate the capability to drop non-essential load. Dropping non-essential load is not generally a serious disadvantage since normally this load will be picked up in less than 60 seconds and in many cases, the outage will not extend over 10 seconds. The dropping of part of a load can be avoided, or reduced to a minimum, except for serious malfunction, by arranging for another unit to come on the line at a lower percentage of the load capability of the operating units. This, however, will lower the overall economy of the system slightly in the event that all of the recoverable heat is not being used.

Fully automatic systems normally require real *load* sensing to add or drop engines to the bus. If the power factor of the system does not vary over ± 3 percent at any given percentage of the total system load, then *current* sensing can be used with practically no loss in fuel economy. However, if the power factor variation from the mean is greater than ± 3 percent and maximum economy is desired, then real load sensing should be used.

Clock accuracy can be held to a slow drift of ± 10 seconds about a mean point which provides an accuracy of ± .0005%. The necessity of clock accuracy should be carefully weighed. For instance, if the system is visited daily, slight speed corrections can be made and the system can be held within ± 2 minutes per day or less after initial corrections are made without a clock control circuit. However, if the system is set up for a customary weekly visit by a serviceman, clock accuracy could be very desirable. Because clock accuracy control equipment represents a sizeable expense item, electrically wound mechanical clocks should also be appraised from an economic and performance standpoint.

Automatic systems are generally made automatic simply to provide the capability of operating unattended and it follows that since they are unattended, they should have more safety devices than an attended power generating system. The engine should have the customary safety devices such as low oil pressure, high water temperature or high steam pressure, and overspeed. In addition, however, safety devices should be provided to shut down on high oil temperature, low coolant level, excessive vibration, and high inlet air temperature on turbocharged natural gas engines. It is also wise to program an engine off the line if it is not producing the power that the governor position is calling for.

As these fault conditions vary in their respective seriousness, they can and should be used for immediate shutdown if the fault will cause immediate danger. If, however, the fault is dangerous only when allowed to continue for long intervals, the standby unit can be started and placed on the line before the faulty unit is shut down, thereby avoiding any minor interruption of power. System units should also be equipped with reverse current trips so they cannot be motored.

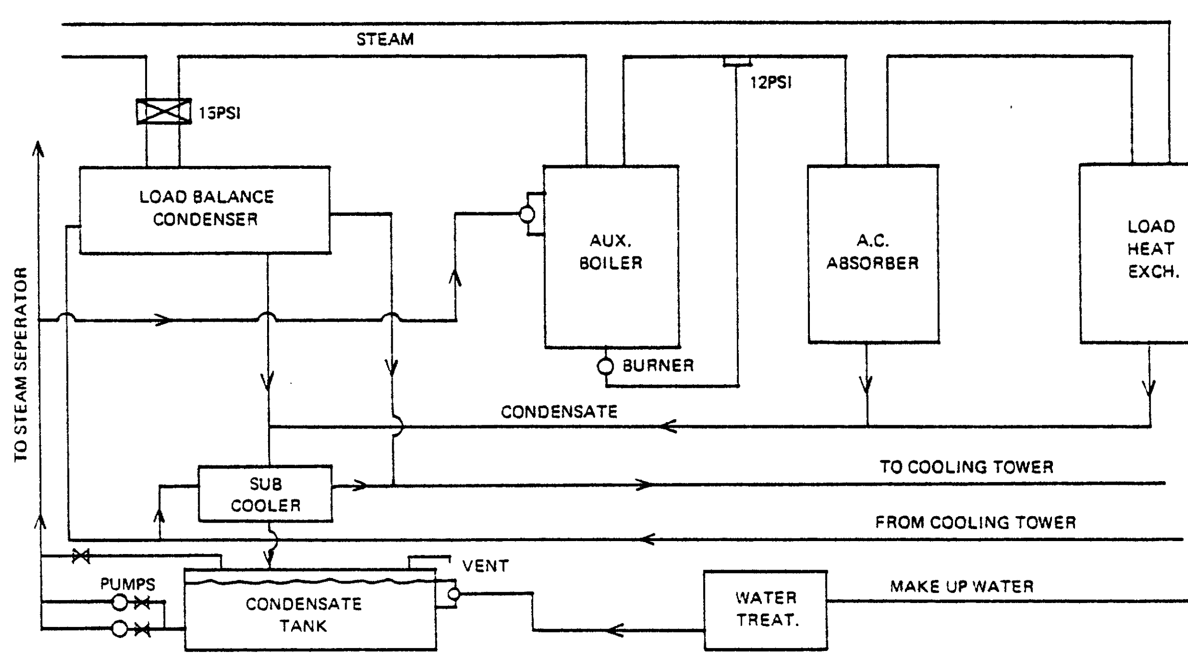


FIGURE 9
FLOW DIAGRAM, SUGGESTED AUXILIARY PIPING

TABLE 6

CONTROLS AND SAFETY DEVICES
(TA Gas Engines)

Malfunctions:

Unit	Unattended	Attended
Low oil pressure	I	I
High oil temperature	P	A
Excessive vibration	I	I
Overspeed	I	I
High inlet air temperature	P	A
Overcrank	I	
High water level	A	A
Low water level	I	
Loss of power	P	A
Reverse power	I	I
Parallel timing	I	
Overcurrent	I	I
High gas pressure	P	A
High steam pressure	A	A
Sync. relay failure	I	
System		
Low gas pressure	A	A
Overload	A	A
Underfrequency	A	
Over/under voltage	A	
Battery charger failure (AC)	A	
Battery failure (DC)	A	
Low condensate level	A	A
Low tower water level	A	A

I — Immediate shutdown — next engine called
P — Programmed shutdown — next engine called (starts before first engine dropped)
A — Alarm only

INSTALLATION PRACTICES

As with all rotating machinery, engines generate noise, radiate heat, develop some vibration, and require periodic maintenance. However, these characteristics prove troublesome only when their existence is ignored — ignored, that is, during the planning and specification stage, for improperly installed machinery has a way of not allowing anyone to ignore it, including the manufacturers and the responsible engineers. On-Site Power installations are simple engine installations coupled to interdependent non-engine components such as steam separators, condensers, heat recovery mufflers, and related piping.

A complete Total Energy system offers few new installation or design problems. The concept does, however, combine installation and design problems of many previously unrelated functions and systems. The engineer who has designed steam power systems is now faced with designing reciprocating engines in a precise balance with the steam system, while the engineer who is familiar with engine drives now finds himself concerned with steam system design and installation situations. A step-by-step approach to the design and installation of the system's components will yield the most direct method of approach to the Total Energy concept.

The On-Site Power installation centers around the prime mover, therefore, the majority of the design and installation criteria is related to the engine, and justly so, for the engine generally accounts for most of the initial cost as well as the largest percentage of the operating costs.

ENGINE COOLING SYSTEM

Cooling is vital to all internal combustion engines, for without proper cooling the engine will be short lived. The heat rejection data reveals that about one third of the input fuel energy is rejected to the engine cooling system. Regardless of how the heat is removed from the engine — by radiator, heat exchanger, or the ebullient system, the primary function is cooling the engine; and heat recovery, while vitally important economically, is of secondary importance operation-wise.

RADIATOR: SELECTION AND INSTALLATION

Radiators, when used, should be installed in a manner that will insure a continuous supply of fresh air to the radiator, with particular provisions to prevent recirculation of air (unless recirculation is intentionally used as a means of heat recovery or temperature control, as is sometimes the practice in extremely cold climates). When the radiator is located in an opening in the engine room wall, a "blower" or "pusher" radiator fan is usually used. In any event, consideration should be given to the direction of prevailing winds. If wind direction is changeable, an air duct should be provided outside the wall to direct the air inlet or outlet, as the case may be, in a vertical direction, using a large radius "L" in the duct to avoid air turbulance or restricted flow. Horizontal, remotely mounted radiators using vertical air flow are often used to nullify the effect of changing wind direction. Such radiators are often used in Total Energy plants to dissipate all or part of the rejected engine heat during periods when there is little or no demand for heat by the facility being served.

Radiators should be sized to accommodate the necessary air flow required at the given altitude. At altitudes above sea level, increased air flow in CFM is usually required in order to maintain the equivalent weight of air per unit of time required at sea level. Also, as is the practice for sizing all types of cooling systems, radiators should be sized to accommodate a heat rejection load at least 10 percent greater than the established heat rejection of the engine. The additional 10 percent is intended to compensate for possible variations from published or calculated heat rejection rates, overloads, or engine malfunctions which might increase the heat rejection rate momentarily. It is not intended to replace all factors which affect heat transfer when calculating the heat transfer area required for selecting the proper tube material.

Radiator fan noise should be given adequate consideration when locating the air inlet or outlet. When remote mounted radiators are used, such as roof mounted units, if the static head resulting from the elevated location causes excessive pressure on the engine jacket or jacket water circulating pump, (25 PSIG or more) a heat exchanger (shell and tube type) should be used in conjunction with the radiator, using the radiator coolant as the "raw" water circuit. This requires an additional pump for circulating the raw water coolant. This will also require an expansion tank in the jacket water circuit. Temperature of the jacket water circuit should always be thermostatically controlled to maintain a minimum inlet temperature of 180° F. with maximum change of temperature across the engine block of 20° F. When remote mounted radiators are used, automatic make-up water control or a low water level alarm is usually desirable. If the system requires two circuits, (raw water and jacket water) each should be equipped with water level controls or alarms. High temperature (jacket water) safety shut down controls should always be used.

HEAT EXCHANGER: SELECTION AND LOCATION (SHELL AND TUBE)

As with radiators, heat exchangers should be sized to accommodate a heat rejection rate approximately 10 percent greater than the established engine heat rejection.

The selected heat exchanger should accommodate raw water temperature and flow adequate to cool the engine when operating at maximum anticipated load, with the temperature differential between jacket water in and out of the heat exchanger not exceeding approximately 20° F. and not less than 10° F. Temperature of coolant entering engine should not be below the usually recommended 180° F.

Heat exchangers should always be located at a lower level than the coolant level in the surge tank, preferably several feet lower. The surge or expansion tank must be the highest level in the circuit, and must be located down-stream from the heat exchanger. (A heat exchanger system requires a surge tank in the jacket coolant circuit). When the engine is mounted on spring type vibration isolators, it is good practice to install the heat exchanger on the floor near the engine, or at some location free of vibration. This will require flexible fittings in the coolant circuit to the engine.

JACKET WATER FLOW

When selecting a heat exchanger, or pump, for engine jacket water, the jacket water flow for a given engine can be calculated by using the following equation, which assumes a 15° F. temperature differential between "jacket water in" and "jacket water out":

$$\text{Flow (GPM)} = \frac{\text{Max. Rejected Heat (BTU/min.)} + 10\%}{15^\circ \text{ F.} \times 8.33 \text{ lb.}}$$

As a safety factor, the equation provides flow to accommodate 10% more heat rejection than would be normally expected under maximum operating conditions. This equation does not apply for ebullient cooling.

AUXILIARY WATER REQUIREMENTS

All cooling systems utilizing jacket water temperatures above 220° F. require a cooling water circuit for the oil cooler separate from the jacket water circuit. This is illustrated in Figures 5 through 8. Also, all turbocharged and aftercooled gas engines, regardless of cooling system temperature, require a separate cooling circuit for the aftercooler.

AFTERCOOLER AND OIL COOLER (TURBOCHARGED GAS ENGINES)

On turbocharged-aftercooled natural gas engine arrangements for high temperature water or ebullient cooling, the aftercooler and oil cooler are connected in series on the G398 and G379 and in parallel on the G353 and G342. A good clean source of treated water should be used. The water circuit provided for this service is orificed to provide the recommended water flows, as listed in Table 7. In the event that a pump other than the one normally furnished with the engine is to be used for this circuit, the pressure drop across the aftercooler and oil cooler must be considered when determining the flow resistance or head. The total pressure drop across the aftercooler and oil cooler is as indicated in Table 7.

TABLE 7

AUXILIARY WATER FLOW REQUIREMENTS FOR EBULLIENT COOLED TURBOCHARGED GAS ENGINES

Engine Model	Water Flow (GPM) (Aftercooler & Oil Cooler) Min.	Max.	Approximate Pressure Drop at Max. Flow PSIG
G399	80	130 @ 90° F.	3
G398	80	130 @ 90° F.	3
G379	80	130 @ 90° F.	3
G353	80	100 @ 90° F.	2
G342	70	90 @ 85° F.	2

Cat ebullient cooled gas engines are equipped with thermal bypass oil cooler circuits which maintain the lubricating oil temperature at 180° F. ± 5° F. (190° ± 5° F. in the G342) to the engine bearings. This system bypasses oil around the cooler when the engine is cold.

OIL COOLER ONLY
(Naturally Aspirated Gas Engines)

Naturally aspirated gas engines when used with high temperature cooling systems require a separate cooling circuit for the oil cooler; however, since there is no aftercooler in the circuit the maximum cooling water temperature (oil cooler circuit) may be as high as 160° F. as opposed to 90° F. for turbocharged engines. Flow and temperature data are listed in Table 8.

TABLE 8

WATER FLOW REQUIRED FOR OIL COOLERS ONLY FOR NATURALLY ASPIRATED GAS ENGINES

Engine Model	Raw Water Flow (GPM) Min.	Max.	Max. Cooling Water Temp. °F.	Approximate Pressure Drop at Max. Flow
G399	65	190	160° F.	2 PSIG
G398	65	190	160° F.	2 PSIG
G379	65	190	160° F.	2 PSIG
G353	30	60	150° F.	1.5 PSIG
G342	40	60	140° F.	1.5 PSIG

The minimum water flow is based upon providing a sufficient tube velocity in the oil cooler to prevent tube fouling and to provide adequate cooling capacity. The maximum water flow is based upon a tube velocity which will normally not cause tube erosion in the oil cooler.

The water flow rates for oil coolers obviously are quite high considering the relatively small amount of heat to be removed (approx. 5.5 BTU/min./hp), thus the water temperature rise across the oil cooler will be quite low. For example: A G398 using the minimum flow of 65 GPM (Table 8) and operating with a 400 hp load would develop a temperature rise of only 4° F. [$\Delta T = (400 \times 5.5) \div (65 \times 8.33) = 4.05°$ F.]

For applications where the oil cooler is not in the jacket water circuit or in series with an aftercooler on a gas engine, it is often practical and convenient to use water from a storage tank for this cooling circuit. In such an event, the water is simply pumped from the storage tank, through the oil cooler, and returned to the tank, using another circuit with a much lower flow rate to remove excess heat from the storage tank in the event that the temperature exceeds 160° F.

EBULLIENT COOLING

Ebullient cooling entails a few design requirements that are peculiar to this type of cooling. The steam separator, load balancing condenser, and condensate return system become an integrated part of the engine cooling circuit, and the engine depends upon these units to remove the heat as it would a radiator or heat exchanger in a conventional cooling system.

The engine, of course, should be equipped as an ebullient cooled arrangement with no water pump in the jacket system, proper provision for oil cooling, and proper coolant piping. The steam separator (not a part of the engine arrangement) should include gauges and safety valves to limit pressure and temperature to 15 psi and 250° F. The separator should have mounted on it a high water alarm, a low level alarm, and a low water shutdown along with a pressure regulating valve to maintain a minimum steam pressure in the separator when the down-stream system pressure drops below a given value. This latter item is of vital importance and is necessary to prevent "flashing" within the engine. The usual practice is to select a valve that closes at a pressure approximately 3 PSIG below the design operating pressure. See Figures 7 and 8 for illustration of valve location. The steam separator should also include a modulating liquid level control, water gauge glass, and a vacuum breaker to relieve the vacuum created when the plant is shut down. The low water shut down level should be a minimum of 3 feet above the highest water level in the engine. The height of the steam separator above the engine, however, should be limited to not more than 10 feet, when using 15 PSIG steam, in order to limit the total pressure on the engine jacket to approximately 20 PSIG. Also long pipe runs increases the friction head and reduces coolant flow.

COOLANT FLOW, ENGINE (Ebullient Cooling)

The flow of coolant through an ebullient cooled engine (with no pump) will normally be approximately 25 lb. of coolant per pound of steam produced. All coolant piping to and from the engine should be sized accordingly and long runs between the engine and steam separator should be avoided.

PIPING AND CONNECTIONS

A steel "bellows" type expansion joint, or equal, should be used for the connection between the engine coolant outlet and the piping leading to the steam separator. The expansion joints should be adequate to compensate for dimensional changes in the respective piping systems caused by temperature as well as providing vibration isolation between the engine and all connected systems. Rubber hose should never be used.

The best rule for design and installation is to never use a pipe size smaller than the engine fitting to which it is to be connected. The 3" inlet connection on the G398 is intended to be connected to a 3-inch pipe to insure proper operation of the engine. The jacket system pipe sizes provided with Cat ebullient cooled engine arrangements are given in Table 9.

TABLE 9

PIPE SIZES FOR
CAT EBULLIENT COOLED ENGINES

Engine Model	Outlet Connections Std. 150 lb. Flange	Inlet Connections Std. Pipe Thread
G399	Two 4"	One 3"
G398	Two 4"	One 3"
G379	Two 4"	One 3"
G353	One 4"	One 2½"
G342	One 3"	One 2"

These sizes are provided to limit the water velocity to approximately 5 ft./sec. or less. Figure 10 can be used to determine the water velocity in standard pipe sizes, or to determine the pipe size required when the flow and velocity are known.

WATER VELOCITY NOMOGRAPH (Figure 10)

When sizing pipes for engine cooling systems, the water velocity should be limited to a maximum 5 feet per second. To determine the water velocity, the rate of flow and pipe size is required and as with most nomographs, any two of the variables will yield the third.

Example 1

Determine the velocity of water if it is flowing through a standard pipe with an internal diameter of 2.067 inches (nominal size 2 inches) and with a rate of 500 lbs. per minute. Extend a line from 500 on the flow scale, lb. per minute, to 2.067 on the internal diameter scale and read 5.70 feet per second at the intersection with the velocity scale.

Example 2

Find the velocity of water flowing at the rate of 400 gpm through a standard 6 inch internal diameter pipe. Extend a line from 400 on the flow, gpm scale to 6 inches on the internal diameter scale and read 4.4 feet per second at the intersection with the velocity scale.

