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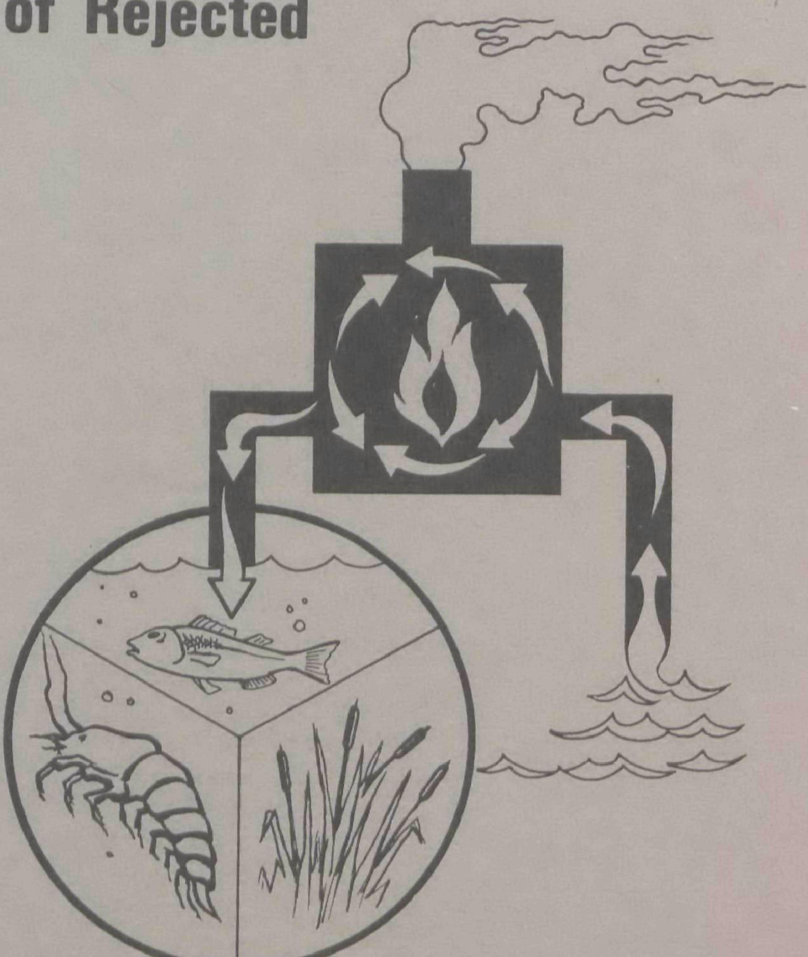
A SURVEY OF ALTERNATE METHODS FOR COOLING CONDENSER DISCHARGE WATER

Total Community Considerations in the Utilization of Rejected Heat



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A SURVEY OF ALTERNATE METHODS FOR COOLING CONDENSER DISCHARGE WATER

Total Community Considerations in the Utilization of Rejected Heat

by

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for the

ENVIRONMENTAL PROTECTION AGENCY

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ABSTRACT

The quantities of electric energy consumption and associated heat rejection quantities, their present and projected allocation throughout the different sections of the country, their relation to other forms of energy consumption are reviewed and tabulated. Thermodynamic constraints on a solution to the thermal pollution problem are defined. Feasibility of possible application of waste heat usage are reviewed in the field of heating and air-conditioning, aquaculture, process industry, irrigation, sewage treatment, desalination, snow or ice melting and integration with municipal water system.

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Section 1

INTRODUCTION

1.1 Overall Program Goals

In December 1968, Dynatech R/D Company initiated an investigation for the Federal Water Pollution Control Administration with the overall aim of surveying and providing a comprehensive, economic analysis of alternate methods for cooling condenser discharge water from thermal power plants. The program was structured to focus on three aspects of the overall problem in a two phase study. The three subject areas were:

1. Large-Scale Heat Rejection Equipment
2. Power Plant Operating Characteristics
3. Total Community Considerations

The first phase of the effort was to bring together available information on state-of-the-art technology in each of these areas. The second was to propose and evaluate advanced concepts. This report will present the results of the total effort of Task III - Phase I and Task IV - Phase II of this study --- Total Community Consideration in the Utilization of Heat Rejected from Thermal Power Plants.

1.2 Consolidation of Phase I and Phase II

It became clear at the outset that a distinction between state-of-the-art and "advanced concepts" in the area of Total Community Considerations was an artificial one. There were, in fact, no instances of what could be called state-of-the-art concepts in that no installations existed in which beneficial, community-oriented distribution of the waste heat was being carried out. The occasional instances of warmed waters leading to apparently increased fish catches were purely fortuitous.

Such consideration as had been given to beneficial uses of waste heat was usually in the category of non-technical speculation. Most of the proffered concepts fell short in that they

1. did not really understand what constitutes a "solution" to the problem of thermal pollution; or
2. did not appreciate the simple "problems of scale" which are involved in the quantities of heat rejected from a modern power plant.

It was recognized that none of the concepts were developed to a sufficient degree to permit even the crudest economic analysis. The best that could be accomplished within the scope of this program was the identification of those areas where

1. a real need existed in the community which could be met in a technologically reasonable way with low temperature heat; and

2. a capacity match with the heat rejection requirements of modern power plants.

3. a consideration of the technical and economic feasibility of moving away from centralized power generation based on the steam cycle.

1.3 Scope of Present Task -- Format of Report

This task, as reflected by the format of this report, was broken into three parts. The first part, documented in Section 2, constituted a review of the magnitude of the problem. That is, the quantities of electric energy consumption and the associated heat rejection quantities, their present and projected allocation throughout the different sectors of society, their relationship to other forms of energy consumption are reviewed and tabulated. A clear definition of the thermodynamic constraints on a "solution" to the thermal pollution problem is provided. Finally, a number of possible applications of waste heat usage are reviewed. From these,two areas are chosen for further consideration and the reasons for these choices are documented.

Sections 3 and 4 deal with the two areas selected for further consideration in the integration of a power plant with the larger community. These areas are "High Density Population Centers" and "Aquaculture".

Section 5 provides a brief introduction to some of the recent concepts of total-energy systems based around the gas turbine. This refers not to the simple adoption of gas turbine units to meet peak loads in conjunction with steam plants, but to the decentralization of electric power production. This would be accomplished through the distribution of gas turbine driven generators throughout the load using region and the extraction of high temperature waste heat from the turbine exhausts for the fulfillment of all energy requirements which can be satisfied by heat input.

Section 2

INTEGRATION OF THE POWER PLANT WITH THE COMMUNITY

2.1 Thermal Pollution -- What Is "A Solution"

Ever since the ecological dangers of uncontrolled rejection of large quantities of heat to our environment became widely recognized and identified as "thermal pollution," a favorite subject of speculation among "pseudo-scientists" and the popular press has been on "ways to use waste heat." Many of the proposed solutions, while creative and ingenious, often lose sight both of the nature of the problem and of the simple fact that energy does not simply "go away" when it is put to some use in a process. It is well, at this stage, to review the fundamental thermodynamics of the thermal pollution problem and to define what can be considered to be "a solution."

The thermodynamics of the electric power generation cycle are straightforward. Figures 2.1 and 2.2 present the basic block diagram and thermodynamic state diagram (temperature/entropy) for a simple, idealized Rankine power cycle.

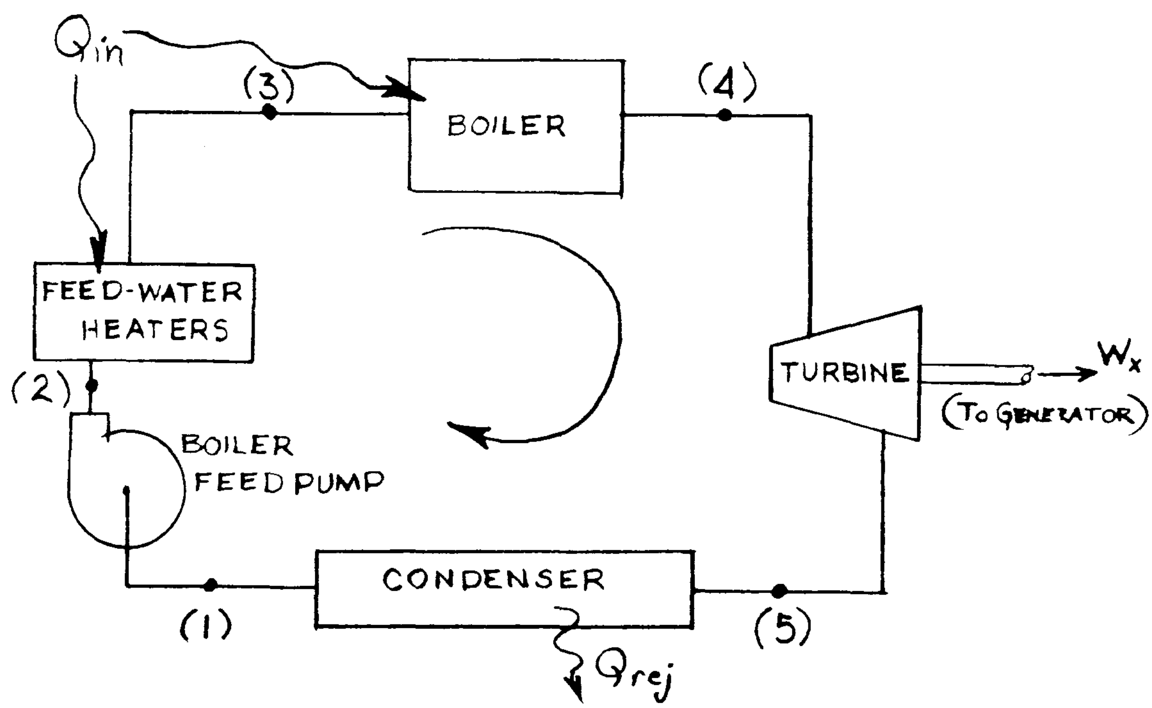


Figure 2.1
Block Diagram of Simplified Power Cycle

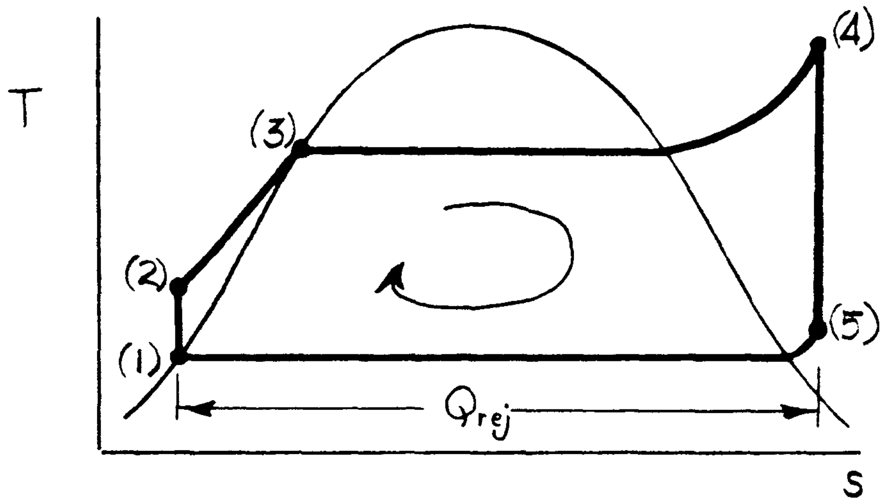


Figure 2. 2
Idealized Thermodynamic State (T-S) Diagram

The second law of thermodynamics, which states that "a system cannot operate in a cycle, and produce net work, while exchanging heat with but a single reservoir and that such a device constitutes a 'perpetual motion machine of the second kind' " defines the amount of heat which must be rejected in the condenser. In simpler, physical terms, this results from the fact that, if the vapor were compressed back up to turbine inlet pressure (p_4) without being condensed, more work would be required by the compression process than is produced in the expansion through the turbine.

