POWER PLANT EFFLUENT—thermal pollution or energy at a bargain price?

Approximately two-thirds of the fuel energy, chemical or atomic, used to make electric power is waste heat. To avoid "thermal pollution" we can use cooling towers. But there may be a better plan: "new-town" applications with 100 percent temperature control of all living space and office working space.

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In EARLY 1970, the Svenska Teknologföreningen (Swedish Association of Engineers and Architects) and other Swedish groups sponsored a worldwide idea contest: "Engeri till Reapris" or "Energy at Bargain Price." It sought out proper uses in the manufacture of electric power for the enormous quantity of residual energy now rejected as heat and largely returned to the water course selected as a source of cooling water. The concepts outlined below were honored by the technical jury.

"New-Town" Applications

The ideal use or uses for the enormous quantity of residual energy from steam electric power plants require large demand, 24 hr per day, 365 days per year. Most of the obvious applications use too little energy.

Also, many uses of energy are available in the winter, but not in summer. Thus, finding large-scale valuable uses of thermal energy in summer without insult to the environment must be a key to developing beneficial uses.

To get the necessary large scale with sound economics, we have been led right back to the source of the demand for electric power—the city and its people. We propose "new-town" applications with 100 percent heating of all living space and office working space. By new town, we mean any area where we do not have the problem to modify existing buildings, their equipment, and utilities. We include the free-standing new town, the new-town-in-town, and satellite towns adjacent to existing large cities.

The total energy used in the U. S. for air conditioning is roughly equivalent to the total energy used for residential and office space heating. Although the low-grade energy typically dumped from electric power generation is not readily usable for air conditioning, it is possible to stop the expansion of steam at a temperature slightly in excess of 94 C and use the residual energy to drive an absorption refrigeration system, such as a lithium bromide–water system.

The criterion of minimum heat rate for electric power generation should be abandoned in favor of a systems approach to the use of fuel energy in an energy center in a new town in which the overall system for production of electric power *and* residential and office space heating and cooling is optimized. The economic results appear promising. Further elaboration will show additional benefits as we look at diversified applications of residual thermal energy, particularly spring and fall uses.

Optimization of an Energy Center

Central plants providing heat to many residences are certainly not new. An excellent example is the use of the geothermal hot water in Iceland for the past 45 years for home heating now serving 81,000 people in the vicinity of Reykjavik, described by Bodvardsson [1].[3] The costs compared to other sources of energy for heating are quite favorable. Bodvardsson's data show an average cost of 60 percent compared to the cost of similar heating with fuel oil. There are also some 50 district heating utilities operating in the U. S.

For summer cooling, a heat-driven refrigeration system is needed to provide chilled water into the homes and office space. A lithium bromide–water absorption system looks like a good candidate. It requires hot fluid input at about 94 C. This would require energy from the energy center at a higher temperature than 94 C to provide for transmission losses. A turbine extraction temperature of about 100 C with good thermal design of the transmission lines should provide for transmission losses for a large-size city. The 15.3-km line connecting the thermal area at Reykir to the city of Reykjavik in Iceland has an average temperature drop of only about 3 C.

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[3] Numbers in brackets designate References at end of article.

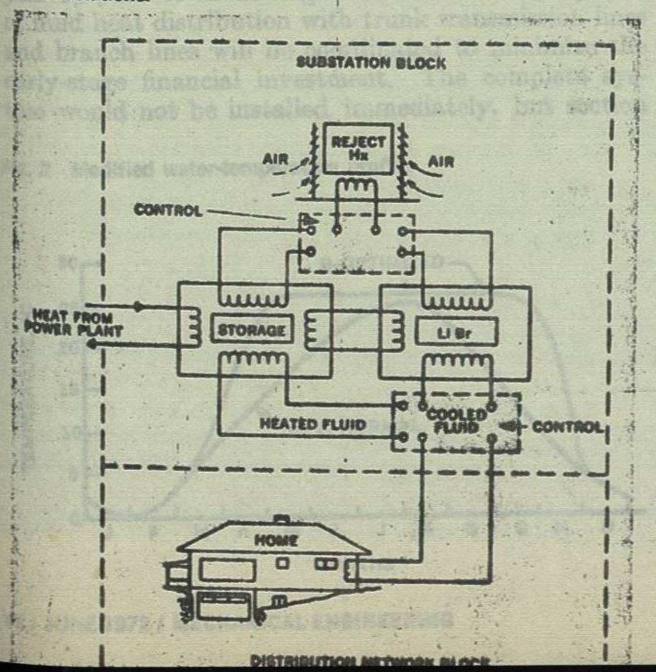
An excellent match exists between the peak power demand for home heating in winter and for home cooling in summer. A three-bedroom home in New York City or St. Louis might require a peak of 50,000 Btu/hr for heating and 24,000 Btu/hr extraction for cooling. Since the coefficient of performance (COP) of a good lithium bromide-water refrigeration system is about 0.5, the summer driving power peak would also be about 50,000 Btu/hr.