'FIG. 10

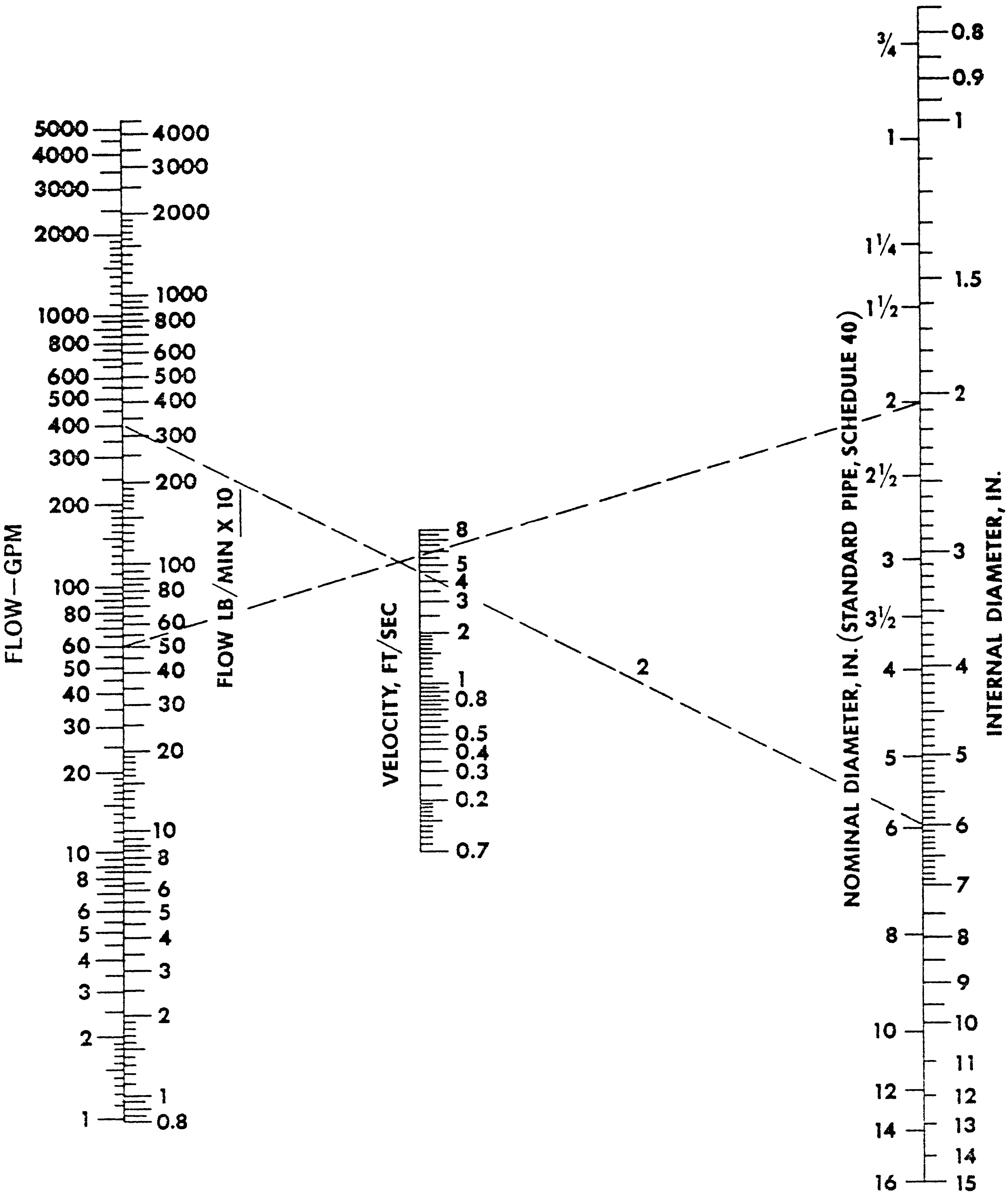


Chart Courtesy of Power Magazine

JACKET WATER TREATMENT

Only soft water treated with a suitable inhibitor should be used in the jacket water system. Make-up water should also be treated. Consult a reputable water treatment specialist in the area for a recommendation. The degree of acidity or alkalinity of the coolant should be maintained at a pH value of 6.5 to 8. A latent heat of vaporization greater than 90 percent of the latent heat of vaporization of water is required. To maintain the proper level of treatment, check the coolant weekly, or more often, using methods described in the ASTM Manual on Industrial Water.

LOAD BALANCING HEAT EXCHANGERS

Load balancing condensers are required for heat recovery systems which produce steam and load balancing heat exchangers for systems using high temperature water. In either case the load balancing unit, or units, must be sized to accommodate the maximum heat rejection from the engine, or engines, in order to assure adequate engine cooling during periods when the demand for heat is low or nonexistent.

CONDENSATE TANKS AND PUMPS

The tank should be sized to provide adequate make-up water when the plant is operating at full capacity. The time required for the steam to pass completely through the system and return must also be taken into account. Any condensate tank make-up water should be treated before being added to the tank.

The condensate pump should be sized about three times the evaporative rate of the heat recovery units. If a boiler is included in the system, an amount of 1-1/2 times the boiler evaporative rate should be added to the pump's capacity. Pressure should be calculated with wide open level controller at full flow.

Centrifugal pumps are recommended. They are generally long lasting, jam proof, non-overloading and inexpensive. The pump should run continuously and a standby pump should always be in series with the prime condensate pump. In steam systems, a sub cooler may be required to assure that the return to the condensate tank is solid water.

ENGINE EXHAUST SYSTEMS

A good exhaust system should (1) reduce the noise to an acceptable level as determined by the demands of the area in which the engine must operate; (2) should not impose a back pressure upon the engine of more than 25 in. H_2O for naturally aspirated engines and not more than 20 in. H_2O for turbocharged units, measured at the engine exhaust manifold outlet or turbocharger outlet if turbocharged; (3) should discharge the exhaust at a point not harmful or annoying to people or industry in the vicinity; and, (4) should dissipate a minimum amount of heat to the engine room.

It is good practice to locate the muffler as close to the engine as practical. A stainless steel "bellows" type flexible connection should be used at the engine exhaust manifold outlet. The weight of the piping system must be supported independently of the engine and should be so installed that the expansion and contraction of the pipe will not impose damaging forces upon either the engine or the muffler (see Figure 10).

When the exhaust system, for any reason, is likely to develop excessive back pressure, an induced draft fan should be used at or near the exhaust outlet. This might be necessary where engines are located in the basement of a multi-story building and the environment is such that the exhaust must be discharged at roof level. For such installations, the fan should be sized to reduce the back pressure to acceptable limits.

For naturally aspirated engines, even a small vacuum might be desirable (2 in. H_2O); however, for turbocharged engines, a vacuum is not desirable because of possible damage to turbocharger seals, and a small positive pressure should prevail.

Exhaust noises can be reduced somewhat at the point of discharge by cutting the end of the discharge pipe at an angle of approximately 60 degrees to the axis of the pipe.

If possible, a complete exhaust system, engine to atmosphere, should be provided for each engine. When several units discharge exhaust into a common header, exhaust gas will find its way into any non-operating engine; this will usually result in condensation of the water vapor formed by combustion. This not only deposits water in the piping system, but also, water collects inside the engines which are not in operation. Although a common exhaust system is not recommended, the damaging effects inherent with such a system can admittedly be reduced materially by employing some rather expensive precautions; namely, (1) install a suction fan at the system outlet, if necessary, to maintain system back pressure within the limits given previously and (2) install automatically operated cut off valves between each engine and the common header. Such valves should close automatically when the engine is not in operation and open automatically when the signal is received, to start the engine. Also, to protect the engine in the event of a valve malfunction (failure to open), an engine shut down or interlocking control should be applied for each engine, sensing either high back pressure or valve position.

When an exhaust heat recovery muffler or boiler is used, the same requirements for installation apply. In addition to providing support and the necessary flexible fitting, care should be taken to insure that the recovery unit is *never operated dry*. When a steam generating type is used, a modulated make-up water circuit is required to maintain a full water level in the muffler. Failure of the unit is inevitable when the muffler is allowed to operate either dry or partially filled.

Approximately 2.25 lb. of water are formed as a product of combustion for every 25 cu. ft. of natural gas burned. When gas is burned in an internal combustion engine, the water so formed is discharged with the exhaust gas in the form of steam. Thus, an engine producing 400 hp and using 3500 cu. ft. of fuel (natural gas) per hour will discharge approximately

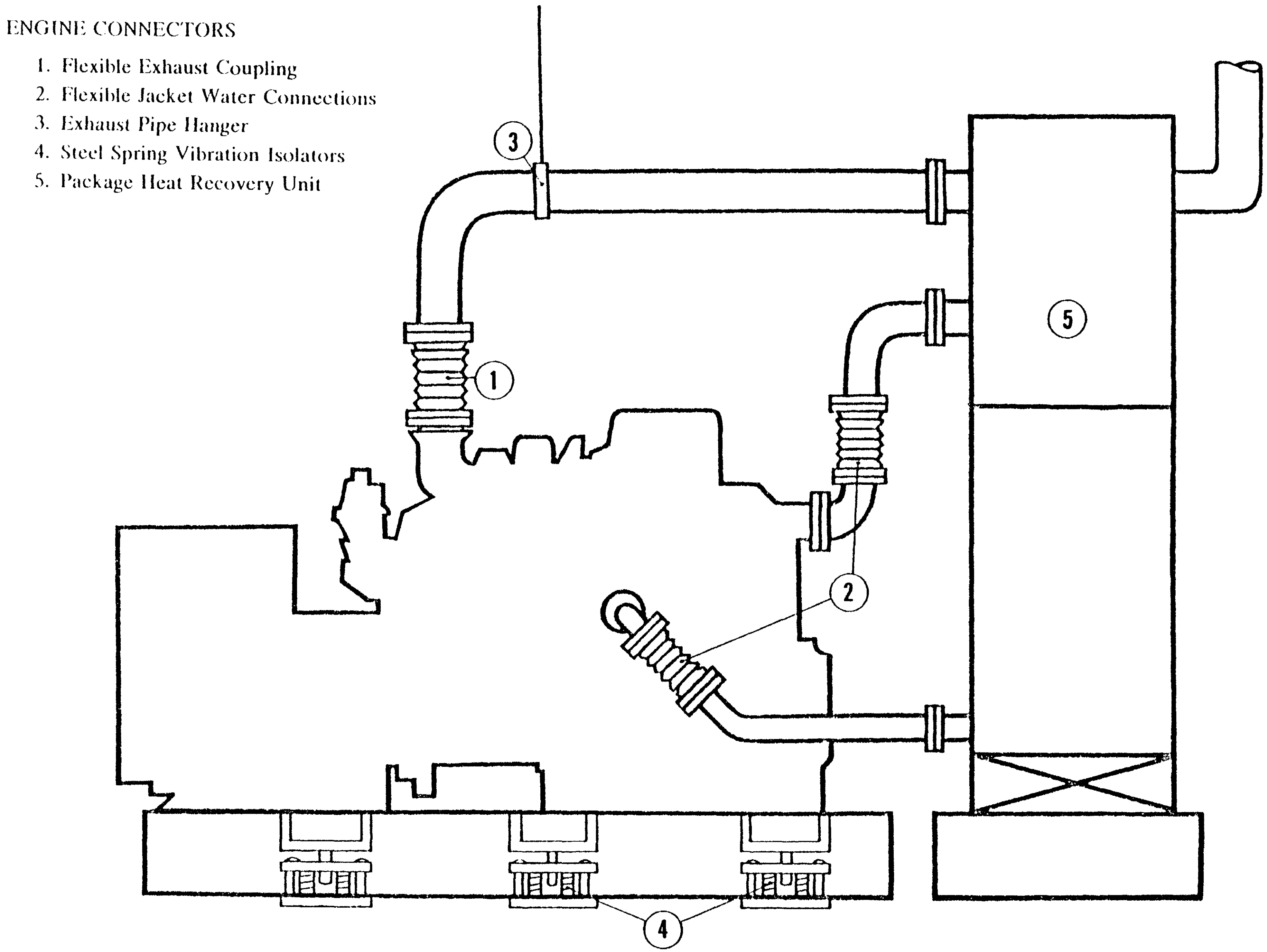


FIG. 11
ENGINE MOUNTING AND FLEXIBLE CONNECTIONS

300 lb. (36 gal.) of water per hour with the exhaust. Therefore, any exhaust piping system which may be of such extended length or which may be exposed to cool temperatures to the extent that the temperature of the exhaust gas may at times drop below the dew point of the water vapor in the exhaust gas, should be equipped with proper traps or drainage features to prevent the condensed water from draining back to the engine or muffler.

FOUNDATIONS AND ENGINE MOUNTING

Modern, multi-cylinder, medium speed engines do not require massive concrete foundations, although concrete often offers advantages in cost and in maintaining alignment for certain types of driven equipment. Fabricated steel bases have proved satisfactory for direct coupled, self-contained units such as electric sets. Steel bases mounted on vibration isolators (steel spring or equal) are completely adequate and need no special foundation other than a floor designed to accommodate the weight (see Figure 11).

Concrete bases are also satisfactory for such units provided such bases are equally well isolated from the supporting floor or sub-floor. Fiber glass blocks have proved quite effective as isolation material for concrete bases. Concrete bases need only be thick enough to prevent deflection. Excessively thick bases only serve to increase sub-floor or soil loading. Such bases should always be supported by a concrete sub-floor, using some type of acceptable isolation material between the base and sub-floor. An engine base or foundation should never rest directly upon natural rock formations if the transmission of vibration is to be avoided.

FUEL SUPPLY SYSTEMS

The prime function of a gaseous fuel supply system is to deliver clean gas to the engine carburetor at the required pressure and in an adequate volume to insure rated engine output, with a minimum of delay in response when the engine is subject to sudden load changes. All piping and accessories must comply with local codes when applicable.

An automatic shut-off valve should be placed in the fuel supply line to each engine; it should be located as close to the engine as practical but so located that the line upstream from the cut-off valve will not be exposed to danger of damage in the event of equipment failure. It is also advisable, and required by some codes, to place a manually operated cut-off valve in the gas line upstream from any automatic shut-off valves in the system. A flexible connection should be placed in the fuel line at some point between the cut-off valve nearest the engine and the engine mounted regulator. A cleanable strainer (wire mesh type or equivalent) should be placed in the fuel supply line to each engine, located upstream from the regulator.

When two gaseous fuels of different heat values are to be used alternately through the same carburetor, two sets of regulators and fuel supply lines must be provided, one for each fuel.

GAS PRESSURE

Naturally-aspirated Engines: Cat naturally-aspirated gas engines require gas pressure in the range of 5-1/2 inches of water, or 3-1/2 oz. gauge, at the carburetor when operating at sea level and at rated output using natural gas with a high heat value of 1000 BTU/cu. ft. The exact pressure required at the carburetor varies with the heat value of the fuel. Fuels with a high heat value less than 1000 BTU/cu. ft. will require slightly higher pressure. Precise gas pressure regulation within ±1/2 inch of water to the carburetor from no load to full load is essential for best performance and fuel economy. Thus, a pressure regulator should always be used and should be located in close proximity of the carburetor (within 1 to 3 ft.). For good engine response to sudden load changes, gas pressure to the regulator should be not less than one PSIG. Since specifications for the regulator(s) will be dictated by the gas "line" pressure available, the heat value of the fuel, and to some degree, the type of load, either specific recommendations should be obtained from the engine manufacturer or the engine specifications should call for the engine to be equipped with a regulator or regulators suitable for a specified set of prevailing conditions with regard to fuel supply pressure, heat value, type load, etc.

Turbocharged engines: Caterpillar turbocharged natural gas engines are equipped with the necessary regulators to accept gas pressures up to approximately 25 PSIG. Turbocharged engines require gas pressure of approximately 10 PSIG minimum at sea level for loads not requiring precise engine governing and 12 PSIG minimum for electric power generation or service requiring quick engine response. Higher line pressure assures better response. Also, since engine intake manifold pressure must increase with altitude for these engines, gas supply pressure must likewise increase with altitude if sea level performance is to be maintained. The minimum gas pressures of 10 and 12 PSIG respectively must, therefore, be increased by an amount equal to the loss in barometric pressure due to altitude.

DIESEL FUEL SYSTEMS

A diesel engine fuel system should include an auxiliary "day tank" in or near the engine room to provide an immediate supply of fuel to the engine driven transfer pump. The auxiliary tank voids the need for lengthy return lines and permits the location of venting, fuel shut-offs, and strainers to be accessible to the operator. The size of the day tank will vary according to the number and size of engines being served by it; however, it is good practice to provide sufficient capacity in this tank to operate the plant for at least one hour, provided storage of this quantity of fuel within the engine room does not violate local codes.

Fuel transfer from the main storage tank to the day tank is usually accomplished by use of an electrically driven pump, controlled by a float actuated switch at the day tank to maintain the proper fuel level in the day tank.

For Cat diesels the day tank should preferably be located sufficiently above the engine fuel transfer pump to provide gravity flow to the engine.

LUBRICATING OIL SYSTEM

The lubricating oil supply system beyond the engine should provide storage for "make-up" oil in quantities proportionate to the demands of the engines. The supply tank should be sized to accommodate a minimum of 30 days of operation without refilling. If possible, the oil supply tank should be so located with reference to the engine that oil will flow by gravity to the engine. It should be conveniently accessible for refilling and, in cold climates, should be in a heated building. An automatic oil level control should be applied to each engine to provide automatic addition of make-up oil as required.

In multiple engine installations the economics quite often justify installing a piping system to facilitate the lubrication oil changes. A line to drain the oil and a second line to provide new oil from a common supply would greatly reduce maintenance time for large installations.

ENGINE ROOM VENTILATION

Approximately 6 to 8 percent of the fuel consumed by the average internal combustion engine is dissipated to the surrounding air by radiation. Removal of this heat is an absolute necessity, and is usually accomplished by the use of induced draft or ventilating fans.

Air should be removed from the immediate vicinity of each engine in a manner that will insure an upward flow of air around each engine at all times. The ventilating system should further provide sufficient air distribution and removal to prevent excessive temperatures in any part of the engine room.

In applications where the engine room noises must be contained within the engine room, the ventilating air should be supplied to, and removed from, the engine room through sound insulated air ducts with properly located inlets and outlets to insure a minimum of noise transmittal. The use of louvered openings in the engine room wall for ventilating air inlets or outlets is, generally speaking, not satisfactory when noise must be contained.

To correctly size the engine room ventilating fan, or fans, the following equation will provide a quick determination of the amount of air required:

$$CFM = \frac{400 \times hp}{\Delta T}$$

where HP is equal to the maximum engine horsepower and Δ T is equal to the desired temperature rise in the engine room above ambient. The result, expressed in CFM, should be increased 10 percent for every 2,500 ft. altitude increment above sea level.

It should be recognized that in cold weather the desired temperature rise in the engine room may be as much as 80° F. instead of the usual 10° F. or 20° F. rise when, for instance, the ambient air is at −10° F. In such a case, theoretically, only 1/8 of the ventilating air is required and, hence, it is good practice to use a number of smaller fans rather than one large unit. This also permits correct ventilation at reduced plant output.

COMBUSTION AIR

An ample supply of cool, clean air is equally as essential for good engine performance as an adequate supply of fuel. The cooler the air, the higher the potential output; thus, while not absolutely necessary for well ventilated engine rooms, it is always good practice to extend the air intake piping from the engine air cleaners to a suitable outside point, exercising care in locating the air inlet to avoid contaminants such as engine exhaust, process fumes, dust, etc. As a rule, the air cleaner should remain attached to the engine where it can be serviced with convenience. Restriction in the intake piping to the air cleaner should not exceed three inches of water when the engine is operating at rated output. The air flow required for gas engines can be calculated by multiplying the fuel consumption (in cfm) by ten since the air-fuel ratio remains essentially constant at 9.5:1 to 10:1.