It is possible, through the use of auxiliary equipment (feed water heaters, extraction steam, reheats) to reduce the thermodynamic inefficiencies and to approach a theoretical maximum efficiency. (References 2.1 and 2.2.) This theoretical maximum efficiency, known as the Carnot efficiency, is set by the maximum and minimum cycle temperatures and is approximately

$$\left.\begin{aligned} \eta_{max} &= 1 - \frac{T_{min}}{T_{max}} \quad (^\circ\text{Rankine}) \\ &\cong 1 - \frac{70 + 460 \ (\sim \text{ambient})}{700 + 460 \ (\sim \text{critical point})} \\ &= 1 - 0.46 \\ &= 54\% \end{aligned}\right\} \qquad (2\text{-}1)$$

Present day plants operate at lower cycle efficiencies. The actual efficiencies depend on the tvpe of plant and some representative values are summarized below:

Fossil	38 - 40%	
Nuclear, lightwater	30 - 33%	(2 - 2)
Nudlear, gas-cooled	37 - 39%	

These actual efficiencies represent an economic optimization since plant designs which yield higher efficiencies entail greater increases in capital costs than can be recovered in reduced operating costs. Furthermore, while increases in efficiency over typical present-day values toward the theoretical maximum do yield significant reductions in quantities of rejected heat, even if the maximum efficiency were immediately attainable, the projected growth rates in electric power consumption would soon wipe out these gains.

A sample calculation is given below.

From a simple heat balance:

$$Q_{rej} = \text{Mwe} \left\{ \frac{1}{\eta} - 1 \right\} \qquad (2\text{-}3)$$

Therefore, for a 500 Mwe plant, a typical heat rejection requirement for present-day plants might be

Fossil: $$Q_{rej} = 500\left[\frac{1}{.38} - 1\right]$$

$$= 815 \text{ Mwe} = 2.78 \times 10^9 \ \frac{\text{Btu}}{\text{hr}}$$

Nuclear: $$Q_{rej} = 500\left[\frac{1}{.32} - 1\right]$$

$$= 1,065 \text{ Mwe} = 3.65 \times 10^9 \ \frac{\text{Btu}}{\text{hr}}$$

while if the maximum efficiency were attainable

Carnot: $$Q_{rej} = 500\left[\frac{1}{.54} - 1\right]$$

$$= 425 \text{ Mwe} = 1.45 \times 10^9 \ \frac{\text{Btu}}{\text{hr}}$$

which is about one-half of a well-designed, present day fossil-fuel plant. However, with expected growth rates of total power consumption of 7-8% per annum, even this advantage would be nullified in eight to ten years.

However, the problem is not definable simply in terms of the total amount of heat rejected in the power plant condensers. The identification of heat as a pollutant comes primarily from the localized nature of the thermal discharges. Two items point this out. First, even though the quantities of energy involved in thermal discharges are huge, they are still small in terms of the overall heat balance on the surface of the earth. Crude estimates of the incident solar radiation on the continental United States indicate an average heating rate of the order of 5×10^8 Mwe. The total installed capacity of electric power in the United States is approximately 3.3×10^5 Mwe (Reference 2.3) or less than one-tenth of 1% of the solar incidence.

Second, it is clear that if the basic concern is that of quantities of heat released to the environment, then not only the "rejected heat", but the useful power generated as well, must be included since virtually all of the generated power is eventually, either directly as in resistance heating elements, or indirectly as in light or motors, dissipated to the surroundings in the form of heat. Again, although these quantities are great, they are small in comparison to a global heat balance.

The identification of heat as a pollutant, therefore, is only relevant if the dissipation is so localized as to cause significant temperature rises in natural waterways so as to cause ecological imbalance. Even the distinction between once-through cooling and the use of cooling towers is really only one of alleviating local effects in natural waters, since the ultimate heat rejection mechanisms of evaporation and conduction to the atmosphere are the same in both cases. There is, in fact, no present alternative to rejecting heat to the atmosphere, but this appears acceptable at the present time simply because the atmosphere represents a vaster sink than any natural waterway and is capable of dispersing local disturbances more quickly.

Therefore, in order to qualify as a "solution" to thermal pollution, a heat rejection or usage technique must do one of four things:

1. reject the heat directly to the atmosphere in a way which, although still localized, does not involve natural waterways (cooling towers, air-cooled condensers, etc.)
2. reject the heat over a wide area (decentralize the rejection process) in a manner similar to the way the electrical power itself is eventually dissipated (district heating, defrosting of highways, irrigation)
3. use the heat in such a way as to satisfy (1) or (2) and, at the same time, reduce the demand for electricity (district heating, industrial process)
4. use the heat in such a way as to generate additional profitability to bear the cost of solutions of type (1) (aquaculture, recreational sites, sewage treatment).

The integration of the power plant with the community in such a way as to insure solutions of these types was first seriously studied in regard to underdeveloped nations (and quite unrelated to the question of thermal pollution) in a study performed at Oak Ridge National Laboratory and reported on to the AEC in 1968 (Reference 2.4). The concept was referred to as an "Agro-Industrial Complex" and centered around a nuclear-fueled power plant. It was intended to be a $1-billion unit, operated by a community of approximately 100,000 farmers, factory workers and their families, producing food and water for about 5 million people. Here the major concern is the production of food from formerly arid land, and most of the electric power would go into desalination and into some industrial processes related to the recovered salts and chemicals. The waste heat would be rejected to the irrigation system. While this sort of technology is not relevant to our industrialized, non-arid society, the inter-related systemic approach reflected in the concept is the key to the simultaneous implementations of the four criteria set down as necessary for "solutions."

2.2 The Magnitude of the Problem

In Section 1 it was implied that a large part of the difficulty in dealing with the thermal pollution problem derived from the enormous quantities of heat to be handled, while in Section 2.1 it was suggested that the overall quantities of heat are small on a global basis. While this is an apparent contradiction, the essence of the problem has been shown to be the intense localization of the power generation sites and the thermal discharges.

The economics of power generation have tended to intensify the problem of localization. As was shown in Reference 2.5, the average plant size has steadily increased until single units of 1000 Mwe or above are not uncommon. From the point of view of thermal pollution, just the opposite trend would be more favorable. Individual gas turbine/generator units in each dwelling or factory, while posing difficult maintenance problems and perhaps contributing more heavily to air pollution, would represent an improved situation with regard to thermal pollution.

In addition, the major users of electric power, namely industry and large population centers, tend to cluster together into densely populated urban regions. In order to decrease transmission costs, the power plants also cluster in selected locations, and, in an attempt to maximize operating efficiencies, prefer to utilize once-through cooling with minimum condenser cooling water temperature rises. Therefore, the rejected heat intrudes on the environment in a concentrated form involving a tremendous amount of energy in a small geographical areas. The simple dissemination of this heat over a sufficiently wide area as to minimize its consequences involves considerable distribution problems while the utilization of the heat in areas close to the power plant normally results in a bad capacity match.

It was suggested that one response might be to utilize waste heat in such a way as to supplant the need for prime energy (electric power) and hence reduce the total amount of required heat rejection. To evaluate the possibility of that approach, it is necessary to know the present and projected breakdown of power demands. The following tables indicate the distribution of required power by user category and application.

The total capacity figures, both installed capacity and net generation are listed through 1980 in Table 2.1. The fraction of the total attributable to nuclear plants is indicated.

	1960	1965	1970	1975	1980
Total Inst. Cap. (Thous. Mwe)	168	236	328	440	575
Nuclear	0.1	0.9	11.7	51	120
Percent Nuclear	--	--	3.5%	11.5%	21%
Net Generation (bkwh)	753	1055	1461	2009	2730
Nuclear	0.1	4	72	337	814
Percent Nuclear	--	--	4.9%	16.8%	29.9%

Table 2.1
Power Generation - Projected Growth

In comparison to the total energy consumption in the United States, which has grown at approximately 3% per year for the past thirty years (Reference 2.3), electrical energy has grown at more than twice that rate (~ 7% per year). While in 1965, electric power accounted for approximately 20% of all the energy consumed, by 1980 it is expected to represent nearly 30%.

The distribution of electric power consumption among different classes of users, as of 1965, is indicated in Table 2.2.

	% of Output (-)	Generation (bkwh)	% of Revenue (-)
Industrial	45%	475	26%
Commercial	21%	222	28%
Residential	30%	317	42%
Other	4%	41	4%
		Total:	~ $15 x 10^9$

Table 2.2
Distribution of Electric Power Usage -- 1965

The distribution in the future is expected to shift slightly toward increased industrial use, with the residential market continuing to represent approximately 1/3 of the total usage.

	1965		1980		2000	
	bkwh	%	bkwh	%	bkwh	%
Industrial	475	45	1100	55	2240	56
Commercial	222	21	308	15	554	14
Residential	317	30	594	30	1188	30

Table 2.3
Projected Distribution of Electric Power Usage

2.2.1 The Residential Market

In terms of the residential market, the biggest potential increase in consumption is electric space heating followed by air-conditioning.

The total energy per household required for space heating is expected to decrease with the result that between 1960 and 2000 the following changes are expected:

Population	+ 84%
No. of Households	+ 89%
Energy for Heating	+ 50%

This apparent discrepancy is due to these items:

1. increased use of the "heat pump" concept with effective "efficiencies" of 200-300%.
2. gradual population shift to warmer climates.
3. increased use of multiple-family dwellings (higher ratio of inside space to outside walls).

Since an electrically heated home consumes approximately 20,000 kwh annually as compared to only 5,000 kwh for non-electric, the power industry has set a target of 19 million electrically heated homes by 1980. The "best" estimates from several sources of the breakdown of the residential market are given in Table 2.4.

	Total Usage Totals - Billion kwh			kwh Per Household		
	1960	1980	2000	1960	1980	2000
All Uses	193	594	1,188*	3,669	8,137	11,952
Lighting	43	97	181	817	1,329	1,821
Ranges	21	43	59	399	589	594
Waterheaters	45	120	240	855	1,644	2,414
A/C	7.7	61	130	146	836	1,318
Space Heating	11.7	108	258	222	1,480	2,595
All Other	63.7	165	319	1,211	2,260	3,209

*By the year 2000, electricity will furnish 50 percent of the total domestic energy requirement.

Table 2.4
Breakdown of the Residential Market

Estimated increased use of room and central air-conditioning is given in Table 2.5.

	1960	1980	2000
Millions of Households	52.6	73.0	99.4
With Central A/C	0.5	12.7	43.7
With Room A/C	7.4	29.2	34.8
Consumption of Electricity			
per Central A/C Unit (kwh)	3500	3200	2500
per Household w/Room Unit (kwh)	800	700	600
Aggregate Annual (bil. kwh)	7.7	61.0	130

Table 2.5
Projected Increase in Power Required for Air-Conditioning

Clearly, any approach which will provide heating and air-conditioning from non-electric sources will constitute a proper "solution" in that the demand for electric power will be greatly reduced, the heat release will be dispersed over a wide geographical region, and considerable profit potential can be realized for heating and air-conditioning of large population centers. These possibilities will be explored more fully in Section 3.

2.2.2 The Industrial Market

A recent publication by ORNL for the Department of Housing and Urban Development (Reference 2.6) has provided estimated projections of energy consumption by United States manufacturing industries for 1980. In this study, which sought to identify possibilities for the use of low-temperature heat in urban areas, six industries were identified as major users of process heat. These were (1) food products, (2) paper products, (3) chemical products, (4) petroleum refining and related industries, (5) rubber and plastic products, and (6) textile mill products. Estimates of steam consumption for those industries ranges from 2,000-3,000 bkwh which is roughly equivalent to the projected electric power generation for 1980 (see Table 2.1). Therefore, a rough scaling indicates that a significant amount of thermal discharge from power plants might be utilized by an urban center's manufacturing plant if the area served by the electric plant had a fraction of the nation's steam-consuming industries roughly equivalent to its fraction of the nation's population.