The compatibility of this approach with the patterns emerging in new-town planning should be investigated. The typical present approach to planning new towns includes the concept of building up the complete town starting with many small groupings of perhaps 500 people in 150 residential units free of through automobile traffic, and is known as a cluster. The town plan is built up by analyzing what it is that various-sized groups of people need and want in a town, including communication, transportation of people and goods, waste management services, social facilities, education, etc. Perhaps four clusters are grouped together to form a neighborhood of 2000 people. Perhaps six neighborhoods form a village of 12,000 people. Perhaps six villages make up a town of 72,000. Perhaps six towns make up a city of 400,000 plus. There might be one major cultural center for the entire city, one high school for each town, a major shopping center for each village, etc.

We envision one energy center producing electric power for the entire city or town and providing excess electric power for export. Underground transmission of energy flows as hot fluid to a substation in each cluster of 150 residential units. Each substation processes the energy and distributes hot fluid in winter and chilled fluid in summer to each residence, Fig. 1.

The daily load profile for each substation will show typically a peak heating demand in the early morning with a dip in the afternoon, or an air conditioning peak in the afternoon with a dip in the early morning hours. These peaks should be accommodated by providing an energy-storage insulated water tank at each substation to "flywheel" the demand.

Fig. 1 Schematic of apparatus for year-round home conditioning via substations.



Preliminary estimates show favorable costs compared to our present conventional practice for the services provided by the substations. The substation system must be charged with the value of the electric power not generated because of the early extraction of steam, as well as the costs of transmitting the hot fluid, processing it, and distributing it to the residences. The power not generated because of complete steam extraction at 100 C would amount to about 15 percent of the maximum nominal station rating for a fossil-fuel plant or about 26 percent for a typical nuclear power plant. Some saving is available from flattening of peak demand by grouping requirements for 150 residences into one substation and from flywheeling. This should be conservatively 15 percent. A credit might be taken for the dry cooling tower which is eliminated. Each substation acts as a small dry cooling tower with a heat exchanger discharging unused heat to the air. The system of substations is superior to a central dry cooling tower since it distributes the heat dissipation over the entire city area.

Costs chargeable to heating and cooling will be dependent upon site and upon plant design, and will be quite variable. Preliminary cost studies indicate hot-fluid generation costs typically 10 to 18 cents/10^6 Btu. Transmission costs vary between 5 and 30 cents/10^6 Btu. Processing and distribution costs might range from 15 to 60 cents/10^6 Btu. Miller et al. [2] have made extensive studies of the cost of fluid heat transmission and distribution based on steam heating practice for the federal Department of Housing and Urban Development.

We have projected cost estimates for an example substation of the energy center for a new town as follows:

- Town of 138,000 people, 275 clusters, over 25 sq mi
- Combination-cycle fossil-fuel gas turbine-steam turbine 250-MWe energy center
- 150 residential units in cluster, each with 50,000 Btu/hr
- Peak total demand at substation of 6.4 × 10^6 Btu/hr or 1.9 MW
- 3½-mi transmission line consisting of 3 mi of 10-station trunk and ½ mi of single-substation line
- 40-acre cluster site
- Average distribution distance within cluster, 350 ft.

Major cost items for one substation are estimated at:

- Transmission-line cost, $24,000
- Substation cost, $40,000
- Distribution lines, $133,000.

Costs are based on excavation and installation of piping prior to street paving. The transmission line includes thermal insulation.

The distribution piping system is earth-insulated and of low pressure rating to carry water heated below 90 C from the substation to the homes. This piping assumption greatly reduces cost of the distribution piping system. Further economy of piping is achieved by alternating the heating and cooling functions on a single piping system. This seasonal shift in late spring from heating to cooling and in early fall from cooling

TABLE 1 Estimated Costs for Example Energy-Center Substation for Heating and Cooling

Annualized Costs		
Electric power loss	$ 6.0	K/yr
Transmission	$ 3.4	K/yr
Substation	$ 5.6	K/yr
Distribution	$ 19.2	K/yr
Operation and maintenance	$ 0.7	K/yr
Net total	$ 34.9	K/yr
Cost per residence	$233	/yr
Allowing credit for cooling tower	$ 18	/yr
Cost per residence	$215	/yr

to heating involves transient heat losses that, averaged over the year with the steady-state losses of mid-winter and mid-summer, are comparable to those of conventional insulated steam heating systems.

A dry cooling tower for the combined-cycle 250-MW energy center with 50 percent steam turbine at $40/kw would be $5,000,000.