SOUND ISOLATION

Rotating machinery generates noise which usually should be contained within the equipment room. Good practice dictates the provision of a complete enclosure for the engine room.

Eight or ten inch concrete block filled with sand or poured concrete walls and concrete ceiling will reduce the sound pressure level beyond the engine room to acceptable levels for most facilities. Further reduction in sound pressure level within the engine room may be had by insulating the engine room walls and ceiling with a layer of fiber glass or equal, covered with a perforated wall board.

SPACE FOR ENGINE MAINTENANCE AND SERVICE

Floor space between an engine and a parallel wall or between engines should not be less than the width of the given engine. Overhead space, i.e., space between the top of the engine and the nearest obstruction or ceiling, should be adequate to permit convenient removal of cylinder heads, manifolds, exhaust piping, etc., when such components must be removed for service. For larger engines, provisions should be made to permit the use of a chain hoist or overhead crane to remove the heavier components.

Space between either end of the engine and the nearest wall or other obstruction should be adequate to permit removal of certain components or parts such as camshafts, which may have to be "pulled" from one end of the engine.

When installing package type heat recovery units, ample space should be provided between the engine and recovery unit to allow maintenance on the engine or the recovery unit.

CONTROL AND SAFETY DEVICES

See Table 6 and section on switchgear.

LOCATION AND PROTECTION OF SWITCHGEAR

It is always desirable to provide a separate enclosure or room for all switchgear and control panels which can be located remotely from the engines and other equipment. Such a room usually consists of an enclosure within the equipment or engine room, isolated and insulated against equipment room noise and affording a window for visual observation of the equipment. The room should be well ventilated or air conditioned to protect the switchgear from engine room heat, miscellaneous vapors, etc.

LOAD ANALYSIS

A load analysis for a plant or facility to be complete must encompass a study of the energy requirements for each of the three major services, namely: air conditioning; heating; and electric power and lighting. Complete treatment of all three areas obviously is beyond the scope of this publication; however, much of the basic data employed when making an analysis of the electric load can be assembled and presented in a limited space. The material offered on the pages that follow is an attempt to provide some of the more useful of such data for the convenience and use of those engaged in the preparation of load analyses and economic studies for on-site power applications.

THE ELECTRIC LOAD

The first step in making an analysis of the electric load is to develop and plot a family of load profile charts. A minimum would consist of one chart for a representative 24-hour period and one for a representative 12-month period. The 24-hour chart should reflect the average kilowatt load for each hour, or in some instances each half hour, while the 12-month chart should represent the average KW load for each month. In some instances an additional set of charts should be made to reflect the possible increase in power consumption and demand resulting from anticipated growth.

The development of load profile charts is equally essential and useful whether they apply to existing loads or to proposed loads for facilities not yet constructed — only the method of development differs. Such charts provide a basis for the selection of power generating equipment as well as data for feasibility and economic studies.

For existing loads which are being served by an electric utility company or a similar source of power, either power bills or power consumption records for a representative 12-month period will provide most of the data needed for a 12-month average load profile. The average KW load for each month can be determined by dividing the total kilowatt hours used during the month, by the total number of hours of operation during that month.

Ave. KWH Load = total KWH used ÷ Total Hr. of operation

The average kilowatt load will always be lower than the maximum kilowatt demand of the plant. Therefore, the average load as determined above cannot be used without reservation to establish the engine and generator requirements, unless the load is known to be steady, such as a single air conditioning unit or pump to be operated by the generator. However, when the average monthly kilowatt load is determined for any month, it can be plotted on a bar graph similar to Fig. 12. This, when completed for a year, can illustrate seasonal variation in load and help in the selection of a proper size and number of electric sets.

Most power bills show a demand charge. However, unless the bill clearly points out how this figure is determined, it is not advisable to use it. Some bills will give the maximum KW demand. This figure is usually the highest 15- or 30-minute average demand during the month, and does not show momentary peak KW demands which may be caused by starting large motors and certain other equipment. *The average demand is the normal load on the electric set.* Because the generator has a momentary overload capacity, it is capable of absorbing the peak demand provided it does not exceed its momentary overload capacity. However, the generator must be sufficiently large to continuously supply the power necessary for the average demand.

Acquiring load data from existing plants is a relatively simple operation. Developing similar data, however, for a plant or facility not yet constructed is quite another operation. Most load analyses associated with on-site power generation will be in the latter category. The data available from existing facilities provides a most important source of information for use when estimating loads and power consumption for new facilities. A limited amount of these data are given in Table 10. While the figures given are admittedly average and subject to some variation in different geographic locations because of climate and difference in individual operating conditions, they are quite reliable and are particularly useful for making preliminary or exploratory feasibility and economic studies of proposed installations.

TABLE 10

Load and Power Consumption Estimating Data

	Watts/Square Foot	Power Usage KWH/Sq.Ft./Year
Schools	4-5 average (Total)	11 to 17
Class Rooms	5-6	
Locker Rooms, Auditoriums	2-3	
Halls and Corridors	20 Watts per running foot	
Shopping Centers	5 average (Total)	28 to 34
Stores, Large Department and Specialty Stores	5-6	
Show Windows	500 Watts per running foot	
Office Buildings	5-6 average	28 to 34
Private and General Offices	4	
Professional Offices	6-7	
Dentist, Drafting Rooms, etc.	7	
Hotels and Motels	3-4 average (Total)	12 to 17
Lounge	2	
Rooms	3	
Dining Rooms	4	
Exhibition Halls, Shops, Lobby, Kitchen	3	
Hospitals	1.5 to 2.5 KW per bed average	8500 to 11400 KWH per bed/ per year
Lobby, Wards, Cafeterias	3 Watts/Sq. Ft.	
Private Rooms, Operating Rooms	5 Watts/Sq. Ft.	
Operating Tables — Major surgeries	3000 Watts each	
Operating Tables — Minor surgeries	1500 Watts each	
Apartment Houses	2-3 KW per unit (Total)	11 to 17
Lobby	2 Watts/Sq. Ft.	
Apartments	3 Watts/Sq. Ft.	
Small Appliances	1.5 KW/unit	

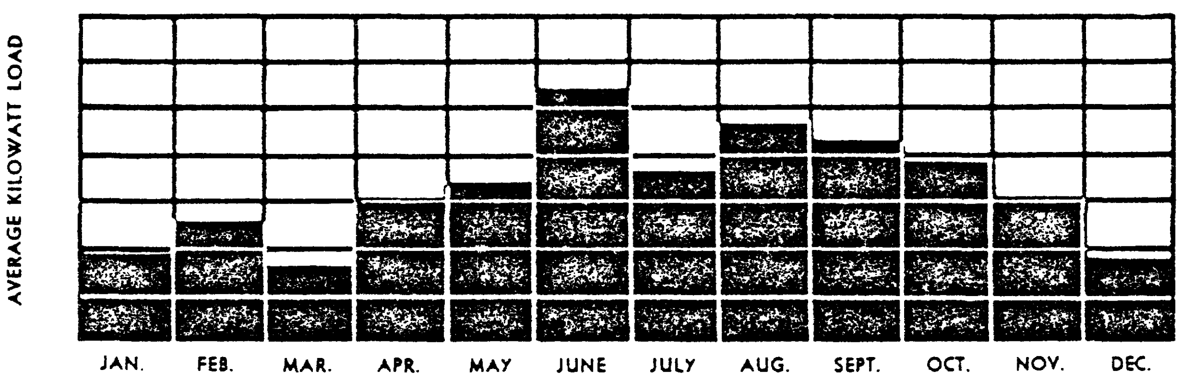


FIG. 12
Average monthly KW load curve showing seasonal variation

CONVERSION TABLES

WEIGHT EQUIVALENTS

Unit	Kilograms	Ounces Avoirdupois	Pounds Avoirdupois	Tons Short	Tons Long	Tons Metric
1 Kilogram	1	35.27	2.205	—	—	—
1 Ounce	0.02835	1	0.0625	—	—	—
1 Pound	0.4536	16	1	—	—	—
1 Short Ton	907.2	32000	2000	1	0.8929	0.9072
1 Long Ton	1016	35840	2240	1.12	1	1.016
1 Metric Ton	1000	35274	2205	1.102	0.9842	1

LENGTH EQUIVALENTS

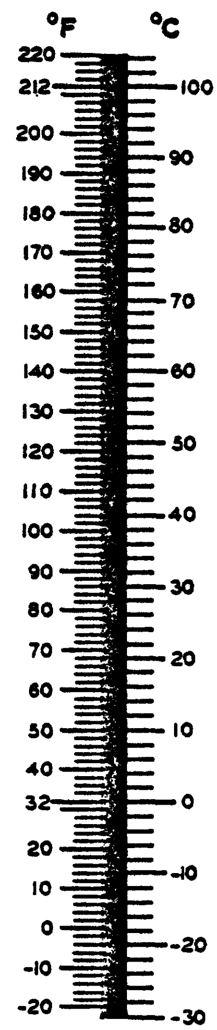
Unit	Centimeters	Inches	Feet	Yards	Meters	Kilometers	Miles
1 Centimeter	1	0.3937	0.03281	0.01094	0.01	—	—
1 Inch	2.540	1	0.08333	0.02778	0.0254	—	—
1 Foot	30.48	12	1	0.3333	0.3048	—	—
1 Yard	91.44	36	3	1	0.9144	—	—
1 Meter	100	39.37	3.281	1.0936	1	—	—

Inches to Centimeters and Centimeters to Inches

Inches or Centimeters	Inches	Centimeters
1	0.39	2.54
2	0.79	5.08
3	1.18	7.62
4	1.57	10.16
5	1.97	12.70
6	2.36	15.24
7	2.76	17.78
8	3.15	20.32
9	3.54	22.86
10	3.94	25.40
11	4.33	27.94
12	4.72	30.48
13	5.12	33.02
14	5.51	35.56
15	5.91	38.10
16	6.30	40.64
17	6.69	43.18
18	7.09	45.72
19	7.48	48.26
20	7.87	50.80
21	8.27	53.34
22	8.66	55.88
23	9.06	58.42
24	9.45	60.96
25	9.84	63.50
26	10.24	66.04
27	10.63	68.58
28	11.02	71.12
29	11.42	73.66
30	11.81	76.20
31	12.20	78.74
32	12.60	81.28
33	12.99	83.82
34	13.39	86.36
35	13.78	88.90
36	14.17	91.44
37	14.57	93.98
38	14.96	96.52
39	15.35	99.06
40	15.75	101.60
41	16.14	104.14
42	16.54	106.68
43	16.93	109.22
44	17.32	111.76
45	17.72	114.30
46	18.11	116.84
47	18.50	119.38
48	18.90	121.92
49	19.29	124.46
50	19.69	127.00

How to use:
11 inches = 27.94 centimeters
11 centimeters = 4.33 inches

TEMPERATURE CONVERSION



$$\text{Temp. °F} = \frac{9}{5} \times (\text{Temp. °C}) + 32°$$

$$\text{Temp. °C.} = \frac{5}{9} \times (\text{Temp. °F} - 32°)$$

Absolute Temp. (Centigrade) = °C + 273°
Absolute Temp. (Fahrenheit) = °F + 459°

AREA EQUIVALENTS

Unit	Sq. Cm.	Sq. In.	Sq. M.	Sq. Ft.
1 Sq. Cm.	1	0.155		
1 Sq. In.	6.4516	1	.00064516	.006944
1 Sq. M.	10.000	1550	1	10.764
1 Sq. Ft.	929	144	0.0929	1

CONVERSION TABLES

VOLUME AND CAPACITY EQUIVALENTS

Unit	Cu. In.	Cu. Ft.	Cu. Yd.	Cu. Cm.	Cu. M.	U.S. Liquid Gallons	Imperial Gallons	Liters
1 Cu. In.	1	.000579	.0000214	16.39	.0000164	.004329	.00359	.0164
1 Cu. Ft.	1728	1	.03704	28317	.0283	7.481	6.23	28.32
1 Cu. Yd.	46656	27	1	764600	.765	202	167.9	764.6
1 Cu. Cm.	.061	.0000353	.00000131	1	.000001	.000264	.00022	.001
1 Cu. M.	61020	35.31	1.308	1,000,000	1	264.2	220.2	1000
1 U. S. Liquid Gal.	231	.1337	.00495	3785	.003785	1	.833	3.785
1 Imperial Gallon	277.42	.16	.00594	4545.6	.004546	1.2	1	4.546
1 Liter	61.02	.03531	.001308	1000	.001	.2642	.22	1

UNITS OF FLOW

Cubic foot per second, also written second-foot, is the unit of flow in the English system used to express rate of flow in large pumps, ditches, and canals. Flow in pipe lines, from pumps and wells is commonly measured in gallons per minute.

Rates of water consumption and measurement of municipal water supply are ordinarily made in million gallons per day. The Miner's Inch is still used in some localities for irrigation and hydraulic mining, but is not suitable for general use.

Units	U.S. Gallons per Minute	Million U.S. Gallons per Day	Cubic Feet per Second	Cubic Meters per Hour	Liter per Second
1 U. S. Gallon per Minute (U. S. G.P.M.)	1	.001440	.00223	.2270	.0631
1 Million U. S. Gal. per Day (M. G. D.)	694.5	1	1.547	157.73	43.8
1 Cubic Foot per Second	448.8	.646	1	101.9	28.32
1 Cubic Meter per Hour	4.403	.00634	.00981	1	.2778
1 Liter per Second	15.85	.0228	.0353	3.60	1

UNITS OF PRESSURE AND HEAD

For measuring pressure the common unit is the pound per square inch.

For measuring head and pumping lift, the most common unit is a vertical foot of liquid. It is the pressure exerted by the liquid through a vertical distance of one foot at atmospheric pressure. To convert head of liquid to pounds per square inch multiply the head in feet by the equivalent pressure for one foot of water (0.433) multiplied by the specific gravity of liquid.

Unit	Lb. per Sq. Inch	Feet of Water	Meters of Water	Inches of Mercury	Atmospheres	Kilograms per Sq. Cm.
1 Lb. per Square Inch	1	2.31	.704	2.04	.0681	.0703
1 Foot of Water*	.433	1	.305	.882	.02947	.0305
1 Meter of Water*	1.421	3.28	1.	2.89	.0967	.1
1 Inch of Mercury*	.491	1.134	.3456	1	.0334	.0345
1 Atmosphere (at sea level)	14.70	33.93	10.34	29.92	1	1.033
1 Kilogram per Sq. Cm.	14.22	32.8	10	28.96	.968	1

***Equivalent units are based on density at 32° to 62° F.**
Absolute pressure is the sum of the gauge pressure plus the atmospheric pressure, at the location under consideration.

CONVERSION TABLES

UNITS OF POWER

Mechanical power and ratings of motors and engines are expressed in Horsepower.
Electrical power is commonly expressed in watts or kilowatts.

Unit	Horsepower	Foot—Lb. per Minute	Watts	Kilowatts	Metric Horsepower	Btu. per Minute
1 Horsepower	1	33,000	746	.746	1.014	42.4
1 Foot-Lb. per Minute	—	1	.0226	—	—	.001285
1 Watt	.00134	44.2	1	.001	.00136	.0568
1 Kilowatt	1.341	44,250	1000	1	1.360	56.8
1 Metric Horsepower	.986	32,550	736	.736	1	41.8
1 Btu per Minute	.0236	778	17.6	.0176	.0239	1

MISCELLANEOUS EQUIVALENTS

1 Btu = Heat required to raise 1 lb. water 1°F. = 778 ft. lb. = .000292 KW-hr. = .252 KG.-cal. = .00039 HP-hr.

1 HP = 746 watts = 33,000 ft. lb. per min. = 550 ft. lb. per sec. = 42.4 Btu. per min. = 1.014 metric HP.

1 KW = 1000 watts = 1.341 HP = 3413 Btu. per hr.

1 HP-hr. = 2544 Btu.

POWER vs. TORQUE

$$HP = \frac{T \times N \times 2\pi}{33,000} = \frac{T \times N}{5252}$$

or

$$\text{Torque (T)} = \frac{5252 \times HP}{N}$$

where: N = RPM
T = Torque, in lb. ft.