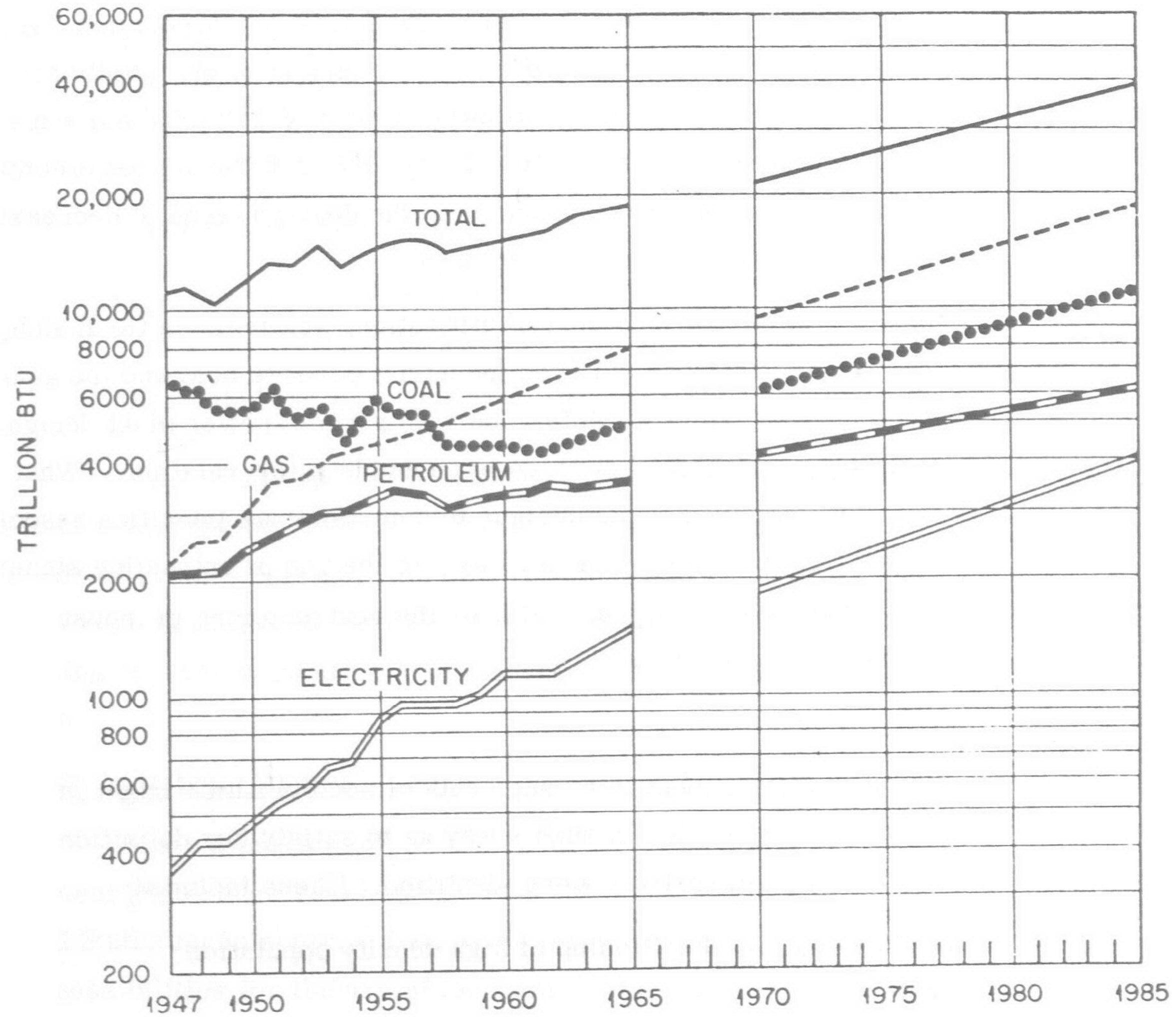
A comparison was provided for the amount of steam consumed per kilowatt-hour of electricity used for these same industries over the last few years and similar comparisons projected forward into the 1980's. Figure 2.3 indicates these comparisons based on figures from a study by the Texas Eastern Transmission Corporation. A brief summary of these results indicates that the relative amount of electricity are rising and that, while the pounds of steam per kilowatt-hour of electricity was once in the range of 30 lb/kw, it had declined to less than 10 lb/kw by 1965, and is expected to continue tc decrease in the future. This is, of course, counter to the desired trend of decreasing the demand for electricity by utilizing heated discharge.

The primary difficulty in this sort of utilization, however, is the match, or mismatch between the required temperature for industrial process heat and the available temperature of discharges. It is expected that with present power plant designs and present manufacturing processes, that there is no useful inter-relation. What would be required, are analyses of turbine designs to determine the penalties associated with very high back pressure turbines, considerations of the use of extraction steam from power plant boilers to reduce electrical demands, or the restructuring of industrial processes to operate at lower temperatures.

2.3 Potential Areas

As a first approach to identifying segments of society which might inter-relate with the power producing sector in such a way as to satisfy our definition of a "solution," a number of these alternatives were identified. These included:

1. heating and air-conditioning of high density pppulation centers
2. aquaculture
3. process industry
4. irrigation
5. sewage treatment
6. desalination
7. snow or ice melting
8. integration with municipal water system



Source: Competition and Growth in American Energy Markets 1947-1985, Texas Eastern Transmission Corp., Houston, Texas, 1968.

Figure 2.3
Ratios of Total Energy Consumed to Electric Power

Of these, only the first was considered to represent a reasonable concept which satisfies the criteria for a solution to the thermal pollution problem at the time. Aquaculture, while possibly representing a source of additional profitability as required by criterion #4, has ill-defined energy requirements and ecological side effects. Chapter 4 attempts to categorize what information exists in this area, but further consideration of aquaculture as an immediate solution to thermal pollution power plants is not recommended.

The fourth area, irrigation, has been suggested as a menas for disposing of condenser discharge water. This would appear to be an acceptable solution, satisfying the criterion of decentralizing the heat rejection process and possibly serving as source of revenue. While the water will eventually return to the waterways through natural run-off, the processes of evaporation (particularly in the case of spray irrigation) and interaction with the ground should ensure that the run-off is at essentially "ambient" conditions. A possible site benefit to the use of warmed water for irrigation purposes might be a slight lengthening of the growing season through a warming of the soil. This has been demonstrated on a laboratory scale but how to take advantage of this effect in a reliable manner is not yet well understood.

Some disadvantages are noteworthy. First, irrigation itself has been recognized as a form of thermal pollution, particularly if ditch-type irrigation methods are used. Water as it is held up in the irrigation ditches is warmed by the sun and can return to the river at elevated temperatures. The use of initially warmer water will probably not have much effect on the final equilibrium temperature, however.

Second, while the use of the discharge water for irrigation does eliminate the problem of highly localized, high temperature mixing regions in the river at an outfall, it can represent an enormous decrease in flow rate of the river for a great distance below the plant with resultant changes in the waterway which are both thermal and physical. Furthermore, those organisms which are entrained in the intake and which might have survived a brief heating and quenching are almost certainly doomed if they are held at elevated temperatures for long periods of time while being used in an irrigation system (Reference 2.7). In addition, the run-off of nutrient-rich water from the fertilized fields can have its own effect, for good or ill on the ecology of the river (Reference 2.8).

Finally, the potential hazards of contamination of edible crops by these amounts of radioactive materials in the condenser water and any associated naturally occurring concentrating mechanisms should be investigated thoroughly before giving further consideration to such a scheme.

The use of heated discharges in conjunction with sewage treatment plants seemed inappropriate for three reasons. First, and foremost, in order to produce attractive benefits to any aspect of sewage treatment temperature levels far in excess of any that might reasonably be expected from even highly futuristic plant designs were required (of the order of 200-250° F at a minimum) (Reference 2.9). Second, the capacity matches were poor. It was difficult to see how any sewage treatment plant of a size commensurate with a given population could use even a few percent of the heated discharge from a power plant a size appropriate for the same population. Third, the thermal pollution load would simply be transferred from the power plant to the sewage plant with no net benefit to the environment. Each of these considerations applies in equal measure to the use of waste heat for desalination purposes. In this case, a proper capacity match, while not even close for municipal water, could perhaps be attained if one considered desalination of sea water for irrigation. While this may have some merit (Reference 2.4), the problems of intrusion on the environment which are posed by the desalination and irrigation processes far exceed the simple thermal pollution from power plants (Reference 2.10).

The use of water heat for melting snow and ice on highways or for maintaining ice-free navigation routes has been discussed at some length in the popular press. The use of the heat on highways appears to provide insurmountable distribution problems and, even in the northern-most areas of the country, provides a suitable heat sink only for a small fraction of the year, and, in particular, that fraction of the year for which thermal pollution is not a severe problem. Furthermore, the installation of piping in the roadways would add enormous costs to highway construction. While the same can be said for ice-free navigation routes, the distribution problem and construction problems are not nearly so acute. A serious study of this application of waste heat to maintaining the St. Lawrence Seaway in an ice-free condition was carried out by Dingman et al of the Cold Regions Lab at Hanover, New Hampshire (Reference 2.11).

The abstract of this report is repeated:

An attempt is made to calculate the length of the ice-free reach that develops during the winter below a thermal pollution site on a river. A differential equation for the steady-state heat balance of a volume element of a river is developed, which leads to the expression

$$x = C_x \int_{T_{wo}}^{T_{wx}} dT_w/Q^*$$

where x is distance downstream from the pollution site to the cross section where the water temperature equals T_{wx}, T_{wo} is water temperature at x equals zero, Q^* is rate of heat loss from the water surface, and C_x is a constant that includes flow velocity and depth. The value of x at T_{wx} equals 0°C is taken as the length of the ice-free reach. Q^* is the sum of heat losses due to evaporation, convection, long- and short-wave radiation, and other processes, each of which is evaluated by an empirical or theoretical expression. The two principal limitations in accurately calculating downstream temperature changes are related to difficulties in evaluating the degree of lateral mixing in natural rivers and the convective and evaporative heat losses under unstable atmospheric conditions. Observations of lengths of ice-free reaches on the Mississippi River are in good agreement with the calculated values. Significant portions of the St. Lawrence Seaway can be kept ice-free by the installation of nuclear reactors at appropriate locations.

Table 2.7 indicates a comparison of the results obtained from the analysis with those observed at two locations on the Mississippi River. The agreement is reasonably good.

A review of conditions on the St. Lawrence Seaway which is closed by ice for 3-1/2 to 5 months each year indicated that the proper location of nuclear plants in the 1,000 to 3,000 Mwe size range could effectively lengthen the shipping season and perhaps keep the seaway open year round. No account was taken of the possible ecological effects of this practice nor were any considerations made of how to reject the heat in the remaining 7 to 10 months. For these reasons, this concept was not pursued further.

	Riverside				Highbridge			
			Calculated Length				Calibrated Length	
Date	Observed Area km^2	'Observed' Length km	Russian Winter Eq. km	Kohler Eq. km	Observed Area km^2	'Observed' Length km	Russian Winter Eq. km	Kohler Eq. km
Jan 65	2.169	12.0	17.9	26.6	4.597	40.0	42.6	62.5
Jan 65	0.777	4.3	4.3	7.0	0.882	7.8	11.8	18.6
Feb 65	0.890	4.9	5.8	10.0	1.036	9.0	15.1	25.6
Jan 66	---	---	---	---	2.428	21.2	15.7	21.8
Jan 66	2.023	11.3	16.0	28.9	4.233	36.8	11.3	73.2
Jan 66	1.311	7.3	3.2	5.8	1.546	13.4	12.1	21.2
Jan 66	1.287	7.2	3.5	5.3	1.076	9.4	10.4	13.8
Feb 66	2.161	12.0	17.1	60.8	5.063	44.0	39.5	124.6

Table 2.7
Ice-Free Reaches for Heated Water Discharge

A final concept was the use of municipal water supplies as cooling ponds. It was felt that, at least for the residential market, much of the water consumption was either for purposes for which the temperature was not critical or required further heating. Therefore, the possibility of having city water enter the home at somewhat higher temperatures (70 - 90°F) (with perhaps each home provided with a small chiller unit on the sinks for drinking water) might well be acceptable and result in a reduction of domestic electric consumption.

It was found, however, that residential usage of municipal water normally represents a small fraction of the total usage, most of which is consumed by industry for cooling. On this basis the 1968 report of the Technical Advisory Committee (Reference 2.12) recommends strongly against "any water temperature change that decreases the acceptability of the water for cooling and drinking purposes. Brief computations, based on electric power consumption and water usage in the Boston area, also indicate a somewhat unfavorable capacity match involving water temperature uses of the order of 50°F to 100°F. This, of course, could be alleviated by using the water supply as only a partial solution but gives further evidence of the magnitude of the problem.