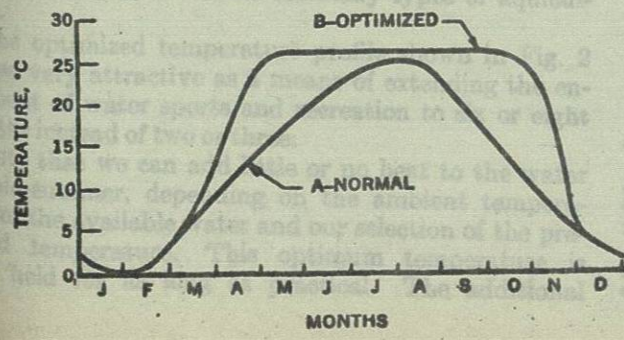
Table 1 shows estimated annualized costs per substation and per residence.

For comparison, the same residential units equipped with individual standard heating and air conditioning units exclusive of distribution within the home would represent an initial cost to each homeowner of approximately $1400 at retail and an annualized cost including fuel of about $520. If this were restated in basic costs for a volume representative of an entire city, the cost would be at least $260 per residence. Thus, the estimated costs permit a satisfactory selling price which is still quite a bargain to the buyer. For high-rise residential or other high-density use, the costs are still more favorable.

For lower density and greater transmission distances, the costs are less favorable, but still promising.

A characteristic of the well-planned new town is design to minimize cost of infrastructure and lead time of costs. It may be assumed that in a well-planned new town there will be an optimized staging plan for year-by-year town development and that the system of fluid heat distribution with trunk transmission lines and branch lines will be coordinated to minimize the early-stage financial investment. The complete system would not be installed immediately, but section by section as needed. In the initial stages before the energy center has been completed, the first few clusters might be served by temporary boilers.

Fig. 2 Modified water-temperature profile.



Other Uses

If we go no further than to provide energy centers in our new towns which optimize electric power production and living-space temperature control for reduced total cost and less harsh impact on the physical environment, we have made good progress. There are, however, additional benefits available.

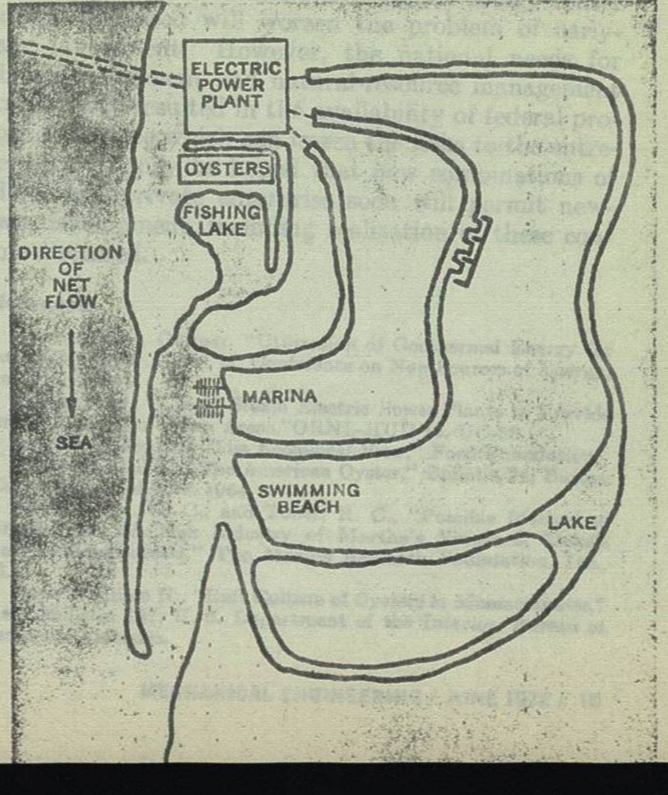
As Harrison [3] points out, diversity in our systems increases stability. He also urges movement toward recycling and closed systems. We should introduce additional uses of residual thermal energy for stability and balance, as well as for their direct benefits.

In a general sense, given the availability of large quantities of water in a new town, there is much that can be done to improve the quality of living. Many of the most charming cities of the world owe much of their charm to the presence of extensive open water. Low-cost, modern earth-moving techniques make creation and exploitation of lakes, lagoons, and canals practical in a new town. We can add aesthetic appeal, multiply waterfront footage for residential property, provide fishing, provide water sports and recreation, provide an extensive heat-sink system, and provide bodies of water for commercial use.

Several electric utilities have made a start in this direction by creating artificial ponds for cooling of new power-generating facilities, and providing fishing and recreational use of ponds as a bonus.