SPEED vs. WHEEL DIA.

$$RPM = \frac{336.13 \times M.P.H.}{\text{Wheel Dia. (In.)}}$$

$$M.P.H. = \frac{RPM \times \text{Wheel Dia. (In.)}}{336.13}$$

BAROMETRIC PRESSURES AND BOILING POINTS OF WATER AT VARIOUS ALTITUDES

Altitude	Barometric Pressure			Point Water Boiling
	Inches Mercury	Lb. per Square Inch	Feet Water	
Sea Level	29.92 In.	14.69 P.S.I.	33.95 Ft.	212° F
1000 Ft.	28.86 In.	14.16 P.S.I.	32.60 Ft.	210.1° F
2000 Ft.	27.82 In.	13.66 P.S.I.	31.42 Ft.	208.3° F
3000 Ft.	26.81 In.	13.16 P.S.I.	30.28 Ft.	206.5° F
4000 Ft.	25.84 In.	12.68 P.S.I.	29.20 Ft.	204.6° F
5000 Ft.	24.89 In.	12.22 P.S.I.	28.10 Ft.	202.8° F
6000 Ft.	23.98 In.	11.77 P.S.I.	27.08 Ft.	201.0° F
7000 Ft.	23.09 In.	11.33 P.S.I.	26.08 Ft.	199.3° F
8000 Ft.	22.22 In.	10.91 P.S.I.	25.10 Ft.	197.4° F
9000 Ft.	21.38 In.	10.50 P.S.I.	24.15 Ft.	195.7° F
10000 Ft.	20.58 In.	10.10 P.S.I.	23.25 Ft.	194.0° F
11000 Ft.	19.75 In.	9.71 P.S.I.	22.30 Ft.	192.0° F
12000 Ft.	19.03 In.	9.34 P.S.I.	21.48 Ft.	190.5° F
13000 Ft.	18.29 In.	8.97 P.S.I.	20.65 Ft.	188.8° F
14000 Ft.	17.57 In.	8.62 P.S.I.	19.84 Ft.	187.1° F
15000 Ft.	16.88 In.	8.28 P.S.I.	18.07 Ft.	185.4° F

DECIMAL AND METRIC EQUIVALENTS OF COMMON FRACTIONS

Fractions of an Inch	Decimals of an Inch	Millimeters	Fractions of an Inch	Decimals of an Inch	Millimeters
1/64	0.015625	0.397	33/64	0.515625	13.097
1/32	0.03125	0.794	17/32	0.53125	13.494
3/64	0.046875	1.191	35/64	0.546875	13.891
1/16	0.0625	1.588	9/16	0.5625	14.288
5/64	0.078125	1.984	37/64	0.578125	14.684
3/32	0.09375	2.381	19/32	0.59375	15.081
7/64	0.109375	2.778	39/64	0.609375	15.478
1/8	0.125	3.175	5/8	0.625	15.875
9/64	0.140625	3.572	41/64	0.640625	16.272
5/32	0.15625	3.969	21/32	0.65625	16.669
11/64	0.171875	4.366	43/64	0.671875	17.066
3/16	0.1875	4.763	11/16	0.6875	17.463
13/64	0.203125	5.159	45/64	0.703125	17.859
7/32	0.21875	5.556	23/32	0.71875	18.256
15/64	0.234375	5.953	47/64	0.734375	18.653
1/4	0.250	6.350	3/4	0.750	19.050
17/64	0.265625	6.747	49/64	0.765625	19.447
9/32	0.28125	7.144	25/32	0.78125	19.844
19/64	0.296875	7.541	51/64	0.796875	20.241
5/16	0.3125	7.938	13/16	0.8125	20.638
21/64	0.328125	8.334	53/64	0.828125	21.034
11/32	0.34375	8.731	27/32	0.84375	21.431
23/64	0.359375	9.128	55/64	0.859375	21.828
3/8	0.375	9.525	7/8	0.875	22.225
25/64	0.390625	9.922	57/64	0.890625	22.622
13/32	0.40625	10.319	29/32	0.90625	23.019
27/64	0.421875	10.716	59/64	0.921875	23.416
7/16	0.4375	11.113	15/16	0.9375	23.813
29/64	0.453125	11.509	61/64	0.953125	24.209
15/32	0.46875	11.906	31/32	0.96875	24.606
31/64	0.484375	12.303	63/64	0.984375	25.003
1/2	0.500	12.700		1.000	25.400

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MARKETING DEPARTMENT
INDUSTRIAL DIVISION
CATERPILLAR TRACTOR CO.
PEORIA, ILLINOIS 61602

CATERPILLAR

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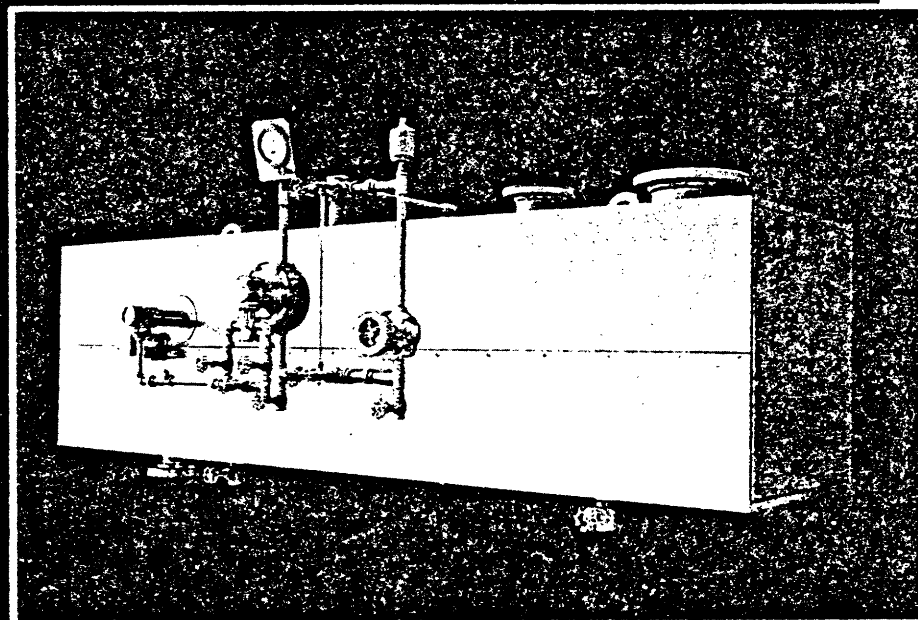
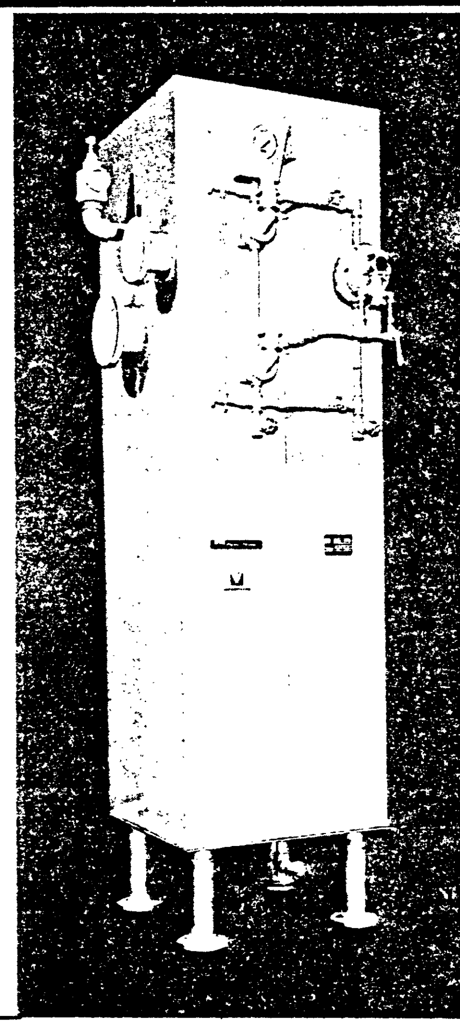
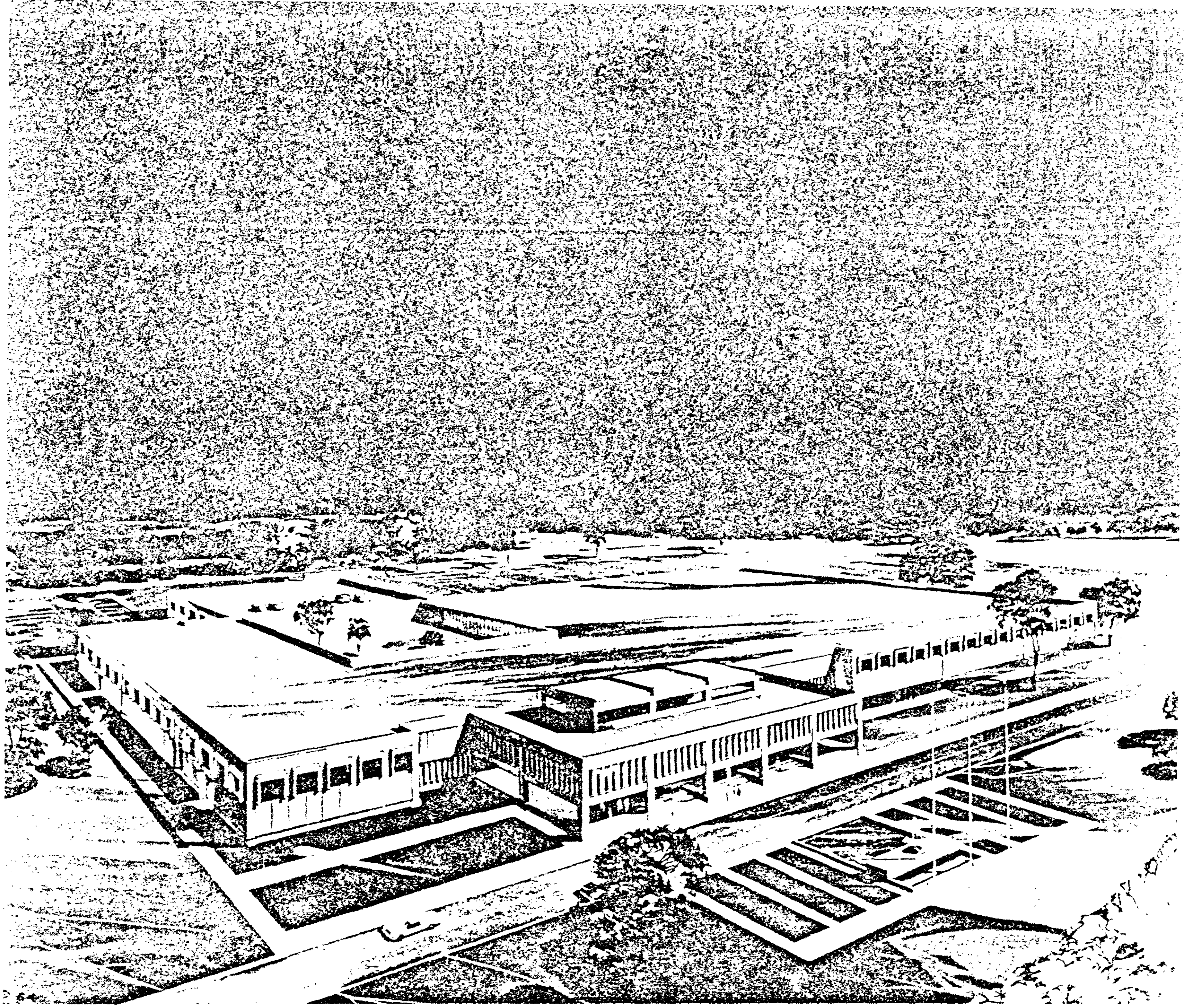
VAPORPHASE MODEL VP
PACKAGED HEAT RECOVERY SILENCER





VAPORPHASE
BY ENGINEERING CONTROLS
DIVISION OF POTT INDUSTRIES INC.
611 E. MARCEAU ST., ST. LOUIS, MO. 63111

...MENT CO.
SOUTH STREET – P. O. BOX 101
HOPKINTON, MASS. 01748



INTRODUCTION
THE WHAT AND WHY OF WASTE HEAT RECOVERY

One of the most important equipment components in an engine driven equipment installation, particularly Total Energy installations, is the Waste Heat Recovery System. This system must be designed to FIRST provide positive engine cooling and SECOND obtain maximum economical heat recovery while insuring reliability and longevity of equipment.

As a "rule of thumb," reciprocating engines are 30% efficient. That is, of the fuel energy input; 30% goes to shaft horsepower; 30% to jacket water heat; 30% to exhaust heat; and 10% to radiation, oil heat, and other losses.

One of the oldest and most successful forms of heat recovery employs VAPORPHASE (ebullient) cooling of the reciprocating engine. Ebullient cooling involves the natural circulation of the jacket water at or near saturation temperature and engine cooling is accomplished through utilization of the heat of vaporization. This is the simplest and least costly form of waste heat recovery. Some of the benefits of VAPORPHASE cooling are, elimination of the jacket water circulating pump, extended engine life due to uniform temperatures throughout the engine (normally 2-3° differential between inlet and outlet), recovered heat in the form of low pressure steam (up to 15 PSIG) and all of the heat rejected to the jacket water is recovered.

Today's Total Energy installations produce large amounts of steam for building heat, building cooling (absorption air conditioning), domestic hot water and various other uses. To provide as much steam as possible for these loads from the engine installation, the heat rejected to the exhaust is also recovered. Because exhaust temperature cannot be lowered to ambient air temperature, only a portion of this exhaust waste heat can be economically recovered. Systems wherein both jacket water and exhaust waste heat are recovered are yielding system efficiencies in excess of 75%.

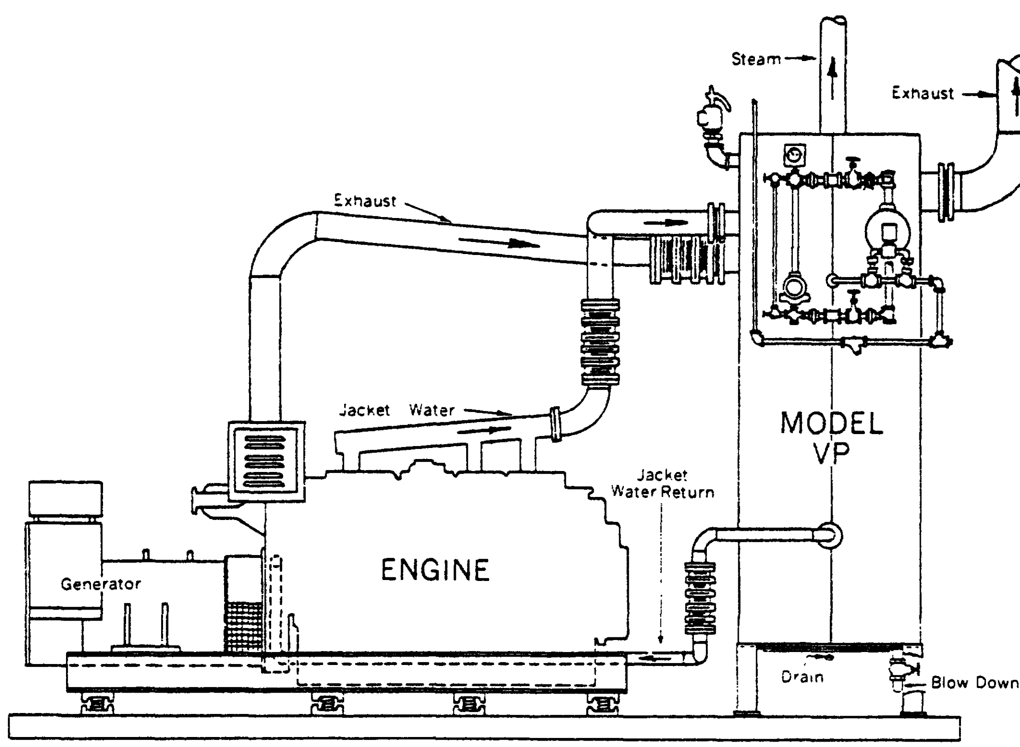
There are several methods of recovering waste heat. One employs recovery of jacket water heat only. Another employs recovery of exhaust heat only. Still another recovers both jacket water and exhaust heat in separate units. Today, however, the most popular and least expensive method is to recover both jacket water and exhaust heat in a single unit. These units are "Packaged" at the factory and include controls, safety devices, instrumentation and insulation. Only simple field connections are required.

The following pages of this brochure describe a newly designed packaged unit which is giving excellent service in actual Total Energy installations.

WASTE HEAT RECOVERY SYSTEM

VAPORPHASE Heat Recovery equipment has been applied to over 1,000,000 engine horsepower all over the world. Installations range from single units through 7 units per site. VAPORPHASE is exclusively designed and fabricated by Engineering Controls. Engineering Controls was incorporated in 1939 and has been successfully serving the Prime Mover Industry ever since. Ebullient cooling, as it is known today, is the result of research and development by Engineering Controls.

VAPORPHASE MODEL VP WASTE HEAT RECOVERY SYSTEM



The VAPORPHASE "Model VP" Packaged Heat Recovery Silencer is specifically designed to provide maximum economical recovery of waste heat from engine jacket water and exhaust while satisfying the many problems encountered in existing Total Energy and other waste heat recovery installations.

SIZES: Standard 100 thru 1500 Horsepower. For larger sizes consult factory.

FEATURES

1. Vertical unit occupies minimum floor space - resulting in lower initial construction cost and lower operating square footage cost.

2. Horizontal unit is suitable for hanging, wall, or floor mounting, if desired.

3. Unit is easily cleaned, inspected and/or maintained as tubes are exposed thru simple removal of access panels—resulting in lower maintenance costs and maximum generating income.

4. Mud drum gives dead water space for precipitating out the solids and chemicals of water treatment—resulting in more positive boiler water control with daily blow-off which reduces to a minimum the shut downs necessary for water washing.

5. Submerged pressure parts insures long life. Tubes, tube sheets, exhaust inlet and outlet and shell are submerged to maintain saturated temperature. Uniform temperatures throughout eliminates stresses normally present with varying temperatures.

6. Single unit provides both jacket water and exhaust recovery. Each engine generator heat recovery package is unitized to provide greater system versatility than available with multi-engine heat recovery units and also gives true standby.

7. Internal tube nest shroud insures solid water to the engine jacket water inlet for uniform engine cooling and directs water for maximum efficient contact with the heating surface. This means positive circulation and maximum steam production.

8. Permanent blanket insulation is attached to the self supporting steel casing which is completely removable without disturbing the piping. Shell side inspecttion openings are exposed for insurance or state inspection by removal of one quarter panel only. Outer casing protects insulation from water damage and resultant high replacement cost.

9. Liberal steam space coupled with adequate steam separating space and internal baffling insures saturated steam with a maximum 2% moisture content.

10. Factory mounted controls and safety devices provide single responsibility for entire unit and insures compatibility of base unit and accessories.

11. Sufficient water volume to prevent low water shut down due to wide load fluctuations, or false low water shut down requiring manual reset when engine shuts down under normal operating conditions. This insures adequate head on engine at all times and prevents engine damage possible with inadequate volume.

12. Provides true residential silencing of engine exhaust.

13. Back pressure is held well within engine manufacturers limitations.

14. Standard controls and instruments consisting of level control, 3-way by-pass, low water shutdown switch, combination air vent-vacuum breaker, pressure gauge and full range tubular gauge glass provide adequate operation on most systems. Optional controls consisting of (but not limited to) city water emergency feeder, low water alarm switch, high water alarm switch, high water shutdown switch and high pressure alarm switch are available for more critical systems.

15. Tubes are expanded into reamed tube holes thereby eliminating difficult and unreliable welding. Welded joints are subject to early fatigue failure with attendant leaks, costly repair and lost operating revenue.

16. Designed, fabricated and stamped in accordance with the latest edition of the ASME Code Section VIII and National Board.

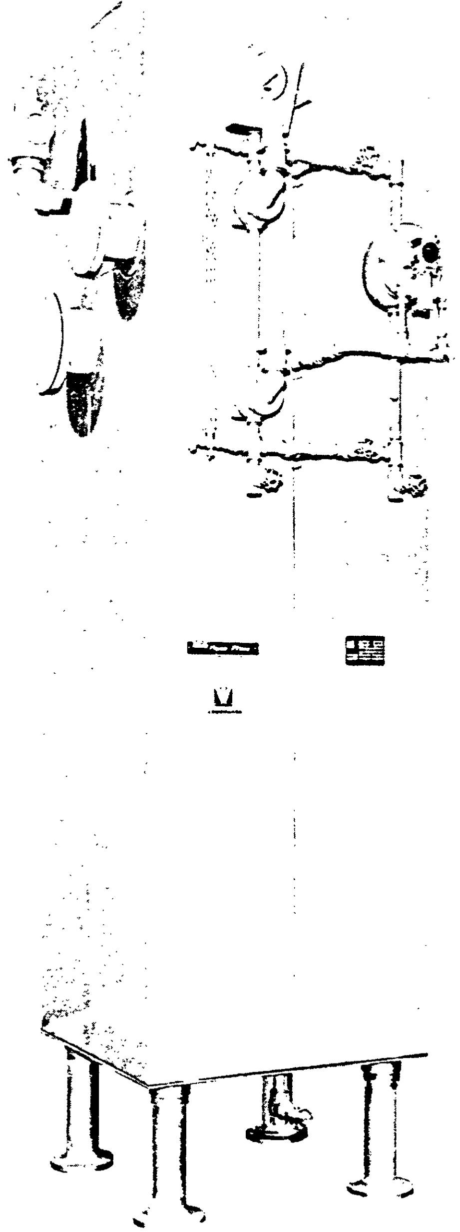
VAPORPHASE

STANDARD CONTROLS & INSTRUMENTATION		
CONTROL	**FUNCTION**	**FEATURES**
Water Control Valve	Maintains normal water level.	• Modulating, float operated for close level control. • Tight shut-off. • Union mounted with isolation valves for easy service. • Popular control insures availability of replacement, parts or service.
Low Water Shut-off Switch	Stop engine in event of low water.	• Union mounted for quick change out or service. • Popular control insures availability of replacement, parts or service. • Properly located to prevent false shut downs.
3-Way By-pass Valve	Allows by-pass of water level control valve.	• Single lever valve operation alows manual feed to unit in event of level control failure or normal service operation.
Air Vent-Vacuum Breaker	Discharge air out of J. W. System and prevents vacuum.	• Thermostatically operated. • Provides reliable air elimination.
Tubular Gauge Glass	Allows visual check of water level.	• Covers full range of control column for constant knowledge of actual water level. • Provided with gauge guard for maximum protection against breakage. • Provided with automatic shut-off cocks for protection in event of glass breakage.
Safety Valve	Pressure relieving device to protect system from overpressures.	• Sized for 100% production capacity of unit. • Quality valve provides tight shut-off. • ASME Approved.
Pressure Gauge	Indicates operating pressure of system.	• 4½" dial gauge insures easy readability from distance. • 0-30# range places normal operating pressure in middle of range with 2% accuracy. • Mounted with shut-off valve and syphon.
Blow Down Valves	Provide surface and mud drum blow off for solids concentration control.	• Surface blow-off facilitates removal of foaming agents thereby eliminating priming and carry over of solids that can foul heat transfer surface of absorption equipment and other steam users. • Blow down located in mud drum (dead water space) where solids formed by water treatment are precipitated out.