2.4 Conclusions

The essential conclusion of these considerations is that the concept of using waste heat from steam power plants as a solution to the problem of thermal pollution is probably not a viable one. Of all the areas considered, only the heating and air-conditioning of buildings gives a reasonable capacity match at conceivable temperature levels without major modifications to existing cycles and processes. Even here, the distribution problems are formidable, and the seasonal fluctuations in hot water demand do not correspond well to seasonal variations in electric power demand. However, as will be documented in Section 3, such an integration has been accomplished in certain European installations and should be kept in mind.

It seems clear, however, that the continuing use of centralized Rankine cycle steam power plants for the nation's power production will inevitably result in large localized thermal discharges to the environment. Furthermore, the only feasible approaches to this situation are the following.

1. the use of heat dissipation equipment such as cooling towers to protect natural waterways by rejecting directly to the atmosphere.

2. a reversal of the trend toward large central power plants and the increased use of small total-energy systems each tied to a particular user.

REFERENCES -- Section 2

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Section 3

HIGH DENSITY POPULATION CENTERS

The heavily populated areas of the United States, particularly cities in which builders are in close proximity to one another, are not only heavy users of electricity, but may also be potential users of waste heat from power plants. District heating is discussed below as one of the more promising potential uses of low grade heat.

3.1 District Heating

The first successful attempt at district heating took place in Lockport, New York in 1877. This installation involved a short underground steam line supplying steam to a small number of residences. Since this first attempt, district heating has become reasonably popular in the major population centers. Figure 3.1 indicates the locations of a number of such systems, both steam and hot water in the United States and Canada.

Figure 3.1
Locations of District Heating Plants in U.S. and Canada
(from Reference 3.2)

Although some early district heating systems in the United States used hot water as a heating medium, most present systems use steam, generated solely for heating purposes. In a few cases (Reference 3.1), electricity is generated when the heating demand is small, and supplied to the local electrical system, but these operations normally represent economic compromise. It should also be remembered that an enormous quantity of low grade waste heat is generated in the United States, and this total heat would be more than sufficient to heat every home in America (see Section 2.2). Furthermore, the usefulness of this concept is limited to the northern half of the country during the winter months.

Some low-pressure hot-water systems (with temperatures up to 200°F) were installed in the early days of district heating. Due to the advantages of steam over hot water most of the systems built in the United States during the past twenty-five years use steam except a number supplying small groups of buildings, such as institutions. In 1949 there were in the United States seventeen hot-water systems and eighteen systems supplying both steam and hot water commercially. Of the latter, some have converted portions of their hot-water systems to steam.

The use of high-pressure hot water as a heat-distributing medium has been successfully developed in Europe. These systems are quite different from the conventional hot-water systems in this country. The high price and shortage of fuel in Europe require more complete utilization of the heat content in fuel at the expense of higher investment.

3.1.1 Tapiola Garden City, Finland (Reference 3.4)

A rather unique experiment has taken place in Finland, and appears to have been successful.

In 1952, a private non-profit organization, Asuntosaatio (Housing Authority) purchased 670 acres in the rural district of Espoo, outside the city of Helsinki, and planned a modern garden city for 17,000 inhabitants.

The community, called Tapiola Garden City, was planned from the beginning from virgin country. A population density of 26 persons per acre was planned, and a district heating system supplying both heat and electricity for the entire community was built. This district heating system even supplies heat to single family dwellings.

The climate of Finland allows this district heating system to be economical. The heating season in Finland is 270 days per year. The mean temperature of the heating season is 33.1° F. The heating system has been designed for -16.6°F.

The turbines used for generating power are back pressure turbines, and the return water from the district heating system is used as cooling water for their condensers.

Electricity generation is independent of the heating load of the city through the installation of a 2-1/2 acre spray pond at the town center. The cooling spouts in the pond can be adjusted in height up to 69 feet and serve both as cooling controls and park decorations.

While the overall thermal efficiency of this plant is quite high (80.8% including line losses) the efficiency of the electrical power generating operation is only 25%.

Approximately 62% of the electricity generated has been used in Tapiola. The complete Tapiola system is summarized in Figure 3.2.

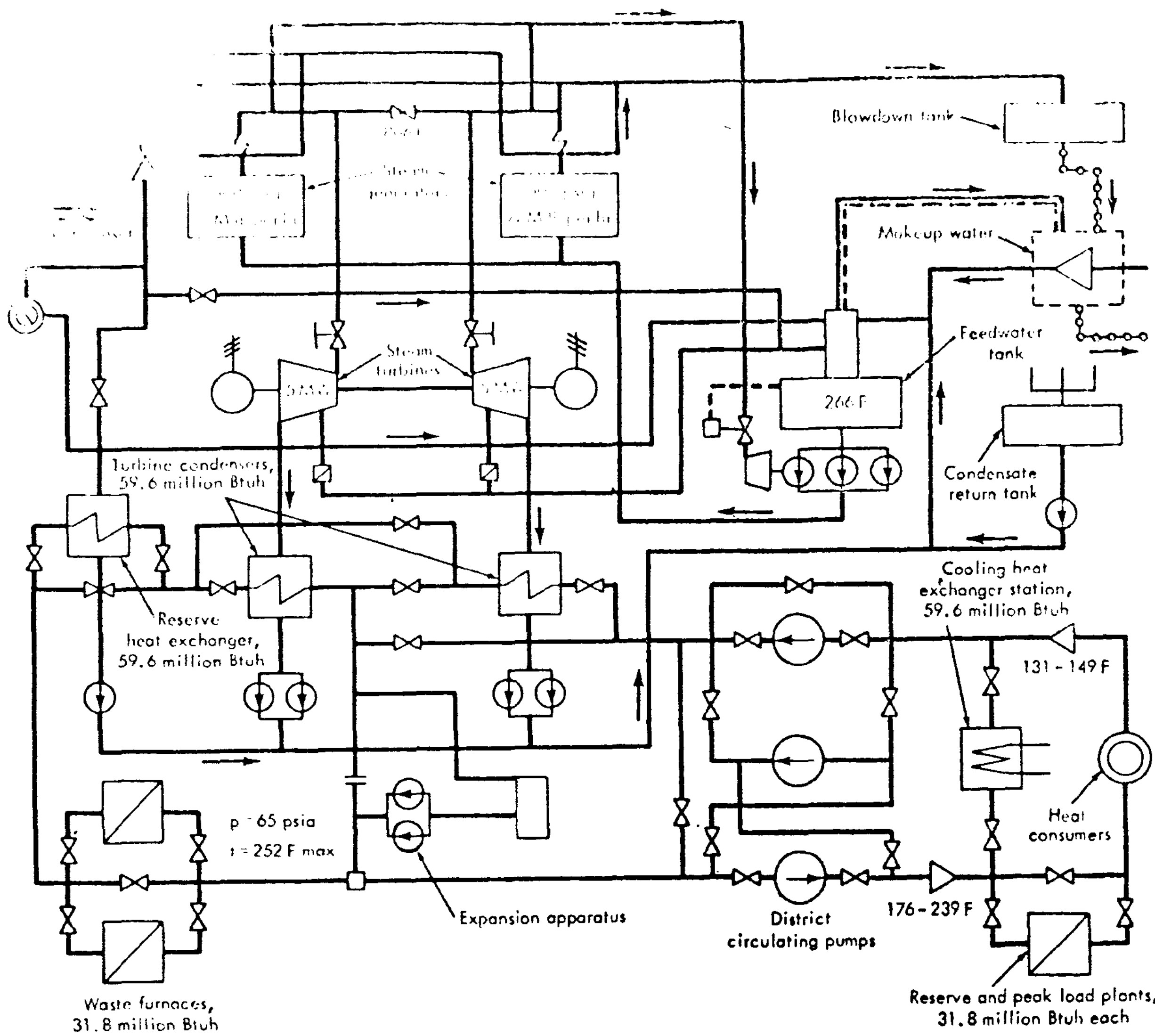


Figure 3.2
Tapiola Garden System

The district heating system was built for a nominal pressure of 142 psia. Its working pressure is 65 psia. The pressure difference at the power plant is 28.4 psia. The distance between the plant and the farthest consumer is 1.74 miles. The total length of the hot water distribution system is 13.7 miles. The temperature of the outgoing water is between 176 - 239°F and the return water is then 122 - 158°F. A typical operating curve is shown in Figure 3.3.

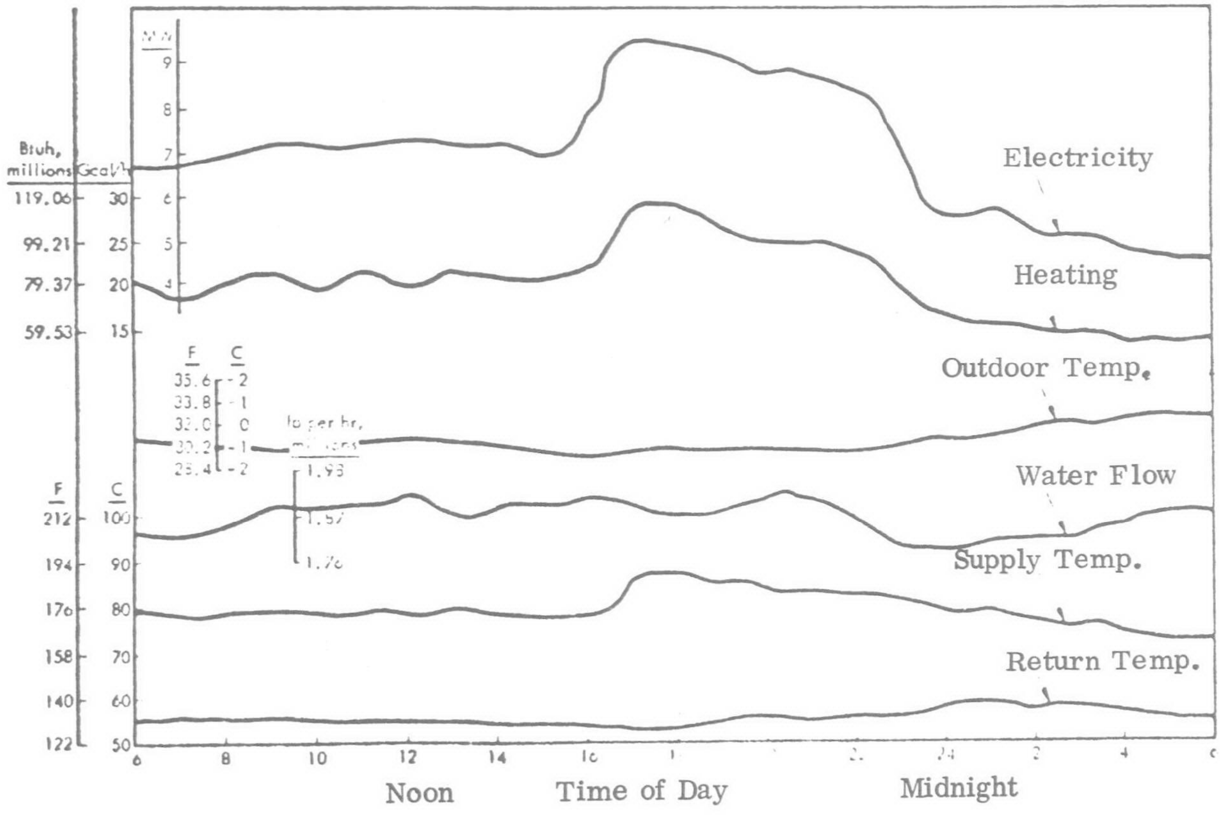


Figure 3.3
Typical Daily Operation

The capacity of this system is summarized below:

Combined Heating Capacity of Power and Heating Plant	15.9 million Btu/hr
Heating Plant C Capacity (peak load plant)	29.8 million Btu/hr
Heating Plant A (reserve plant)	31.8 million Btu/hr
Electric Capacity	12.5 MVA