Heating and cooling give us a good balance between mid-summer and mid-winter load peaks and leave available large quantities of heat in spring and fall. The heat energy from conventional heat exchangers after full steam expansion can be used to bring a large body of water to optimum temperature for aquiculture and hold it there for six to eight months, Fig. 2.

Fig. 3 Example of site sculpturing for water and energy management.



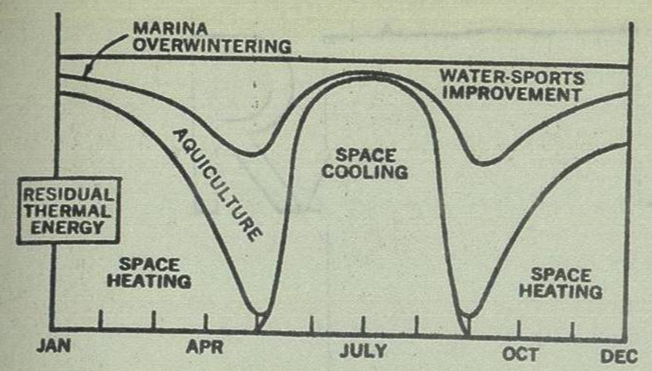


Fig. 4 Concept of using thermal energy throughout the year.

Most fin fish and shell fish under natural conditions live in water which is, for most of the year, substantially too cold for optimum growth rate. The optimized temperature profile shown in Fig. 2, if applied for example to Chesapeake Bay water, could result in raising oysters to marketable size in one season instead of three or four seasons.

There is a large and growing body of knowledge in marine and fresh-water bionomics pertinent to aquiculture which has been largely unexploited to date. There are many promising application opportunities for shell fish and fin fish aquiculture in marine and fresh water. These opportunities include use of selective breeding to optimize ease of culture and marketability of the product. They include selection of uncommon species, perhaps from other parts of the world, which have particularly attractive market features.

Oyster farming in Japan and Australia is now large scale, but primitive in technique and very labor-intensive. Considerable knowledge of and experimental techniques for oyster culture have been developed in this country [4–6], but they have yet to be utilized on a large scale.

The early small-scale experiments in this country are characterized by improvisation. Oysters have been grown on "strings" of oyster shells on wires suspended from a spar. Trays are also frequently used. Extrapolating densities and yields achieved indicates that an oyster farm should yield an annual crop worth $40,000 per acre per year with application of energy-center heat. The knowledge available needs to be put to use with appropriate engineering skill and cost management.

Although many questions concerning optimization of techniques remain unanswered, the substantial body of knowledge and experience in hand should support a well-managed oyster-farming project relying on residual thermal energy from an energy center for optimizing various steps of oyster culture and oyster food culture. The same is true for many types of aquiculture.

The optimized temperature profile shown in Fig. 2 is also very attractive as a means of extending the enjoyment of water sports and recreation to six or eight months instead of two or three.

Note that we can add little or no heat to the water in mid-summer, depending on the ambient temperature of the available water and our selection of the preferred temperature. This optimum temperature is then held for as long as practical. The additional heat is discharged to the air as shown in Fig. 1.

Fig. 3 shows a schematic illustration of water exploitation in a new town. Fig. 4 illustrates the concept of a uniform load of thermal energy use throughout the year.

An inventory of beneficial uses should be developed with assurances that new-town planners have access to this store. Some otherwise insufficient uses become important bonuses to provide off-peak thermal load. Melting snow from streets and sidewalks, for example, cannot stand alone, but may contribute a bonus in the well-planned and optimized new town.

Some of the other potential uses require steam, some require hot fluid at somewhat enhanced temperature, and some use low-grade thermal energy as normally discharged from a steam electric power plant.

Uses of steam for industrial processing combined with power generation have been demonstrated to be advantageous. Sewage distillation with steam from the energy center may be made advantageous with proper planning.

If greenhouses and/or phytotrons can be justified in the new town, a small economic bonus can be obtained by heating with low-grade thermal energy from the energy center. Preliminary studies show that biological processing of sewage can be accelerated by raising the temperature using low-grade heat. Gains of a factor of 10 appear reasonable. This means that for a given plant size, the throughput might be increased by a factor of 10.

Future Prospects

Entrepreneurs who undertake to build new towns for financial gain are more often disappointed than successful. To quote Mr. Joseph Taravella, president of the successful Coral Ridge Properties, "New town building should be approached with humility." The key problems are an underestimate of the early-stage financial investment, or an overestimate of the pace of growth and hence profit potential, or more typically both.

Building a new town incorporating the energy-center concept discussed will worsen the problem of early-stage investment. However, the national needs for urban development and natural-resource management have already resulted in the availability of federal program assistance which can lessen the risks to the entrepreneur. It may be hoped that new combinations of federal and private enterprise soon will permit new-town development, including realization of these concepts discussed.

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