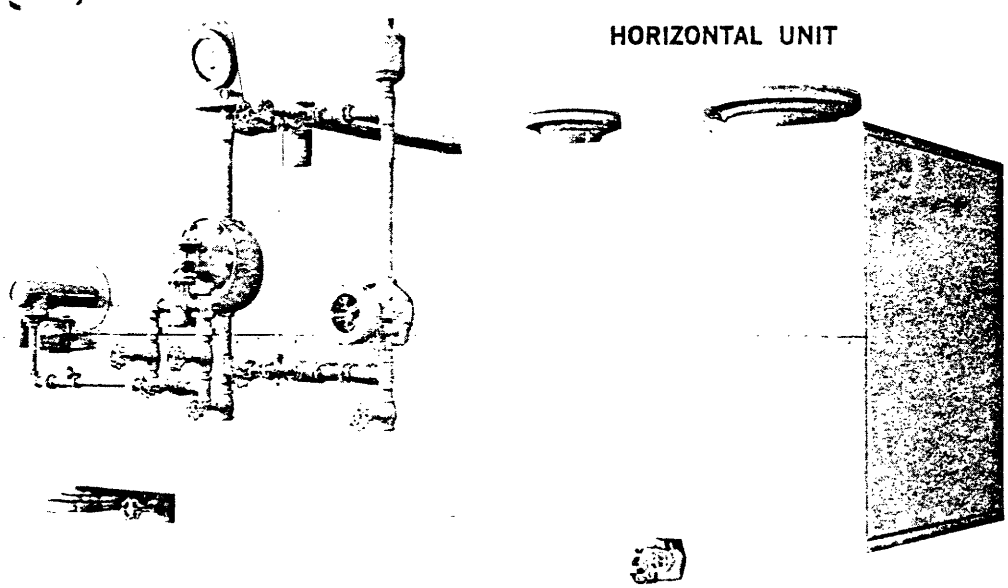
OPTIONAL CONTROLS		
CONTROL	**FUNCTION**	**FEATURES**
High Water Alarm or Shut-down switch	Sounds alarm or shuts down engine in event of high water level.	• Union mounted for quick change out or service. • Popular control insures availability of replacement, parts or service. • Properly located to prevent false shut downs.
Low Water Alarm	Sounds alarm in event low water level is occurring.	• Union mounted for quick change out or service. • Popular control insures availability of replacement, parts or service. • Properly located to prevent false alarm signal.
Low Water Alarm and Emergency feeder	Sounds alarm and feeds treated city water in event of failure of normal feed system.	• Union mounted for quick change out or service. • Popular control insures availability of replacement, parts or service. • Properly located to prevent unnecessary city water feed. • Alarm sounds at same time as city water feeds. • Allows operator to determine source of normal system failure and correct condition without shut down.
High Pressure Switch	Sounds alarm or shuts down engine in event of high steam pressure.	• Mounted on control column. • Popular control insures availability of replacement, parts or service.

VAPORPHASE MODEL VP

PACKAGED WASTE HEAT RECOVERY SILENCERS



VERTICAL UNIT

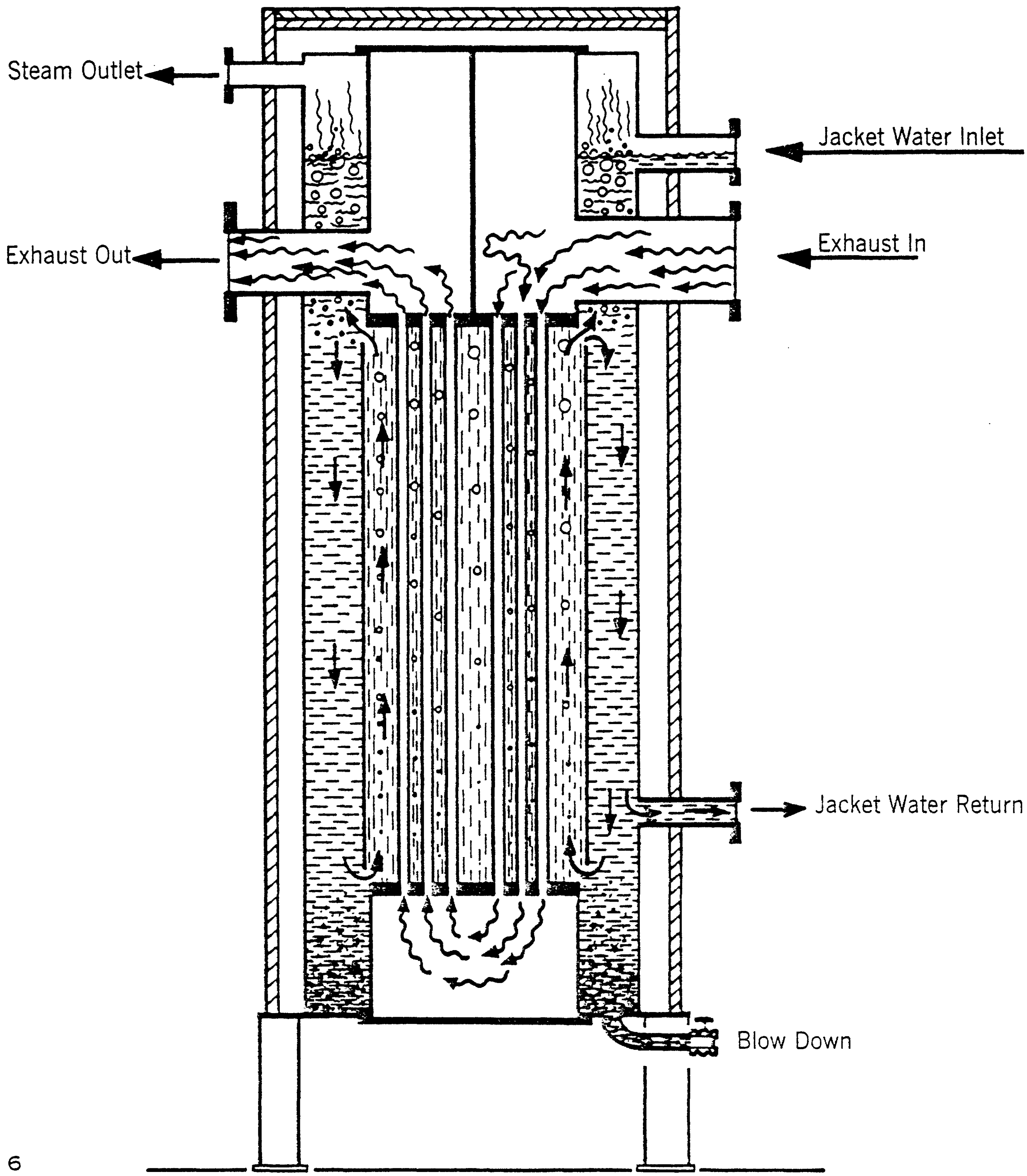


HORIZONTAL UNIT

Over 1,250,000 hp. of VAPORPHASE Heat Recovery Units are now in operation... *twice that of any competitor.*

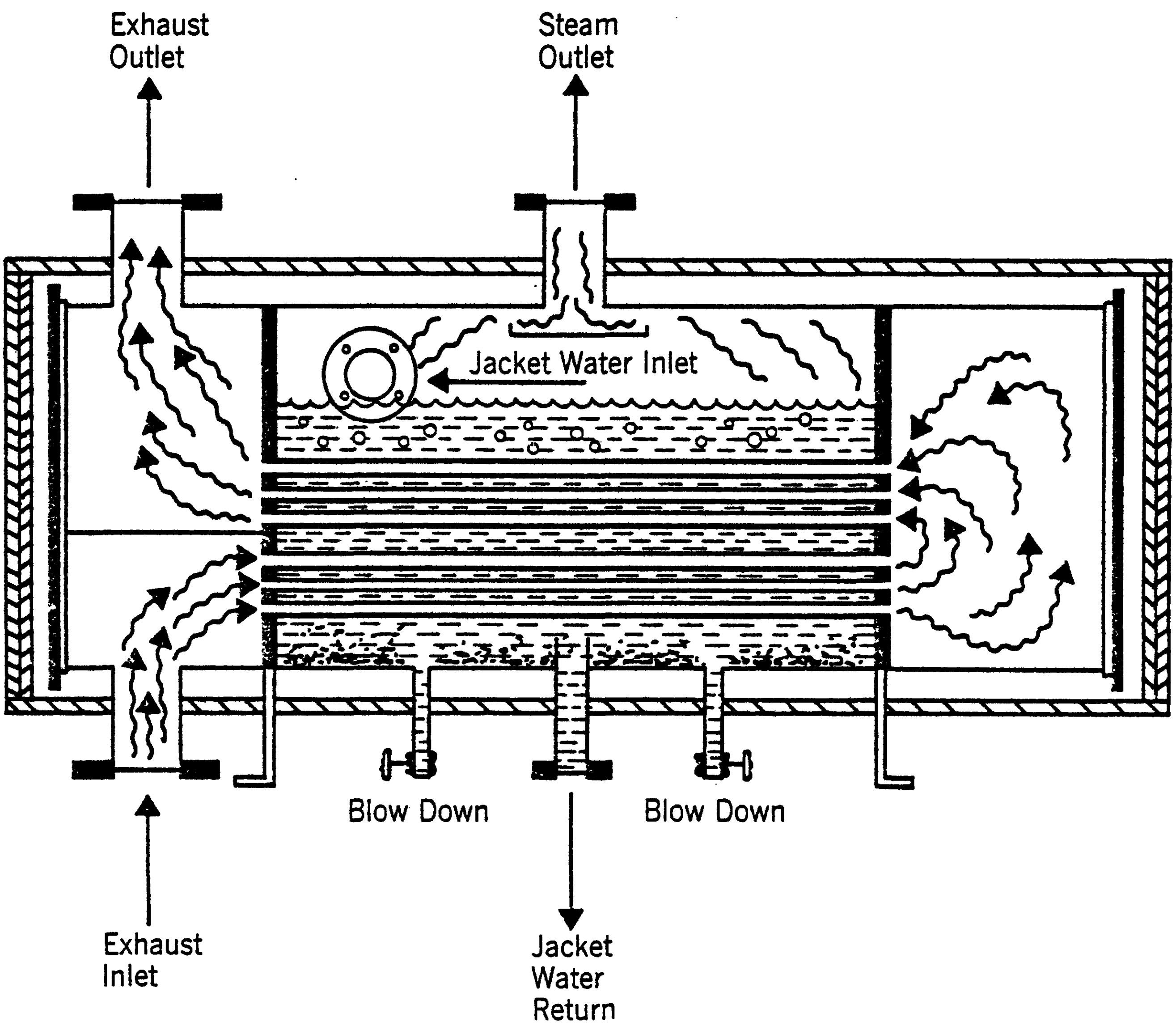
OPERATIONAL SKETCH

VERTICAL UNIT



OPERATIONAL SKETCH

HORIZONTAL UNIT



San Jose-Santa Clara Water Pollution Control Plant
San Jose, California

Consulting Engineers: Consoer, Townsend & Associates, Chicago, Ill.

Above: Aerial view shows 100 acre tract with plant and equipment valued at $30 million. Total engine capacity is 17,986 h.p. All eleven engines equipped with VAPORPHASE waste heat recovery equipment.

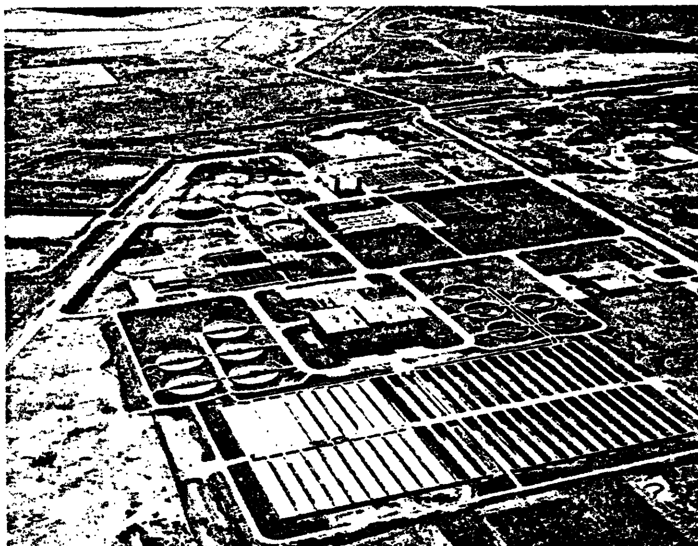
Below: Three of six Cooper Bessemer Model LS8-GDT, multi-fuel, 2,345 h.p. 360 *RPM* engines in the blower building with VAPORPHASE jacket water separators, and exhaust waste heat recovery silencers mounted on balcony.

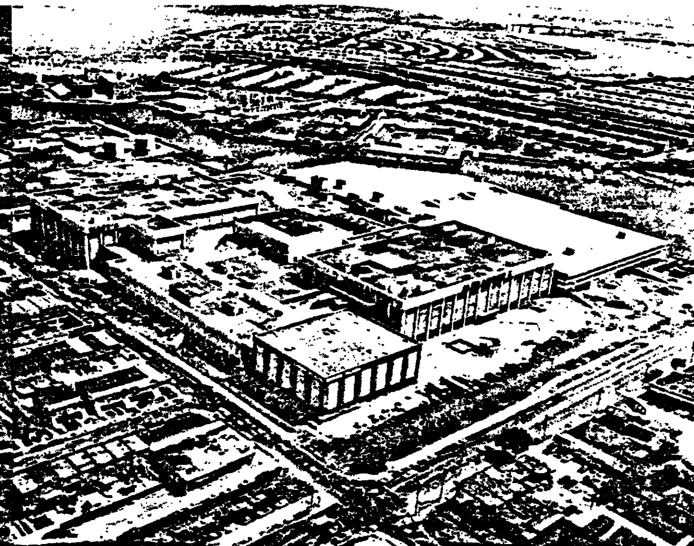
Kings Plaza Shopping Center
Brooklyn, New York

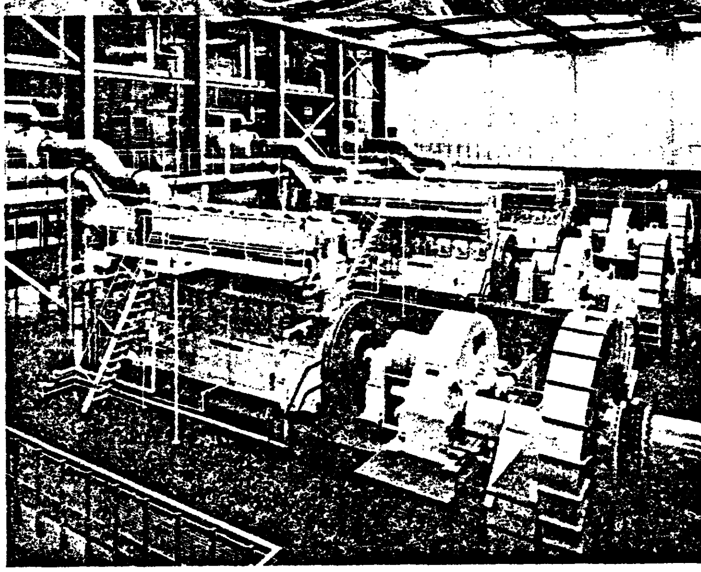
Consulting Engineers: Cosentini Associates, New York, N. Y.

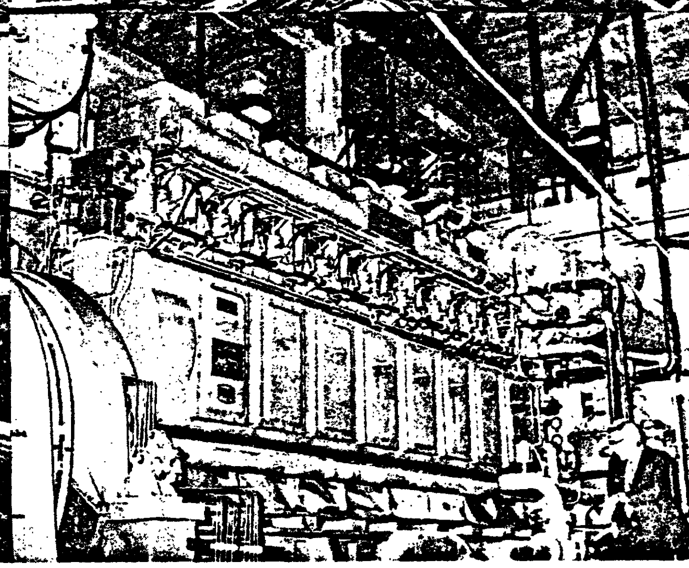
Above: 1,000,000 square feet totally enclosed. Plant power rated at 17,787 h.p., consisting of five 3,087 h.p. (2,200-kw) Nordberg generating sets and three 784 h.p. Waukesha gas engines driving refrigeration machines, equipped with VAPORPHASE packaged units.

Below: One of five Nordberg dual fuel 514 RPM, 2,200-kw generator sets with VAPORPHASE exhaust heat recovery silencers.