Table 3.1

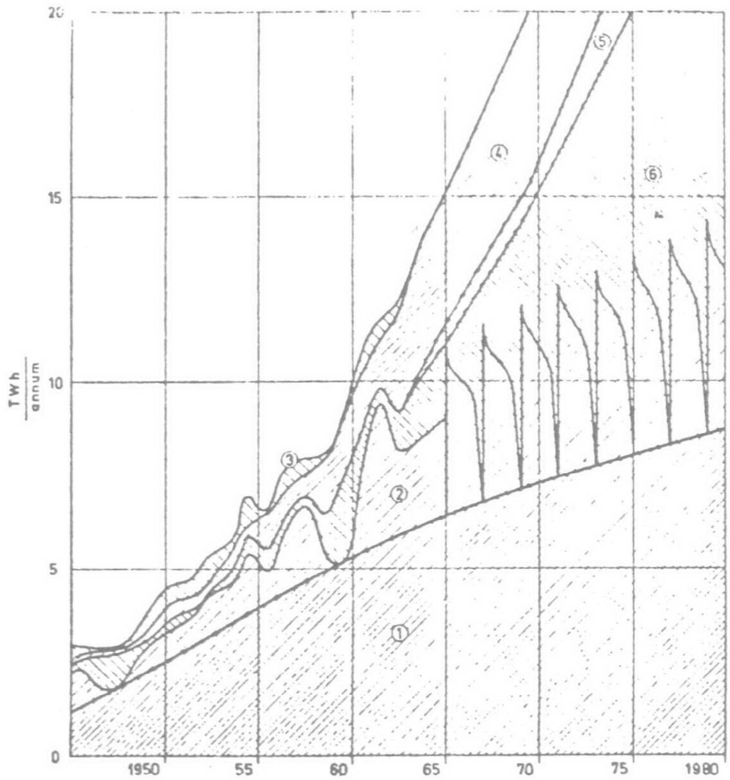
The cost of the district heating system can be summarized as follows:

District and Reserve Heating Plants	$3,156,250
District Heating Network	$2,843,750
Total	$6,000,000

Table 3.2
Cost of District Heating System

3.1.2 Role of District Heating System Power in Finland

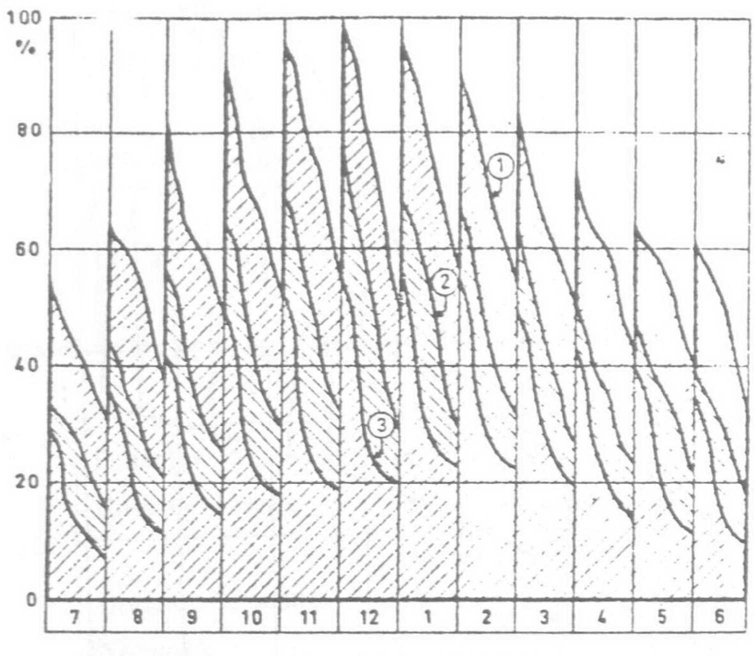
While most of the power produced in Finland at present is of hydro electric origin, the construction of power plants is rapidly becoming necessary due to the almost complete utilization of the available water power. The general structure of the power supply in Finland is illustrated below: (Figure 3.4)



General Structure of Power Supply in Finland
1. Primary water-power; 2. Secondary water-power; 3. Tertiary, water power or surplus; 4. Industrial back-pressure power; 5. District heating power; 6. Independent thermal power. Before 1965–Statistics. After 1965–Forecast.

Figure 3.4

Examination of this figure shows that district heating system produced electricity is, at present, and is forecast to be, only a small part of the overall power generating scheme. Figure 3.5 presents the power demand variations for a number of conditions.

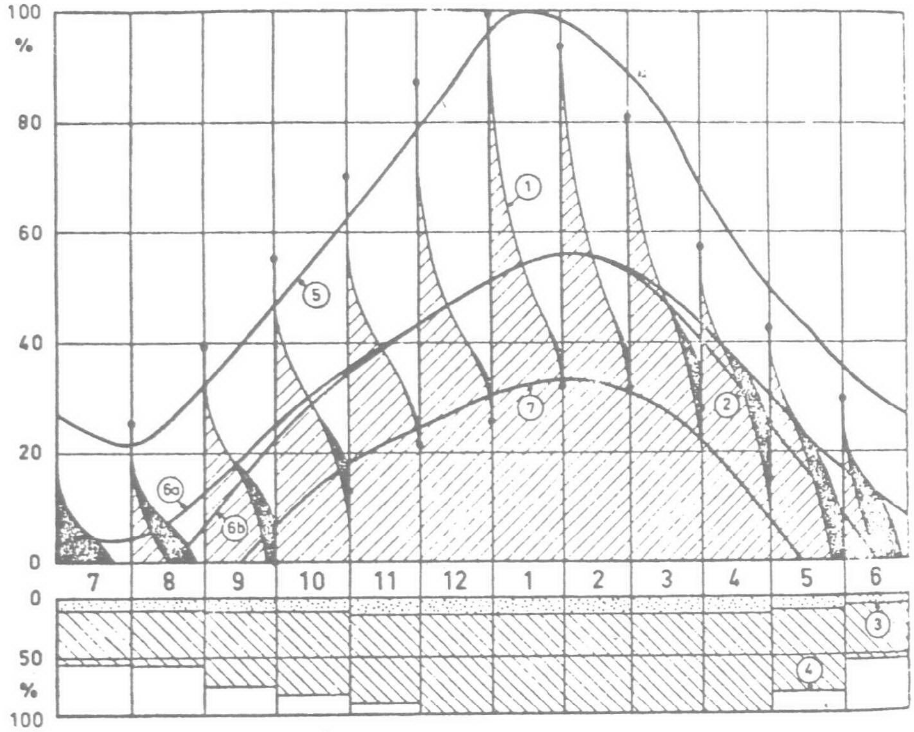


Power Demand Variations

Diagram represents a typical smaller town with the surrounding countryside 1. Day-periods during week-days, 07-22 hours; 2. Day-periods during sundays, 07-22 hours; 3. Night-periods during all days, 22-07 hours. 100% =hourly peak load.

Figure 3.5

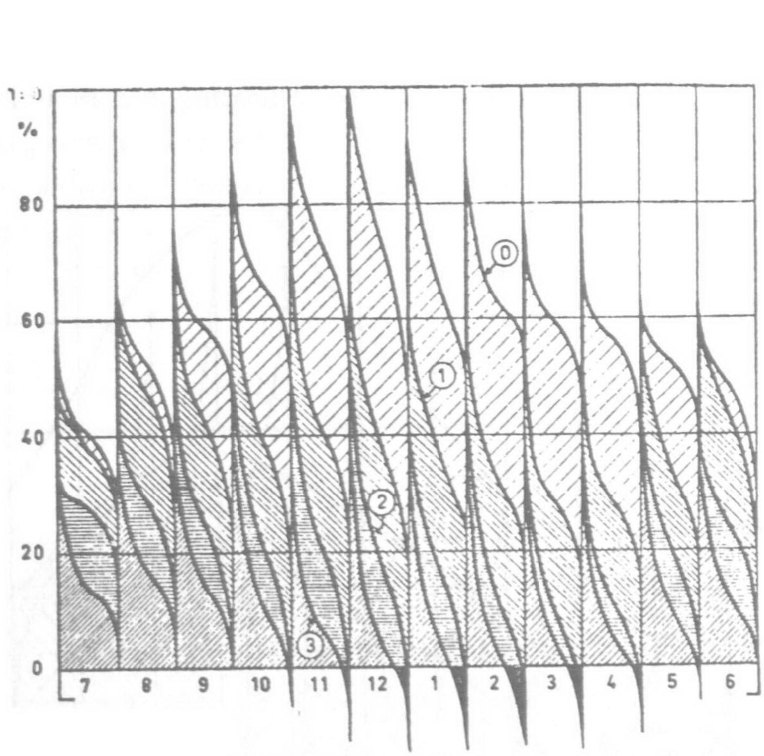
Figure 3.6 presents the variation of heating load in a similar manner.



Basic Data for Heating Load Variations in Finland
1. Conduction and ventilating heat variations, night-periods; 2. Same for day-periods, approximately corrected for sun radiation; 3. Heat demand variations for domestic hot water, night-periods; 4. Same for day-periods; 5. Monthly maximum heat demand for 1; 6. Average monthly heat demand for 1, a) night-periods, b) day-periods; 7. Monthly minimum for 1. The curves 1 are based on daily average out-door temperatures in South-Finland 1931–1960. +20°C=0%, −27°C=100%.

Figure 3.6

Comparison of these two figures will show that the supply of district heating power reaches its maximum in winter at the same time as the maximum demand of electric energy. This fact allows the district heating power to equalize yearly variation of the electrical energy demand, thus improving the load conditions of other power plants. When the district heating power is subtracted from the electric energy demand of the community (Figure 3.5) the remainder represents the amount of power to be purchased. The result is shown in Figure 3.7. Load variations of short duration remain, but the annual variation has been normalized.



Resulting remaining Power Variations

0. Power demand during day-periods, same as curve 1 in Fig. 4; 1. Day-periods during week-days; 2. Day-periods during sundays; 3. Night-periods during all days. Possibilities for day-night regulations has not been taken into account.

Figure 3.7

3.2 Odense, Denmark (Reference 3.3)

The city of Odense, Denmark has about 130,000 inhabitants. This city is served by Fynsvaerket power station which supplies both electricity and hot water. The circulating water is normally heated in heat exchangers by means of steam extracted from the power plant turbines, but additional heaters are provided for standby and peaking purposes. These standby heaters take live steam from the mains.

The mean temperature of the year in Odense, Denmark is 45°F. Its average variation is from a mean of 32°F in February to a mean of 60°F in July. The ratio of district heating load to electrical load varies over a large range. The 1964 average was about 3.2×10^6 Btu/hr per MW, but extremes may range from 1.2×10^6 Btu/hr/MW on a summer day to 12×10^6 Btu/hr/MW during a winter night.

Hot water used in the district heating system is heated in two stages, as indicated below in Figure 3.8.

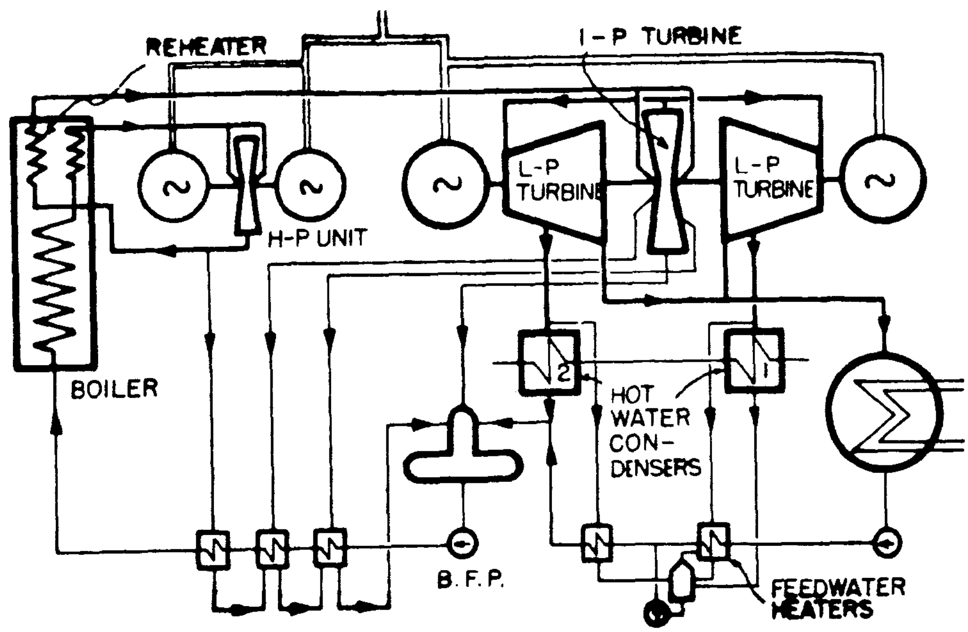


Figure 3.8
Schematic of Odense Hot Water Circuit

Steam is extracted from one low pressure turbine at about 4.2 psia and from the other at about 9.5 psia. Normal hot water inlet is 113°F and outlet is 185°F.

Both extractions are controlled by means of pass-out slide valves which govern the steam flow to the low-pressure stages after the extraction points. This divides the flow to the two heaters in the most economical way at all loads within the governing range.

Figure 3.9 illustrates the principle of the control system.

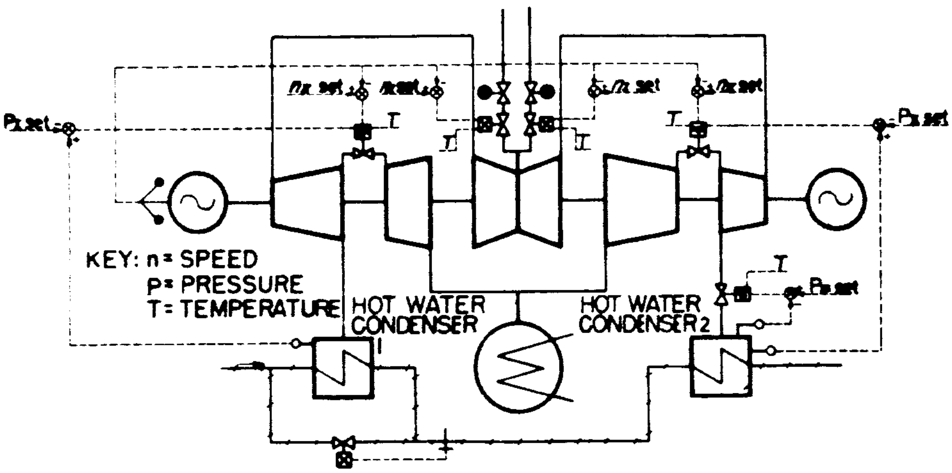


Figure 3.9
Control System Schematic

Measurements of speed, pressure and temperature are combined in the governing action.

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Section 4

AQUACULTURE

4.1 Introduction

The second area of usage which is most often referred to in considerations of the disposition of waste heat from power plants is that of aquaculture. In nearly all surveys of potential uses of rejected heat, this possibility is raised. The specific applications range from the frivolous (raising of ornamental fish) (Reference 4.1), to the "luxury market" (shrimp and lobsters) (References 4.2 and 4.3), to serious considerations of using heat input to the biological cycle to simultaneously cope with the overall systemic problems of world-wide hunger and recycling of human waste into reusable resources (Reference 4.4). Considering the magnitude of the heat rejection problem, it would appear that only a full-scale, serious attempt at aquaculture as part of the basic food chain would be able to utilize a sufficient amount of energy to make the project worthwhile.

It should be emphasized that, in terms of the criteria set forth in Section 2.1, aquaculture does not represent a promising "solution." That is,

1. natural waterways are still involved
2. the heat rejection is not widely decentralized. In fact, the whole aquaculture concept depends on a localized alteration in the natural ecology, albeit hopefully one which is "beneficial."
3. the application does not reduce normal electric power requirements.
4. while some additional profitability may accrue to the power company from food production, the whole process is so far removed from their normal operations, depends on so many factors which they feel are beyond their control, and is so ill-defined both economically and technically, that it is virtually impossible to make a case for aquaculture on economic grounds.

Furthermore, as was indicated in Reference 4.5 in the discussion of cooling canals, the possibility of minute radioactive contaminants from nuclear plants being concentrated in a food chain must always be a paramount consideration. In fact, until sufficient research has been performed to insure beyond question that this possibility does not exist, the potential consequences are so severe that this type of usage should not be attempted.

On the basis of these considerations, it is not felt that the active investigation of aquaculture techniques as an immediate response to the problem of thermal pollution from power plants is justified at this time. However, the need for a substantial increase in the world supply of protein is well recognized. A critical shortage already exists in many parts of the world, and all indications point to increasing deficiencies as the human population continues to outgrow its food resources. Clearly, every possible new source of protein must not only be considered on the theoretical basis of its relative merits, but also it must be brought into actual production as quickly as possible, for only in this way can its potential be properly evaluated and, at the same time, realized and utilized. Among the several possibilities for increasing the world supply of protein is the development and expansion of aquaculture--the rearing of aquatic organisms under controlled conditions using the techniques of agriculture and animal husbandry.

On this basis, the study of aquaculture as a solution to the global food problem should clearly be pursued. In addition, the role that power plants might serve as adjuncts to additional food production should be made known to researches directly concerned with the development of agriculture. Therefore, the following chapter will review what little information has been accumulated in this study, not as a proposed solution to the thermal pollution problem but as a potential resource for another field.

Much of this information has been assembled by Bardach et al in Reference 4.6. The conclusion is that the practice of aquaculture may not only be greatly expanded, particularly in those parts of the world most in need of its products, but also that its yields may be very appreciably increased through the use of modern science and technology. Existing techniques are already available for immediate application and quick return. But the application of scientific methods to the practice of aquaculture is a new and challenging field which holds still greater promise for the future if the research and development capabilities of this and other advanced countries are brought to bear on the problem.

4.2 General Principles of Aquaculture

More or less intensive culture of aquatic organisms, in contrast to their capture from untended stocks, is practiced in many parts of the world. While as yet more prevalent and successful in fresh and brackish waters than in the sea proper, some true marine husbanding operations are being attempted, most notably in Japan, the Soviet Socialist Republic and in Great Britain. No statistical breakdown is available on world tonnage of fish, invertebrates and aquatic plants produced by such active interference of man in the natural life cycles of the organisms or in the management of their environment. If one comprises, for the purpose of this report, under aquaculture any operation that subjects the organisms in question to at least one (but usually more than one) manipulation before their eventual harvest or capture, the total tonnage so produced may lie between 5% and 10% of the total world fish catch.

It has been estimated, only for the fresh and brackish water realm, that consistent application of the best known techniques could raise the fish tonnage produced by aquaculture three to five fold to somewhere around 30 million metric tons. Intensive fish culture (aquaculture) in waters of full marine salinity is in its very infancy; it is technically feasible with some species but it is difficult to project, from present pilot experiments, when, where, and under what conditions larger scale operations might become economically sound.

Fishes are the largest class of vertebrates with some 25,000 species, but one may almost count on the fingers of both hands those that have yielded to attempts at intensive husbandry and even fewer species have been domesticated like some mammals and birds. A still smaller number of aquatic invertebrates have been successfully cultured. However, it is possible today to produce with intensive care significantly larger amounts of high grade animal protein per unit of inshore or fresh-water surface than on fertile dry land. The reasons for this may be found in some basic biological and ecological principles.

Aquatic organisms live in a medium of about the same density as their own. Hence they require less skeletal structure for their support than needed by birds and terrestrial mammals, with a correspondingly greater percentage of their assimilation devoted to the production of edible musculature. The metabolic advantage of aquatic animals lies in their not having to expend a portion of their caloric intake in maintaining a constant body temperature. This advantage would be further enhanced if they were raised in brackish water of an osmotic (salt) level like that of their own body fluids not having to expend metabolic energy in osmoregulatory homeostasis.

It is well-known with regard to the question of metabolic advantage that, while the organisms assume the temperature of their environments, that relatively narrow temperature ranges are acceptable for survival and exceeding narrow limits correspond to conditions for optimum growth. While this is the essence of the thermal pollution threat, it also suggests that a thermodynamic regulatory function could be performed to maintain hatcheries and fish farms at the optimum conditions.

4.3 Some Specific Examples

Much of the advanced research work in developing these techniques has been performed in England. That is due in part to the fact that the average water temperatures there are colder than in the United States and often below levels for optimum growth of even many native species. The efforts of farming sole and plaice are described in Reference 4.7.

4.3.1 Hunterston Nuclear Station

Before embarking on a project the White Fish Authority had to establish that the young hatchery-bred flatfish firstly could be contained, fed and kept alive and equally important, observed. A modest trial was mounted in an enclosed inlet on the west coast of Scotland, and preparations were also made for a trial at a power station. Difficulties were expected from both types of environment, but those at a power station were thought to warrant preliminary trials on a laboratory scale, in tanks both at Port Erin and at power stations.

The laboratory experiments began with a study of the effects of elevated temperatures on the viability of plaice and sole, in order to get some indication of the growth and tolerance within the expected thermal range of the effluent, and also to establish a feeding level with an acceptable food. The results suggested that temperatures of 15°C to 16°C were best for plaice, and 18°C to 20°C for sole. In this initial trial the fish were fed on a diet of chopped fresh mussel flesh (Mytilus edulis) at a daily rate of 10 per cent to 14 per cent and eight per cent to 12 per cent of tank biomass respectively, depending on tank conditions.

Two site trials followed early in 1966, the purpose being to explore the likely effects of chemical additives on the survival and health of the fish. The first trial was held at Carmarthen Bay, a conventional coal-fired station in South Wales, and the second at Hunterston, a nuclear generating station in Scotland. These stations were chosen because they both employ a system of injecting a continuous low level of chlorine into the intake flumes to keep marine organisms from settling. The chemists at Carmarthen Bay had developed the continuous system in an attempt to find an economic and efficient level of chlorine addition. Their technique had later been adopted at Hunterston. In the preliminary experiments no attempt was made to maintain a fixed temperature level as future development would have to accept the diurnal and seasonal variation of the discharge system. The results showed that both plaice and sole survived the low levels of free halogens to which they were exposed (0.02 ppm - 0.1 ppm) and they obviously benefited from daily feeding and attention, and the higher temperature range. Both the trials were begun in winter, and involved nine-month-old fish measuring between five and nine centimeters. A year later most of the fish of both species were of marketable size, that is 23-24 cm. The sole tolerated the conditions better than the plaice in that they withstood the higher summer tank temperatures. This is to be expected, as their natural distribution is in warmer latitudes. Plaice however, were distraught at temperatures above 19°C and there was some mortality at both sites. The extension of the growth period through the year enabled the fish to reach marketable size at least 12 months before the most advanced individuals in natural conditions.

Hunterston is a base load station, and with the agreement of the South of Scotland Electricity Board, it was decided to continue the feasibility study there. Four tanks were constructed, 14.4 m x 7.2 m x 1.0 m deep. These were ready to receive hatchery-reared sole in October, 1966, and a number of young fish, three to four centimeteres in length, were safety transported from the Isle of Man hatchery. But the hatchery stock that year was suffering from the effects of unsuitable larval food, and there were high losses. At Hunterston, more than 30 percent of the fish that died succumbed in the first week. Many more deaths must have gone unrecorded. By March only six per cent were still alive, but of these - not yet two years old - 62 per cent were of marketable size.

Both the preliminary trials and the first field work prove the feasibility of using power station condenser discharges as an environment in which to grow certain species of marine fish, and indicate a feasible system on which a commercial enterprise may be founded. The next stage is to acquire more comprehensive knowledge and expertise in various areas:

1. Improvement of the survival figures at all stages.
2. The understanding of the effects of stock density and of absolute tank dimensions.
3. The production of cheap foods containing all the nutritional requirements.
4. General husbandry.

Conditions in the tanks at Hunterston vary daily and seasonally. Free halogens are always present in small quantity but are more easily dissipated in summer by sunlight. The fish may, however, prefer shady conditions, and a first trial is now underway. Oxygen levels are above saturation in the discharge which is a considerable advantage but, because of the continual presence of free halogens at a fluctuating level, it is not always possible to maintain flow. An auxiliary aeration system is therefore necessary to maintain the level.