BIGGER EQUIPMENT

Over a longer period of time than anyone else

Molybdenum Corporation of America, Questa, New Mexico

Above: **Power for mine producing 20% of the nation's molybdenum is supplied by plant rated at 21,500 h.p. (15,000-kw), and is largest installed gas engine plant in country, with exhaust waste heat recovery equipment. All VAPORPHASE.**

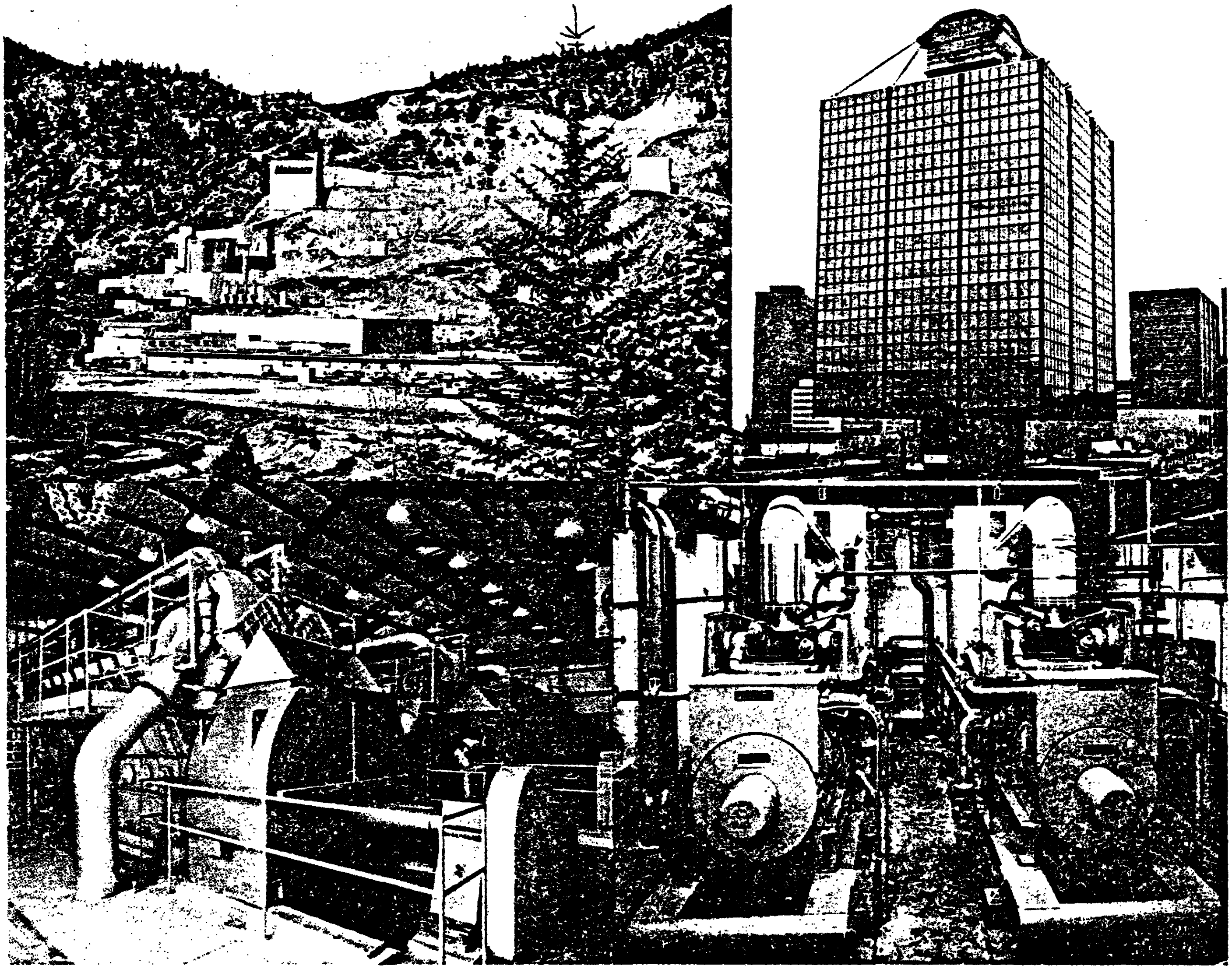
Below: **Four Enterprise dual fuel 5,300 h.p. (3,750-kw) generator sets with VAPORPHASE exhaust units.**

Westcoast Transmission Office Building
Vancouver B.C.—Canada

Consulting Engineer:
Phillips, Barratt, Hillier, Jones and Partners

Above: **Note unique central core construction and cantilevered floors. Total Energy Power Plant is rated at 2,550 h.p. (1,800-kw).**

Below: **Two of three Caterpillar G-399TA gas engines connected to VAPORPHASE VP Model jacket water and exhaust recovery silencers.**



Over 1,250,000 h.p. of VAPORPHASE Heat Recovery Units are now in operation. Twice that of any competitor.

VAPORPHASE heat recovery equipment now in operation, ranges from smaller, single engine, packaged, 100-kw installations (approx. 150 h.p.); up to 15,000-kw (approx. 21,500 h.p.); in the form of 4, low speed, large bore (17" pistons), 16 cylinder, dual fuel, generating sets.

VAPORPHASE installations, by Engineering Controls, have been made in all 50 states, as well as in Europe, Asia, Africa, Australia, New Zealand, South America, Central America, Mexico, Canada, and inside the Arctic Circle.

Engineering Controls is the only company in the field that specializes in the engineering and manufacturing of heat recovery equipment. Our broad and long experience in engineering the largest number of applications will be a great assistance to you. Please call us at (314) 638-4000 or write:

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CONSTRUCTION DETAILS

MATERIALS:
All materials are in compliance with the ASME Code, Division 1, Section VIII for Unfired Pressure Vessels. Pressure Shell (all sections) are SA285 Gr. C steel of ¼ inch minimum thickness. Tube Sheets are SA 285 Gr. C steel of ⅝ inch minimum thickness. Tube Holes are drilled, reamed with tubes roller expanded. Tubes are 1½ inch 12 gauge SA178 Gr. A steel.

All materials are welded in accordance with the latest ASME Code requirements by Code Qualified Welders and are inspected by National Board registered inspectors. Completed units bear the "U" Symbol and are National Board registered.

INSPECTION AND ACCESS OPENINGS:
Access to the gas side of the tube bundle is provided by removable bolted closure plates at both top and bottom. Closure plates are protected inside with insulating, hi-temperature castable refractory. Water side inspection and access is provided by upper and lower 4 x 6 handholes.

INSULATION AND CASING:
The entire unit, except for the controls, is encased in a self supporting 15 gauge painted steel casing. The casing is so designed as to permit complete removal without disturbing the piping. Only one quarter panel need be removed to expose the water side access openings. The casing is insulated inside with copra-fibre hi-temperature blanket insulation which is attached to the casing with standard insulation clips.

CONTROLS AND INSTRUMENTATION:
Water feeder, low water cut-off, gauge glass with guard and automatic shut-off cocks, pressure gauge, safety valve and combination vacuum breaker-air vent are furnished as standards. All controls and instrumentation are factory piped and mounted on the unit.

SUPPORTS:
Four sturdy angle legs of required length are provided on vertical unit to place unit water level at adequate height above engine heads and water cooled exhaust manifolds.

Horizontal unit is provided with hanger brackets or saddles, as required, for ceiling or wall mounting.

CONNECTIONS:

Function	Size	Type
Exhaust Gas Inlet	Per Engine Requirement	ASA Flanged Nozzle
Exhaust Gas Outlet	Same size as inlet	ASA Flanged Nozzle
Jacket Water Inlet	Per Engine Requirement	ASA Flanged Nozzle
Jacket Water Return	Per Engine Requirement	ASA Flanged Nozzle
Steam Outlet	As Required	ASA Flanged Nozzle
Safety Valve	Per ASME Code Requirement	As Required
Surface Blow-off	1 inch	Screwed IPS
Blow-down	1½ inch	Screwed IPS
Equalizer	1½ inch	Screwed IPS
Control Column	1 inch	Screwed IPS
Air Vent/Vacuum Breaker	¾ inch	Screwed IPS
Gas Side Drain	½ inch	Screwed IPS

NOTE: All nozzles are 150 lb. ASA rating.

TYPICAL SPECIFICATION

Furnish and install Combination Engine Jacket Water and Exhaust Gas Heat Recovery Silencer, Engineering Controls Model __________ or approved equal.

Each Silencer shall be designed to reduce the exhaust gas temperature to ______°F. and recover the heat available in the engine jacket water. Steam leaving the unit shall contain a maximum of 2 per cent moisture.

Silencers shall be constructed in accordance with the ASME Code, Section VIII, Unfired Pressure Vessels. In addition, tube to tube sheet or header joints shall be made by mechanically expanding tubes into reamed tube holes. Boiler design pressure shall be 20 psig.

Silencer shall be arranged as a vertical unit with straight bare tubes, gas thru tubes with water outside tubes. Removable cover plates shall be provided top and bottom for access, tube cleaning and tube removal. Provide a minimum of two 4 x 6 inch inspection and access openings, one each top and bottom, arranged for water side inspection of tubes and tube sheets. Silencer shall be insulated and covered with external lagging or removable No.15 gauge steel casing. Insulation and casing shall be designed to provide a maximum casing temperature of 150°F. with 80°F. ambient and 50 fpm surface velocity. To facilitate control of water, solids concentration provision must be made for a settling basin or mud drum in bottom of unit.

The Silencer shall be provided with the following connections:

Exhaust Gas Inlet—Flanged—For gas temperatures equal to or greater than 1200°F. this connection shall be 304L Stainless Steel.*
Exhaust Gas Outlet—Flanged.*
1½" Blowdown and Drain from Mud Drum.
1" Surface Blow-Off.
Jacket Water Inlet—Flanged.*
Jacket Water Return—Flanged.*
2—1" Control Column.
1—¾" Feedwater.
1—¾" Vent.
Safety Valve or Valves per ASME Code.
1—1½" Equalizer Connection.

The following accessories and trim shall be shop mounted and piped on the unit:

Make-up Water Feeder, McDonnell & Miller #551S-B with 3-way By-pass.
Low Water Level Switch, McDonnell & Miller #61.
Gauge Glass, ⅝" Dia. glass with automatic shut-off cocks.
Air Vent and Vacuum Breaker, Sarco #6T.
Pressure Gauge, 0-30 PSI, 4½" dia., with syphon and shut-off cock.
Safety Valve, Kunkle (Sized per ASME Code).
Support legs of length to meet installation requirements.

Heat Recovery Silencer Manufacturer to provide the following performance with his proposal:

Total Steam Production—lbs./Hour—Operating Pressure__________psig.
Feedwater Temperature 200°F.
Pounds of Exhaust Gas/Hour.**
Exhaust Gas Temperature to Unit.**
Exhaust Gas Temperature from Unit.
Heat Recovered from Exhaust Gas—BTU/Hour.
Jacket Water Heat Rejection—BTU/Hour.**
Total Heat Recovered—BTU/Hour.
Maximum Gas Side Pressure Drop thru Unit—inches water gage.

TYPICAL ATTENUATION CAPACITY OF MODEL VP PACKAGED WASTE HEAT RECOVERY SILENCER.

Octave Bands in Hz.	63	125	250	500	1000	2000	4000	8000
Decibels	22	31	35	35	32	29	25	23

*Size determined by Engine Manufacturer.

**Data to be provided by Engine Manufacturer.

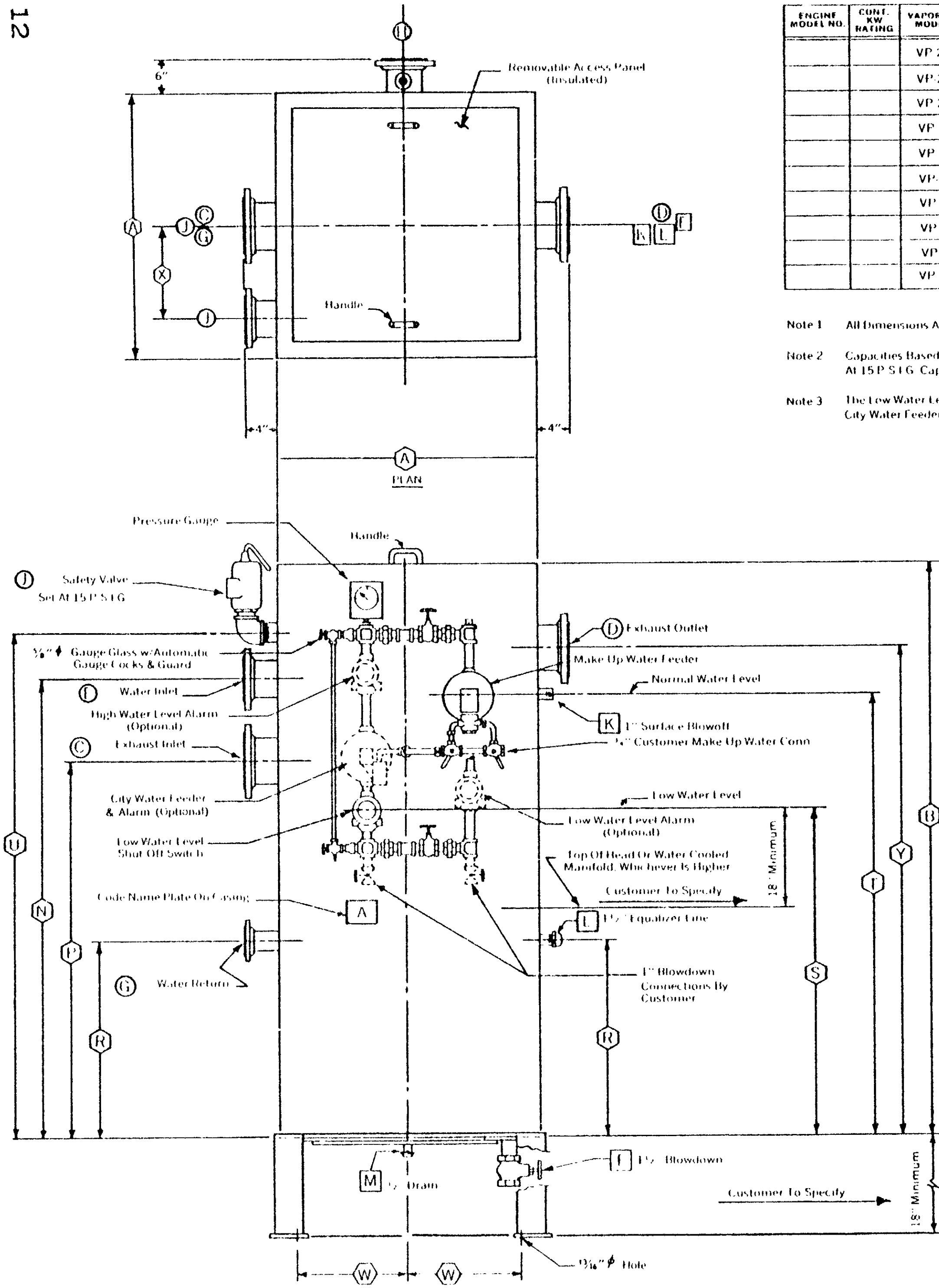
ENGINE MODEL NO.	CONT. KW RATING	VAPOR PHASE MODEL NO.	CAPACITY (SEE NOTE 2)	OVERALL DIMS A	B	C	D	E	G	H	J	N	P	R	S	T	U	W	X	Y
		VP 2260		26	125	4	4	3	2	3	2	101½	91½	30	84	99	118½	10	9 9/16	114
		VP 2460		28	125	6	6	4	3	4	2	108	99	36	90	105	118	11	9½	115
		VP 2860		32	128⅝	6	6	4	3	4	2	108	99	36	90	105	120½	13	10¼	117½
		VP 3060		34	132 1/16	8	8	6	3	6	2	108	99	36	90	105	123½	14	10 11/16	120½
		VP 3660		40	138½	8	8	6	3	6	2	111	100	36	90	108	129½	17	14 11/16	127
		VP 4060		44	138	8	8	6	3	6	2	119	101	36	90	114	129½	19	15 11/16	125½
		VP 4860		52	150	12	12	8	4	6	3	123	108	36	96	120	139	23	19 11/16	132⅜
		VP 5460		58	168	14	14	8	6	6	3	133	115	36	102	129	156	26	22 11/16	153
		VP 6060		64	176	22	22	8	6	6	4	135	119	36	105	132	164	29	26	155
		VP 6660		69	180	24	24	8	6	8	6	135	120	36	105	133	166	312	29½	160

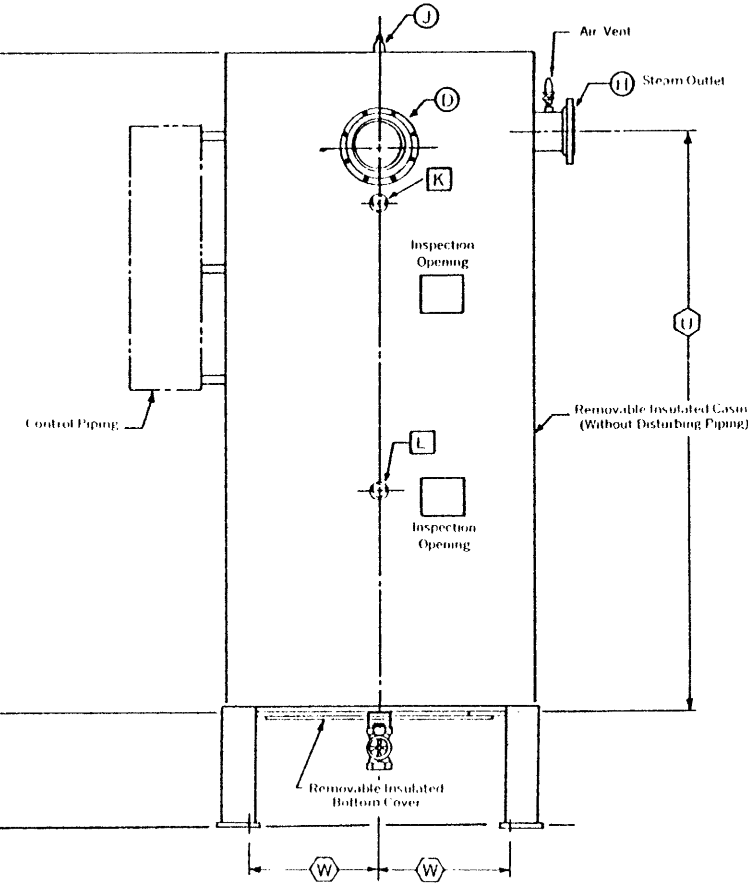
Note 1 All Dimensions Are Given In Inches

Note 2 Capacities Based On Full Load Conditions Producing Saturated Steam At 15 P.S.I.G. Capacities Given In BTU/Hr. x 1000

Note 3 The Low Water Level Alarm Is Not Necessary When The City Water Feeder & Alarm Is Used