Levels of salinity provide no problem, and rainwater is continuously voided by the surface overflow systems. One of the main concerns is the colonization of the environment by other marine fauna and flora. Some animals are predators and others compete for food. In general a modest number of scavenging froms would be desirable to assist with tank hygiene, together with a number of algal browsers. (Algal growth is the principal physical problem.) To date, tank populations have been free from any outbreak of disease, and this may be due in some part to the chemical content of the water suppressing bacterial growth.

The qualitative conclusions of the authors were summarized as follows:

"It is possible to see that even now the power station environment has economic significance. Future development must depend ultimately on the policies of the Electricity Boards producing the primary resource, the warmed water. Maybe we shall see private enterprise catering for a luxury market or, on a national basis, endeavoring to make more protein available for this country and for others, perhaps creating coastal complexes of power station and bay barrages to produce both marine and freshwater species. All these developments are distinctly possible but the speed at which they will be brought to fruition will depend a great deal on the amount of effort put into the science and technology of marine fish farming. Although it is growing, the effort is still not big enough or wide enough to meet the needs of those engaged in development and design. They need more and better knowledge about all aspects of the nutrition, health, environmental requirements and genetic possibilities of sea fish."

4.3.2 Growing of Carp -- Russian Tests (Reference 4.8)

Some work was reported on from the Soviet Union, of which only the abstract was available in translation. The report describes attempts to grow carp in tanks placed in the cooling pond of a hydroelectric plant. The results are summarized below.

> "The carp were reared in tanks placed in the cooling pond of a hydroelectric power plant. The effect of various stocking rates, of diets (blood and fish meal, a new protein-vitamin preparation, duckweed paste), of daily rations and of the number of feedings was investigated. With a stocking rate of 250 specimens/m^2, fish production was 100 kg/m^2 and the weight of carp was 400 g. Animal food in the diet should comprise 10-15%. Although an increase in animal food increase the growth rate, it leads to unproductive protein losses. The biological value of protein-vitamin preparations is similar to that of nutritional hydrolyzed yeast. The daily ration in thermal waters should be 12-40% of the fish's body weight. With 12-fold feeding its effectiveness increases 2-fold in comparison with single feeding."

4.3.3 Lobsters (Reference 4.3)

Figures from the Maine Department of Sea and Shore Fisheries indicate that the annual lobster (Homarus Americanus) catch has declined from 24.5 million pounds in 1957 to 15 million pounds in 1967. At the same time, the average water temperature off the Maine Coast has dropped from 49.5 to 47.5°F (a range considered ideal for lobsters) to an average of less than 45°F. Surveys indicate that the cooling trend has also affected the populations of other shell fish including clams, oysters, shrimp and scallops. A proposed solution is to discharge warmed water from power plants into a protected cone to bring the average temperatures back into the preferred range. Several problems including the tendency for the discharge water to stratify at the surface rather than to mix with the bottom waters where the lobsters live and the strong tidal effects in Casco Bay which was selected as a test site have delayed the implementation of the scheme. No account has yet been taken of possible concentrating mechanisms of radioactive elements in the lobsters themselves in the case of a nuclear plant.

4.3.4 The Thermo-Nutrient Pump (Reference 4.4)

One of the important cyclic processes in nature is that of thermally induced vertical mixing of ocean waters in which bottom waters, which are rich in nutrients are brought to the surface where sunlight can reach them (the so-called photo-synthetic zone) and where they are digested by living organisms. The cycle is completed when the micro-organisms are reduced to the bottom where they live and enrich the nutrient supply.

A recent report investigates the possibility of using heated water discharge from a power plant to convectively pump deep water to the surface for "fish farming." A relatively simple computation of the amount of bottom water which could be pumped to the surface for a given amount of discharge water at different temperature levels above the ambient water. The results of these computations are shown in Figure 4.1.

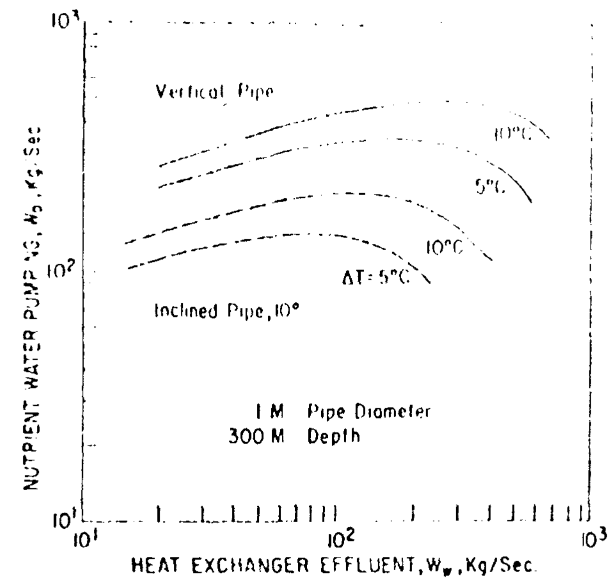

Figure 4.1
Thermo-nutrient pumping rate

The curves pass through a maximum since for a given size pipe the frictional losses due to the heat exchanger discharge itself become dominant above a certain flow.

Some estimates of the net increase in fish production due to such an installation are possible and are not encouraging. Based on the assumption that the bottom nutrient concentration remains at its original, undisturbed high level even after a long period of operation (which seems a dubious assumption), a one meter diameter vertical pipe supplied with 60 kg/sec of heat exchanger water at a temperature 5°C above the average sea water temperature can deliver 300 kg/sec of bottom water to the surface. Assuming maximum utilization, this is reported to produce an additional 3000 kg per year of edible fish which is hardly a reasonable return for the investment. However, the arrangement is structurally and thermodynamically feasible and if means to increase the yield are found, it may bear further consideration.

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Section 5
DECENTRALIZED POWER GENERATION
TOTAL ENERGY SYSTEMS

5.1 Introduction

As indicated at the conclusion of Section 2, it is felt that the only feasible alternative to the addition of cooling towers (or other types of equipment for rejecting heat directly to the atmosphere) is a reversal of the trend toward large central power plants. It seems reasonable to conclude that the total quantity of heat rejected from power generating stations is sufficiently small in comparison to the total energy balance on the land. The essential aspect of heat rejection which leads to its classification as a pollutant in the concentrated nature of its discharge. Therefore, the elimination of large central power stations in favor of small individual gas turbine/generator "total energy" units distributed throughout the community at the individual load sites would appear to be a direct attack on the essence of the thermal pollution problem as it relates to energy production.

Such a system, which will be described in more detail in Section 5.2, would have the following advantages:

- while heat must still be rejected from this system in accordance with the laws of thermodynamics, the heat rejected from a gas turbine is at much higher temperatures and hence useful for heating, air-conditioning, cooling, and other "heat input" energy requirements
- the problem of distribution of work heat is alleviated if the system is on-site
- if such systems were adapted on a wide scale, operating problems unique to large, inter-connected grid systems such as the Northeast blackout of a few years ago would be avoided

There are, of course, some obvious potential disadvantages to such an approach. These would include those listed on the following page.

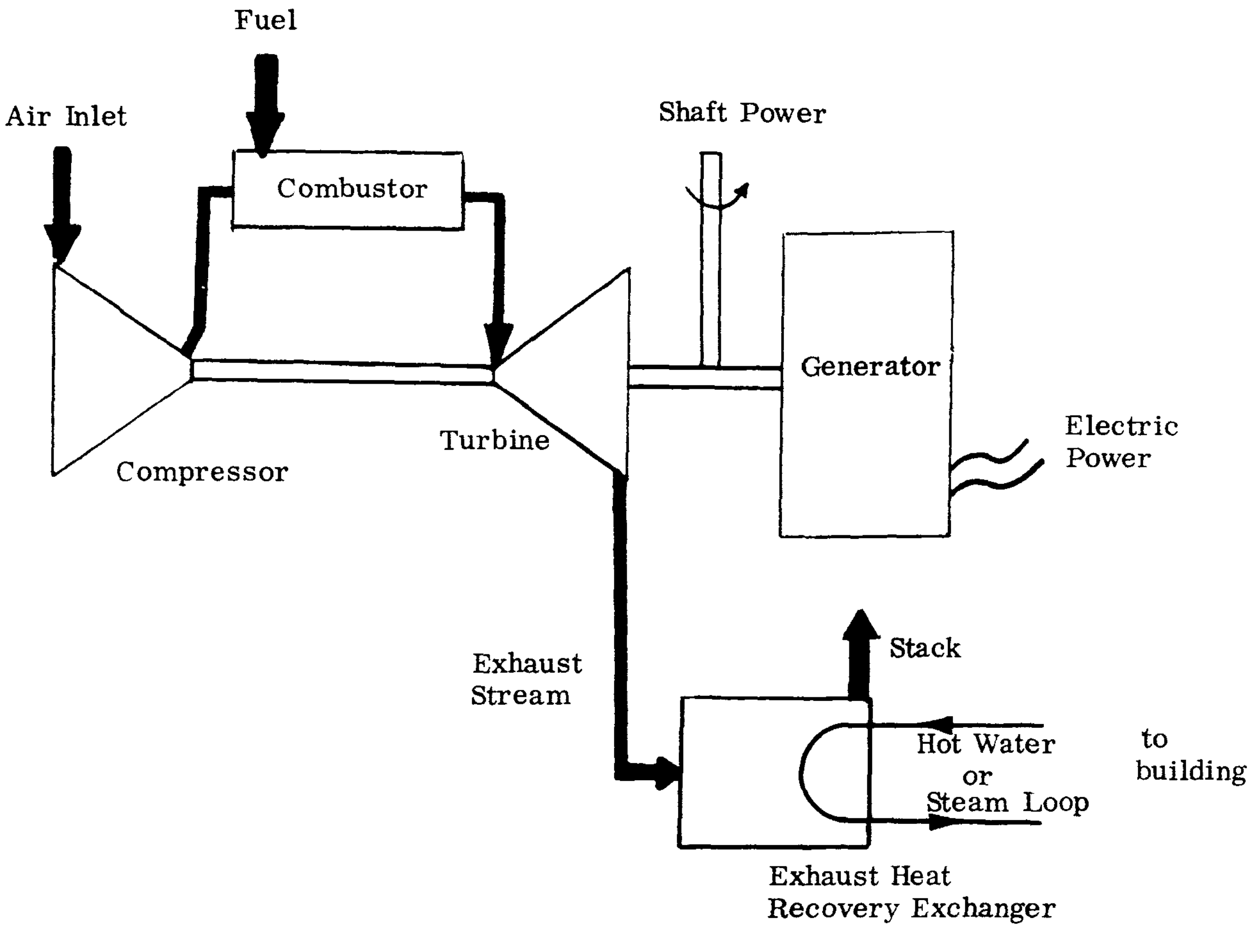
- the possibility of excessive air pollution from a large number of small gas turbine burners. While such burners can be made quite clean, it is clearly more difficult to monitor and maintain a large number of units than a single large plant
- overall system efficiency, while theoretically quite high if good use is made of the waste heat in the turbine exhaust stream, could be lower than central plants since the advantages of running at essentially constant load at the design point would, in general, be lost
- maintenance of a large number of relatively complex systems might statistically be more difficult than maintenance of a single power plant with a full-time maintenance team on location

5.2 Total-Energy Power Generation--A Typical System Description

A total energy system, in its simplest terms, is illustrated in Figure 5.1. The name derives from the concept of meeting all of the energy input requirements of a dwelling or plant from a single system. In general, energy input requirements can be divided into three categories depending upon which of three forms of energy is most appropriate. These energy forms are:

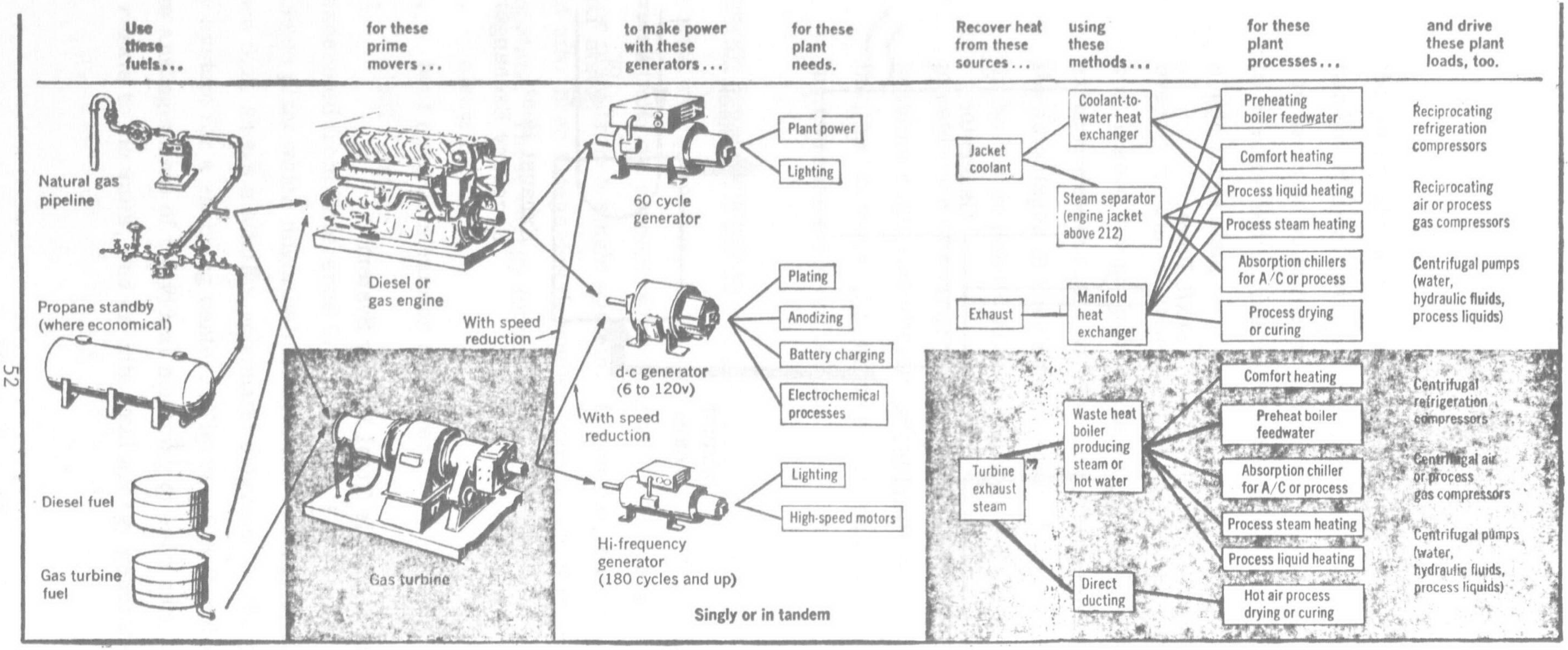
1. electricity
2. heat (usually steam or hot water)
3. shaft rotation

Figure 5.2, excerpted from Reference 5.1, suggests a variety of combinations of loads in a process plant which might be met by a total energy system. Figure 5.3, from Reference 5.2, shows a similar schematic diagram for the possible usage of a total energy system for a shopping center. Figures 5.3 (a), (b), and (c) illustrate the alternative arrangements of individual metering of each unit, central purchasing of power and resale to the units, and on-site total energy generation.



Schematic of Simple Total Energy System

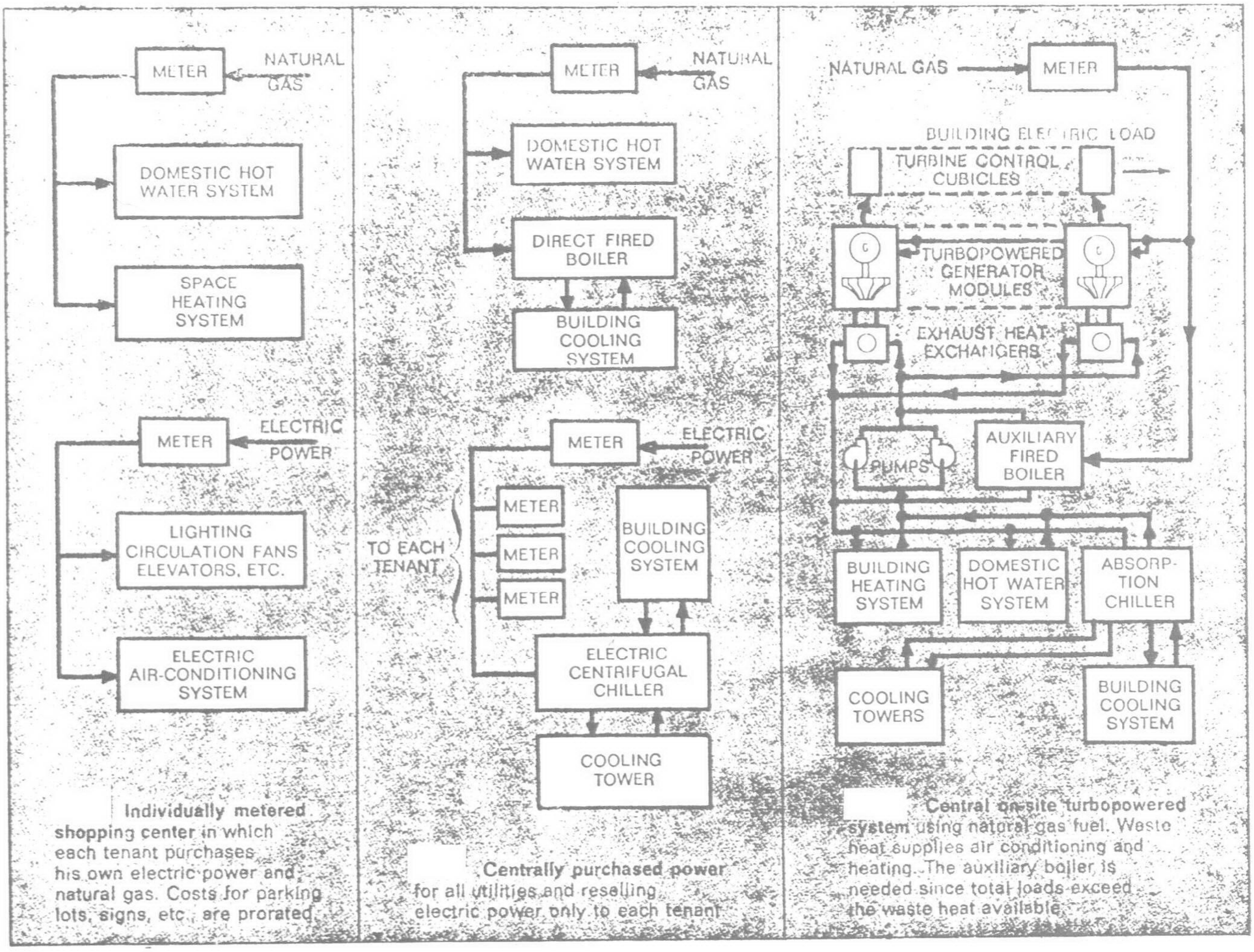
Figure 5.1



Possible Total Energy System Configurations for Process Plant Application

(from Reference 5.1)

Figure 5.2



Possible System Arrangements for Shopping Center Application
(from Reference 5.2)

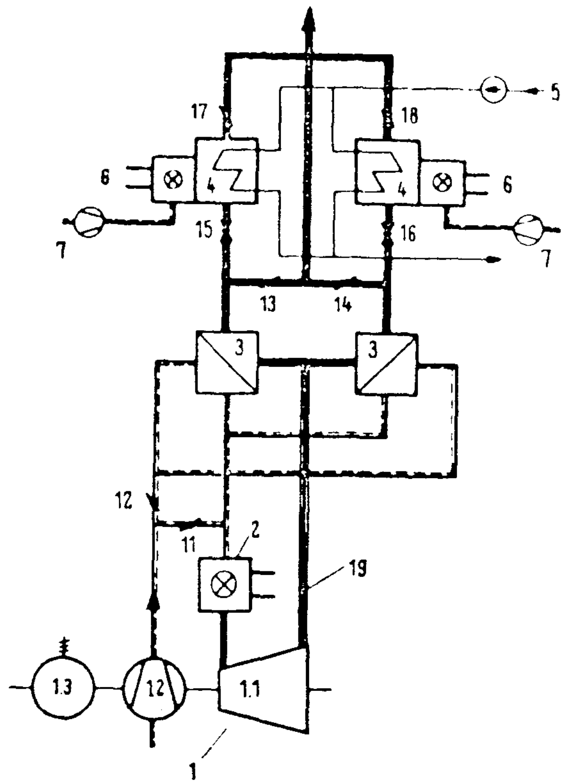
Figure 5.3

5.2.1 Load Requirements versus System Output Capabilities

The essential question to be answered in evaluating the merit of a total energy system is whether or not the user requirements for electric power, shaft power, and heat are divided in such a ratio (or can be divided through changes in plant operation) as to be compatible with the output of the energy system. In order totake good advantages of the potentially high system efficiencies, full use must be made of the waste heat. Fortunately an additional degree of freedom is available in terms of adjusting the systems thermal output over relatively wide limits.

A system at Braunschweig, West Germany which supplies electrical power and distinct heating, separates according to the following specifications. (Reference 5.3) The maximum electrical sendout is 32 Mwe while the thermal output can be varied continuously from 0 to 64 Mwe and, with additional burners can be increased to 92 Mw. The electrical power alone is generated at an efficiency of 32%. If the full thermal output is utilized, the overall system efficiency can reach 80%. Rating data for this plant is given in Table 1 and a schematic of the system is shown in Figure 5.4.

The variation in thermal output is achieved in the following way. The air delivered by the compressor can take two paths to the combustion chamber. According to the damper setting (11 and 12 in Figure 5.4) the air flows either through the bypass or through the regenerator. Intermediate settings provide any desired ratio of thermal output to electrical output of 2.3:1 to 1.3:1. If further reductions in the thermal output are required, this is accomplished by means of dampers 13 and 16 in the exhaust gas ducts between the air heaters and the waste heat boilers. This permits dumping of a portion of the exhaust gas directly to the atmosphere. When the heating demand is heavy, the exhaust gases pass through the regenerator without cooling directly to the waste heat boiler at a high temperature (~800° F). When the heating demand is low, the gases enter the boiler after being cooled in the regenerator to approximately 500° F. In addition extra burners in the waste heat boiler can supply up to 50% more heat on cold days or be used to meet the heating demand in the event of turbine failure.



1—turboset (1.1—turbine; 1.2—compressor; 1.3—generator); 2—combustion chamber; 3—regenerator; 4—waste heat boiler with additional burners (6) and fans (7); 5—circulating water system; 11 and 12—air dampers; 13 to 18—exhaust gas dampers.

Cycle Schematic of Braunschweig System
(from Reference 5.3)

Figure 5.4

	Full Heating Output (no regeneration)		Half Heating Output (partial regeneration)	
1. Compressor Inlet Temp., ° F	40.	60.	40.	60.
2. Air Inlet Flow (lbm/sec)	426.	405.	426.	405.
3. Pressure Ratio	6.3	6.0	6.4	6.1
4. Electrical Output, Mwe	28.6	25.8	28.1	25.3
5. Maximum Output, Mwe		3.2		
6. Efficiency of Electric Power Production, %	23.9	23.1	32.0	30.8
7. Turbine Inlet Temp., ° F		1300		
8. Number of Stages				
compressor		17		
turbine		6		
9. Speed, rpm		3000		
10. Exhaust Gas Flow, lbm/sec	430.	409.	428.	407.
11. Thermal Output, Mw	66.	64.	37.	37.5
12. Fuel Utilization, %	79.	80.4	74.1	76.5

Rating Data on Braunschweig System
(from Reference 5.3)

Table 5.1

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The quantities of electric energy consumption and associated heat rejection quantities, their present and projected allocation throughout the different sections of the country, their relation to other forms of energy consumption are reviewed and tabulated. Thermodynamic constraints on a solution to the thermal pollution problem are defined. Feasibility of possible application of waste heat usage are reviewed in the field of heating and air-conditioning, aquaculture, process industry, irrigation, sewage treatment, desalination, snow or ice melting and integration with municipal water system.

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