Legend
( ) Variable Nozzle Size
Variable Dimension
[ ] Constant Nozzle Size



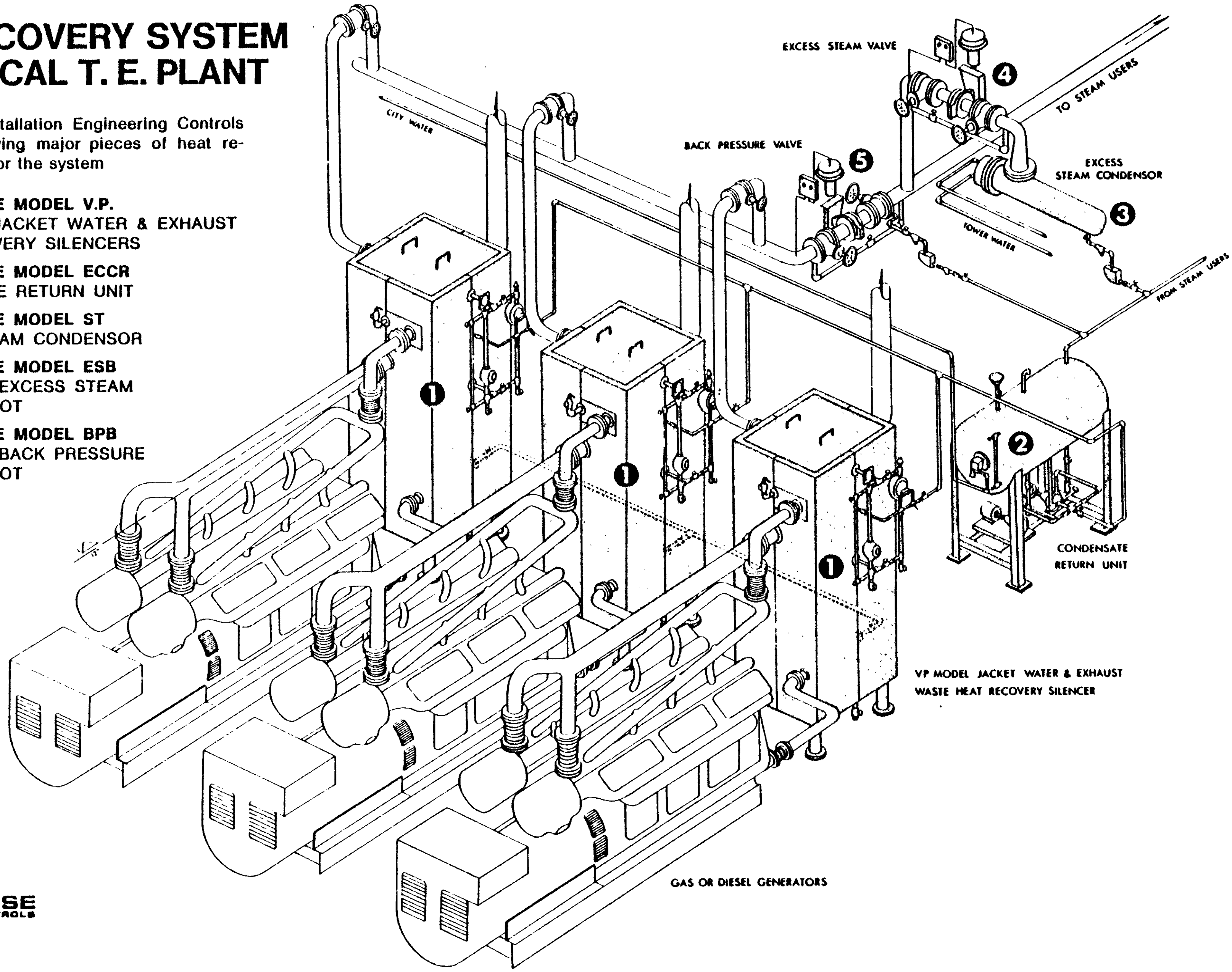


STANDARD MODEL VP WASTE HEAT RECOVERY PACKAGE UNIT

HEAT RECOVERY SYSTEM FOR TYPICAL T. E. PLANT

For this typical installation Engineering Controls provides the following major pieces of heat recovery equipment for the system

1. **VAPORPHASE MODEL V.P.**
   PACKAGED JACKET WATER & EXHAUST HEAT RECOVERY SILENCERS
2. **VAPORPHASE MODEL ECCR**
   CONDENSATE RETURN UNIT
3. **VAPORPHASE MODEL ST**
   EXCESS STEAM CONDENSOR
4. **VAPORPHASE MODEL ESB**
   PNEUMATIC EXCESS STEAM VALVE & PILOT
5. **VAPORPHASE MODEL BPB**
   PNEUMATIC BACK PRESSURE VALVE & PILOT



VAPORPHASE
BY ENGINEERING CONTROLS

PARTIAL LIST OF VAPORPHASE INSTALLATIONS

SHOPPING CENTERS

Kings Plaza Shopping Center
Brooklyn, New York

Westroads Shopping Center
Omaha, Nebraska

Hudson's Bay Store
Richmond, B.C.—Canada

Merritt Square Shopping Center
Merritt Island, Florida

Dixie Square Shopping Center
Harvey, Illinois

Turfland Mall Shopping Center
Lexington, Kentucky

Springmall Shopping Center
Greenfield, Wisconsin

Chapel Hill Shopping Center
Akron, Ohio

Western Mall Shopping Center
Sioux Falls, South Dakota

South Plaza Shopping Center
Worcester, Mass.

University Plaza Shopping Center
Little Rock, Arkansas

Park Plaza Shopping Center
Little Rock, Arkansas

HOSPITALS AND SCHOOLS

Kings County State School
Brooklyn, New York

West Side Vo-Tec School
Pringle, Pennsylvania

Ohio State University
Columbus, Ohio

Melfort Comprehensive High School
Melfort, Saskatchewan—Canada

Paoli High School
Paoli, Indiana

St. Edwards University
Austin, Texas

Malden Catholic High School
Malden, Mass.

Jacksonville, Memorial Hospital
Jacksonville, Florida

Victoria Union Hospital
Victoria, B. C.—Canada

Prince Albert Hospital
Prince Albert, Saskatchewan—Canada

Missouri State Sanitorium
Mt. Vernon, Missouri

John F. Kennedy Memorial Hospital
Stratford, New Jersey

Iowa Methodist Hospital
Des Moines, Iowa

New England Memorial Hospital
Stoneham, Mass.

MANUFACTURING PLANTS

Giles & Ransome, Inc.
Cornwells Heights, Penn.

American Gas Association
Independence, Ohio

Marbon Chemical Co.
Marseilles, Illinois

Marigold Foods, Inc.
Rochester, Minnesota

Waukesha Motor Co.
Waukesha, Wisconsin

Greater Winnipeg Gas Co.
Winnipeg, Manitoba—Canada

United Fuel Gas Company
St. Albans, West Virginia

Molybdenum Corp.
Questa, New Mexico

Sears, Roebuck & Company
Columbus, Ohio

MOTELS, APARTMENTS, OFFICE BUILDINGS

Tollway North Office Center
Deerfield, Illinois

Teamsters Council Plaza
St. Louis, Missouri

Pima County
Tucson, Arizona

KFVS-TV Station
Cape Girardeau, Mo.

Florida Gas Company
Winter Park, Florida

Finning Tractor & Equip. Ltd.
Vancouver, B. C.—Canada

Caterpillar Tractor Co.
Peoria, Illinois

Battlecreek Gas Company
Battlecreek, Michigan

Meadow Lark Hills Apartments
Overland Park, Kansas

Kings Cove Apartments
Merriam, Kansas

Georgetown Apartments
Merriam, Kansas

WHIS-TV Studio
Bluefield, West Virginia

Tenco Tractor Co.
Marysville, California

U.S. Post Office
Pittsfield, Mass.

Western Kentucky Gas Co.
Owensboro, Kentucky

ESSO Hotel
Antwerp, Belgium

Commonwealth Gas Co.
Southboro, Mass.

Western Union Complex
Middletown, Virginia

Mark Construction Company
Honolulu, Hawaii

MUNICIPAL POWER PLANTS OR WATERWORKS

Municipal Water Works
Minneapolis, Minnesota

Municipal Power Plant
New Prague, Minnesota

Nantucket Gas & Electric Co.
Nantucket, Mass.

Naknek Electric
Naknek, Alaska

Kotzebue Electric
Kotzebue, Alaska

Municipal Power Plant
Unalakleet, Alaska

Municipal Power Plant
City of Highland, Illinois

Isachsen Weather Station
Northwest Territories, Canada

SEWAGE TREATMENT PLANTS

Blue Plains Pollution Control Plant
Washington, D.C.

San Jose-Santa Clara Sewage Treatment Plant
San Jose, California

Newtown Creek Sewage Treatment Plant
New York City, N. Y.

West Point Sewage Treatment Plant
Seattle, Washington

Orange County Sewage Treatment Plant
Fountain Valley, California

Atlanta Water Pollution Plant
Atlanta, Georgia

Nassau County Sewage Treatment Plant
Nassau County, New York

VAPORPHASE
BY ENGINEERING CONTROLS
DIVISION OF POTT INDUSTRIES INC.
611 E. MARCEAU ST. ST. LOUIS, MO. 63111

In your area contact:

APPENDIX XIX

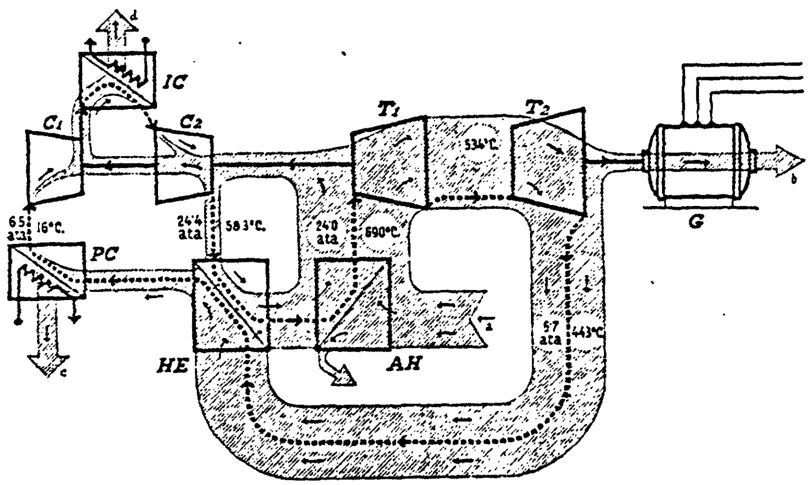


FIG. 37. SANKEY DIAGRAM OF ESCHER-WYSS-AK CLOSED-CYCLE TURBINE

Shaded areas represent energy-flow; broken line shows the flow of air, horizontal unbroken lines the engine-shafts. *AH*, air-heater; T_1, h.p. turbine, T_2, l.p. turbine; *G*, generator; *HE*, heat-exchanger; *PC*, pre-cooler; C_1, l.p. compressor; *IC*, inter-cooler; C_2, h.p. compressor; *a*, heat input from fuel; *b*, power output; *c*, heat discarded in pre-cooler; *d*, heat discarded in inter-cooler.

Thirring, Hans, Energy for Man. Westport, Conn.: Greenwood Press, 1968 (c. 1958).

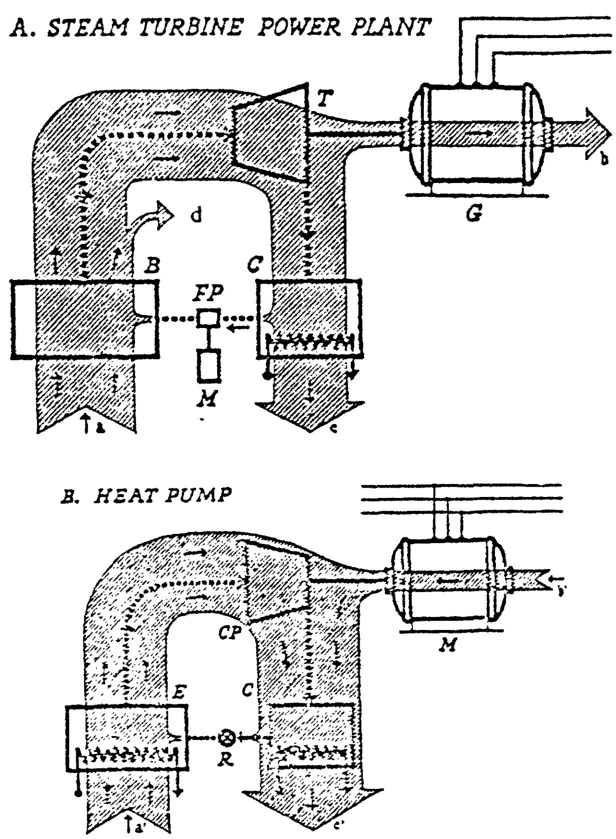
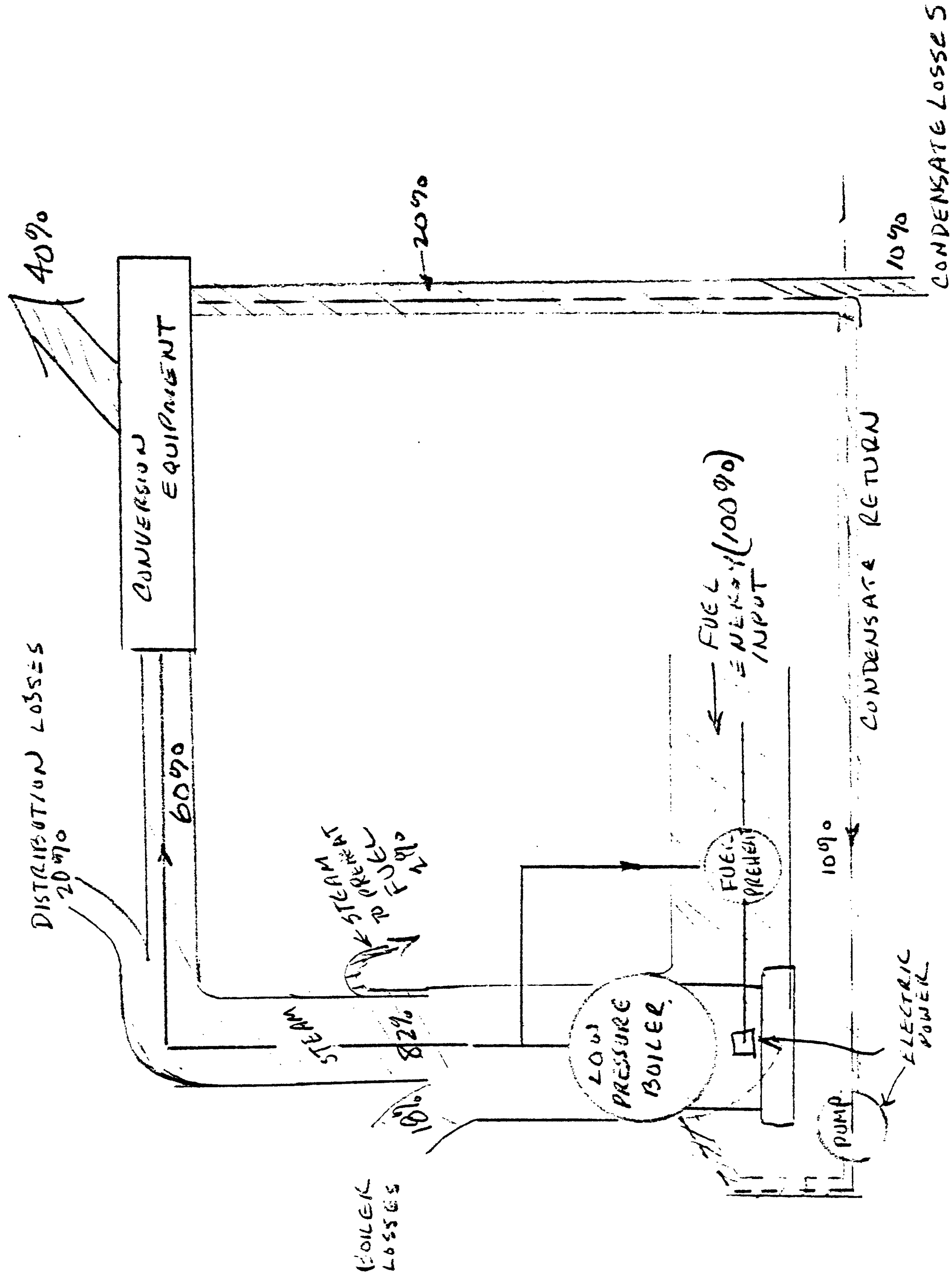


FIG. 40. SANKEY DIAGRAM OF STEAM PLANT AND HEAT PUMP

Shaded area, energy-flow. *B*, boiler; *T*, turbine; *G*, generator; *C*, condenser; *FP*, feed-pump; *M*, motor; *a*, heat supplied from fuel; *b*, electrical energy output; *c*, heat discarded with cooling water; *d*, heat lost in stack; *E*, evaporator; *Cp*, compressor; *R*, regulating throttle-valve; *a'*, heat drawn from river; *b'*, energy input for driving compressor; *c'*, useful heat output.

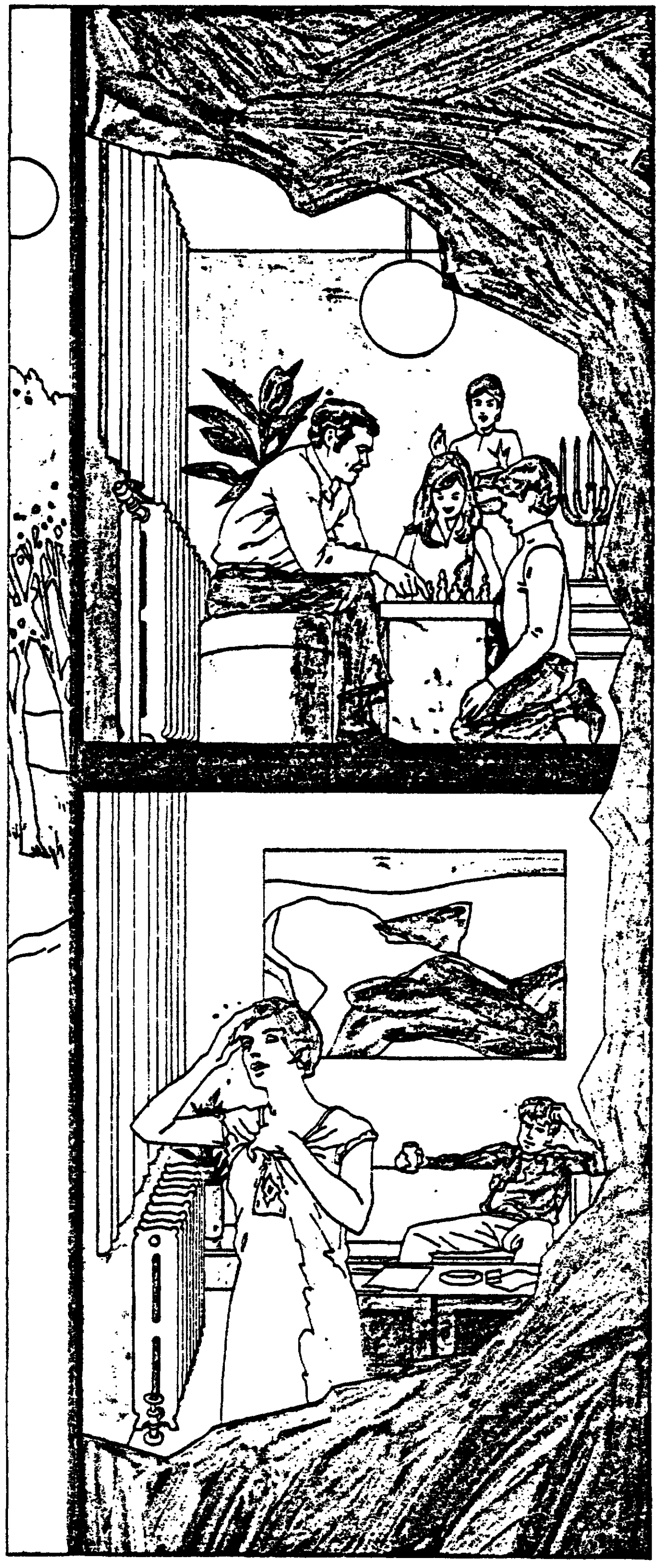
Thirring, Hans, Energy for Man. Westport, Conn.: Greenwood Press, 1968 (c. 1958).



SANKEY DIAGRAM FOR HYPOTHETICAL LOW PRESSURE STEAM SYSTEM

Avoid Wasteful Overheating of Rooms Having Centrally-Supplied Hot Water or Two Pipe Steam

Many buildings have steam or hot water radiators with perhaps only hand valves for control. After a room becomes too warm, it is a little late to turn off the radiator, so use of open windows to dump valuable heat is the common result.



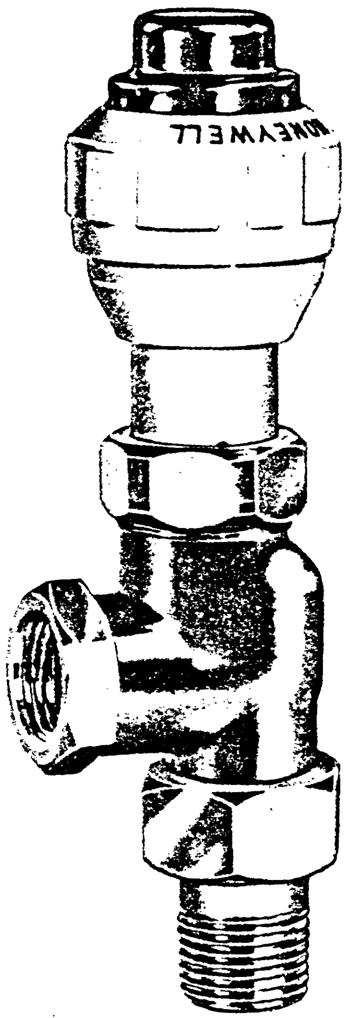
Energy waste problem Where a number of radiators or baseboards or convectors are supplied from a central hot water or steam source, the amount of heat furnished is generally related to average requirements and demands from the coldest areas. This means that many other areas, particularly those on the sunny sides of the building, will be far too warm.

The occupant reaction is to open windows to dispose of the excess heat. Or, even worse, some occupants may run their room air conditioners to bring down the temperature. In either case, there is a needless waste of valuable energy.

At the same time, other rooms in more exposed parts of the building may be too cold. So, there may be complaints of both underheating and overheating, plus waste — all at the same time.

Solution Individual automatic control of radiators can be provided with Honeywell Non-electric Radiator Valves. Each self-contained unit measures the room temperature needs and modulates the steam or hot water supply to the radiator exactly as required. Overheating or underheating may be entirely eliminated. Installation is simple. The cost is low. Energy saving studies have shown fuel savings of up to 27% per year.

Benefits Besides the energy savings of up to 27%, individual radiator control makes tenants more comfortable. It avoids overheating of the warmer rooms and also helps correct problems of not enough heat, thus reducing complaints. Also, the modulating control of these valves smooth the heating/cooling cycles and reduce pipe expansion and contraction noises. The entire system matches the needs of any part of the building without waste.



Equipment needed

1. V5061 Radiator Valve (appropriate model with T5038 Thermostatic Head)

Application Honeywell Non-electric Radiator Valves can be installed directly on two-pipe steam or hot water radiators in apartment buildings dormitories, schools, hotels, hospitals and many other similar applications. These valves are relatively inexpensive, easy to install, and give long, trouble-free service.

Return on investment Since radiator valves are relatively inexpensive and easy to install, they pay for themselves rather quickly, often in two or three years. For example, here is an ROI tabulation for one apartment house:

Material cost (500 valves)	$7,550
Installation cost	$1,670 + 8% interest, 3 years = $2,200
Total cost	$9,220
Fuel savings (1973)	$3,109 + fuel increase = $3,607

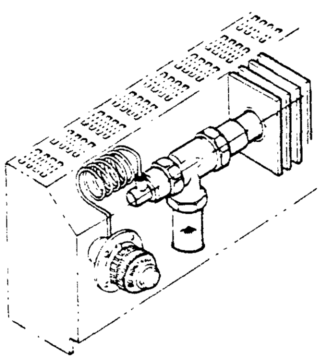
Total cost ($9,220 + $2,220) = $11,420

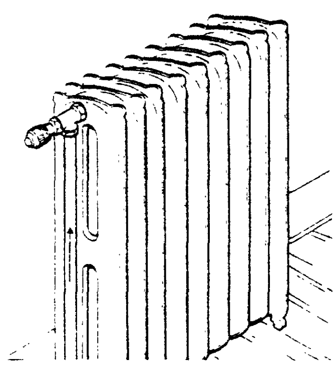
ROI $\frac{\$3,607}{\$11,420}$ = 31.6% or 3.2 years.

Additional reference literature

51-3090, 51-3112, 51-3034 (Envelope stuffers on Thermostatic Radiator Valves)

51-3119 (8½ x 5½ mailer on Thermostatic Radiator Valves)





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Scarborough, Ontario

50-0895 (.038 – 6/74) Printed in U.S.A.

APPENDIX XXI

IN THE BANK... OR UP THE CHIMNEY?

A Dollars and Cents Guide to Energy-Saving Home Improvements

Prepared for the

Office of Policy Development and Research,
Division of Energy, Building Technology, and Standards
U.S. Department of Housing and Urban Development
Washington, D.C.

Under Contract H-2179R by

Abt Associates Inc.
Cambridge, Massachusetts

Federal Energy Administration

April 1975

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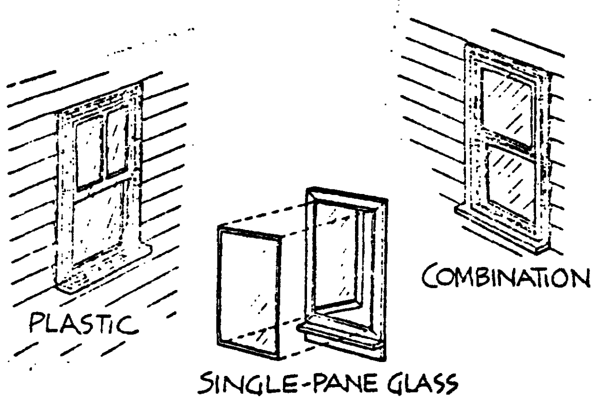
INSTALL STORM WINDOWS



There are three kinds of storm windows:

PLASTIC. These cost only 50¢ each. You may have to put up replacements each year.

SINGLE PANE GLASS. They cost about $10.00 each. You put them up and take them down each year.

TRIPLE-TRACK GLASS (COMBINATION). These have screens and you can open and close them. They are for double-hung windows only (like the one in the picture). They cost about $30.00 each installed. Double-track storm windows are also available, and they cost less.

All three kinds are about equally effective. The more expensive ones are more attractive and convenient.

FILL OUT ONE OR MORE OF LINES A, B, AND C – WHICHEVER ONES YOU'RE INTERESTED IN.

A. PUT ON PLASTIC STORM WINDOWS WITHOUT WEATHERSTRIPPING

Your cost: Count the number of windows you have and multiply times $.50:

_______ X $.50 = [$ ______]
number of windows — total cost

Your Savings: In step A on page 8 you checked either "OK," "fair," or "poor" as the condition of the weatherstripping on your windows.

- If you checked "OK", circle this number **7.9**
- If you checked "FAIR" circle this number **8.2**
- If you checked "POOR" circle this number **10.8**

Multiply the number you circled times the number of windows you have:

_______ X _______ = [______]
number you circled — number of windows — savings factor

B. PUT ON PLASTIC STORM WINDOWS AT THE SAME TIME YOU WEATHERSTRIP
(see Note)

Your cost: Multiply your number of windows times $.50:

_______ X $.50 = [$ ______]
number of windows — total cost

Your savings: Multiply your number of windows times 7.9:

_______ X 7.9 = [______]
number of windows — savings factor

C. PUT ON GLASS STORM WINDOWS
(see Note)

Your cost: Choose which kind of glass storm windows you want.

- If you want single pane windows, multiply the number of windows you have times $10.00 (do-it-yourself installation):
- For combination windows, multiply the number of windows you have times $30.00 (includes installation):

_______ X $ _______ = [$ ______]
number of windows — $10 or $30 — total cost

Your savings: Multiply your number of windows times 7.9:

_______ X 7.9 = [______]
number of windows — savings factor

SEE THE ENERGY CHECKLIST AT THE END OF THE BOOK

NOTE: These cost and savings factors are for storm windows only. They are in addition to the costs and savings for caulking and weatherstripping that you found on the last page.

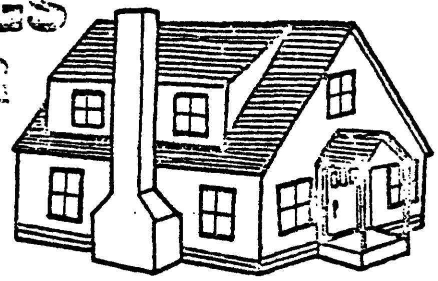
If you filled out Part A here, fill out line 2a of the Checklist.

If you filled out Part B here, fill out line 2b of the Checklist.

If you filled out Part C here, fill out line 2c of the Checklist.

In each case, write the total cost into the red box on that line and the savings factor into the brown box.

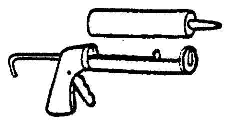
CAULK THE OPENINGS IN YOUR HOME



AN EASY DO-IT-YOURSELF PROJECT

Caulking should be applied wherever two different materials or parts of the house meet. It takes no specialized skill to apply and a minimum of tools.

Tools



1. Ladder
2. Caulking gun
3. Caulking cartridges
4. Oakum, glass fiber strips, caulking cotton, or sponge rubber
5. Putty knife or large screwdriver

Safety

You'll need to use a ladder to reach some of the areas which need to be caulked. Be sure you use it safely.

Level and block the ladder in place. Have a helper hold it if possible.

Don't try to reach that extra little bit – get down and move the ladder.

Carry your caulking gun with a sling so that you can use both hands climbing the ladder.

Where a house needs to be caulked

1. Between window drip caps (tops of windows) and siding.
2. Between door drip caps and siding.
3. At joints between window frames and siding.
4. At joints between door frames and siding.
5. Between window sills and siding.
6. At corners formed by siding.
7. At sills where wood structure meets the foundation.
8. Outside water faucets, or other special breaks in the outside house surface.
9. Where pipes and wires penetrate the ceiling below an unheated attic.
10. Between porches and main body of the house.
11. Where chimney or masonry meets siding.
12. Where storm windows meet the window frame, except for drain holes at window sill.
13. And if you have a heated attic; where the wall meets the eave at the gable ends.

Materials

What you'll need

Caulking compound is available in these basic types:

1. Oil or resin base caulk; readily available and will bond to most surfaces – wood, masonry and metal; not very durable but lowest in first cost for this type of application.
2. Latex, butyl or polyvinyl based caulk; all readily available and will bond to most surfaces, more durable, but more expensive than oil or resin based caulk.
3. Elastomeric caulks; most durable and most expensive; includes silicones, polysulfides and polyurethanes; the instructions provided on the labels should be followed.
4. Filler; includes oakum , caulking cotton, sponge rubber, and glass fiber types; used to fill extra wide cracks or as a backup for elastomeric caulks.

CAUTION: Lead base caulk is not recommended because it is toxic. Many states prohibit its use.

How much

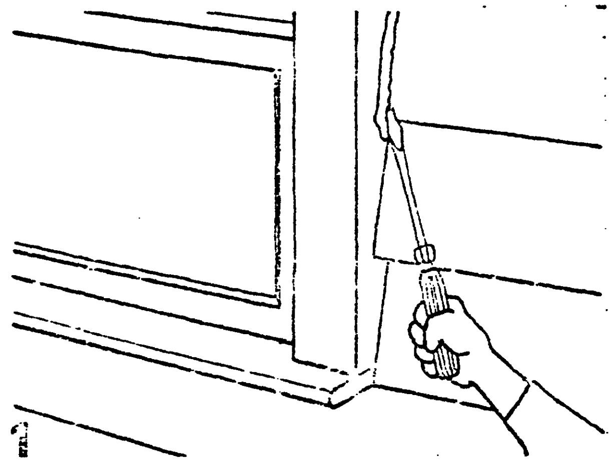
Estimating the number of cartridges of caulking compound required is difficult since the number needed will vary greatly with the size of cracks to be filled. Rough estimates are:

1/2 cartridge per window or door

4 cartridges for the foundation sill

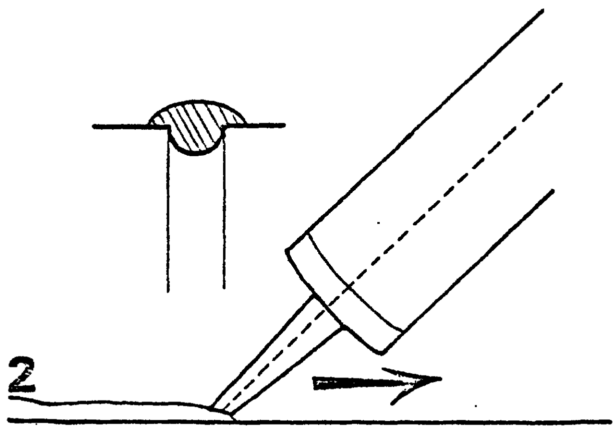
2 cartridges for a two story chimney

If possible, it's best to start the job with a half-dozen cartridges and then purchase more as the job continues and you need them.



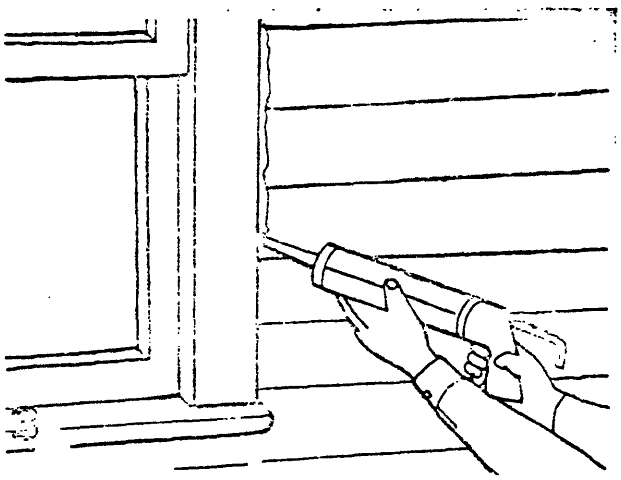
1

Before applying caulking compound, clean area of paint build-up, dirt, or deteriorated caulk with solvent and putty knife or large screwdriver.



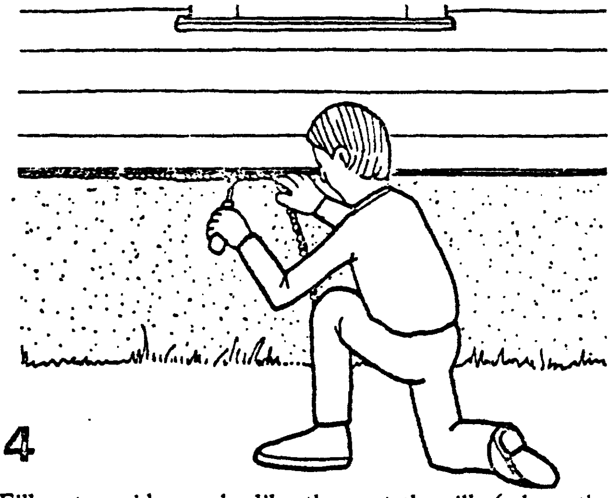
2

Drawing a good bead of caulk will take a little practice. First attempts may be a bit messy. Make sure the bead overlaps both sides for a tight seal.



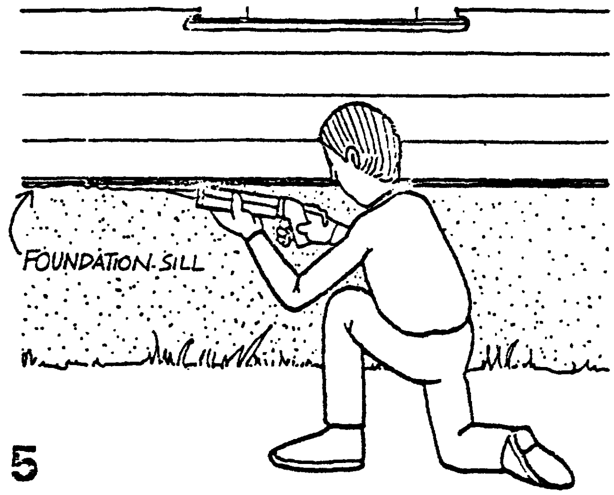
3

A wide bead may be necessary to make sure caulk adheres to both sides.



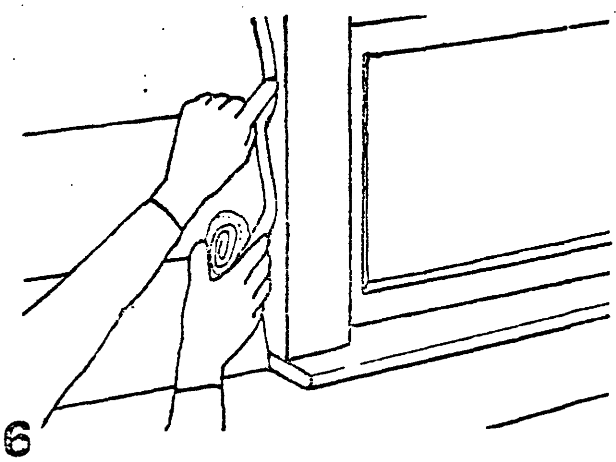
4

Fill extra wide cracks like those at the sills (where the house meets the foundation) with oakum, glass fiber insulation strips, etc.)



5

In places where you can't quite fill the gaps, finish the job with caulk.



6

Caulking compound also comes in rope form. Unwind it and force it into cracks with your fingers. You can fill extra long cracks easily this way.

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