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ZWEITE WELTKRAFTKONFERENZ

TRANSACTIONS
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COMPTE RENDU
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BERLIN 1930

BAND IV

Wärmekraftanlagen
Thermal Power Plants
Installations thermiques

VDI-VERLAG GMBH
BERLIN NW 7
### Section 7

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Construction and Operation of Large Power Plants  
Construction et exploitation de grandes installations énergétiques

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Dr.-Ing. F. Marguerre
United States of America

The Present Status of District Heating in America

National District Heating Association
American Society of Mechanical Engineers

J. H. Walker and A. R. Mumford

Prepared in collaboration with the Educational Committee of the National District Heating Association, whose members in addition to the authors are: Wm. J. Baldwin, Jr., D. S. Boyden, John W. Meyer, Earle Shultz, E. L. Wilder and G. D. Winans.

District Heating—the supplying of heat energy from a central generating plant through underground pipes to the buildings in a city district—is a form of public utility service which has been known in America for many years. Although the energy so supplied is used primarily for heating, it is also used for the operation of engines and pumps, for cooking, for heating service water, and for process work.

The influence of temperature conditions on the use of heat and the influence of the apparatus employed on the means for supplying this heat from a central station must be understood and known if the status of district heating in America is to be clearly pictured. In Canada and in the northern half of the United States the winters are comparatively severe. Fig. 1 shows the normal average temperatures for the month of January, which is the coldest month of the year. The temperatures are quite variable and may fall as low as 40 degrees below these average temperatures during the so-called cold waves which accompany the anti-cyclonic atmospheric disturbances.

The American people, because of these climatic conditions and also due to national habit, demand indoor temperatures which are relatively high when compared with those demanded elsewhere. Seventy degrees Fahrenheit is the accepted temperature for occupied rooms and temperatures as high as seventy-five degrees are found necessary when the outside temperature is very low, because of the extreme dryness of the air at such times. The quantities of heat used are therefore relatively large and the heating apparatus in buildings must be suitable for the large use and for the extreme conditions of outside temperature.

Nearly all American buildings, except those in warm latitudes, are equipped with central heating systems employing steam, hot water or warm air to convey the heat to the various rooms. The open fireplace is now used only as an auxiliary means of heating or for aesthetic reasons.
The steam heating system is quite generally used in large buildings and in many residences while hot water systems though used in residences are seldom found in large buildings except those comprising institutions. The warm air furnace system, consisting of a centrally located heater with ducts delivering warm air to the various rooms, is used in a great many small residences. Except in the case of the warm air furnace, however, these various methods of heating are such that the heat can be readily supplied from a district heating system with little change in heating methods or alteration of the heating apparatus.

![Fig. 1. Normal average temperatures in North America for the month of January, in Degrees Fahrenheit (Average for 25 years).](image)

**Historical**

The first recorded attempt to supply heat to several buildings in a community in America from a central source was made in 1877 by Birdsill Holly. In 1881 The New York Steam Company was organized for supplying steam to consumers in New York City and in 1886 this company listed 304 consumers. In 1882 Harper’s Weekly published drawings of a generating station and street steam main construction in New York City. Later there were also installed, in the middle West, a number of systems using hot water as the circulating medium.

The early development the district heating industry was largely due to the fact that there were a large number of electrical generating stations in operation, most of which discharged to the atmosphere the steam exhausted from their engines and the utilization of this wasted heat for district heating appeared attractive. Many district heating
installations were made upon this basis Prior to and shortly after
prior to and shortly after 1900. At a later date the advent of the
condensing type of electrical generating plant and of the hydro-electric
plant, and the development of long distance electrical transmission led
to a concentration of electrical generation in large plants with a conse-
quent elimination of the smaller units in the scattered non-condensing
plants. Many plants were thus forced to resort to the use of live steam
direct from the boilers to continue their district heating business; and
having established prices for heating service based upon the assumption
that the steam was a by-product of low value, many undertakings were
rendered unprofitable unless or until they were permitted to increase
their prices considerably.

A majority of the district heating projects were either originated or
later absorbed by the electric light and power supply companies and in
cases where the operation was unprofitable the burden was borne by
the profitable electricity business. A district heating system is a de-
sirable auxiliary to an electricity supply company because it aids the
sale of electricity through making it possible for the building owner
to purchase all of his service from outside sources.

The financial returns from many of these early projects were un-
satisfactory. This was due in some cases to unwise exploitation or to
improper management, but in the majority of cases to inadequate
selling prices or lack of proper devices for measuring the service. During
the transition from the use of exhaust steam to the use of live steam
great difficulty was experienced in readjusting the prices to correspond
with the increased cost of operation. However although district
heating was formerly not sufficiently profitable to be attractive to
capital it has recently attracted much attention and is experiencing
a rapid growth. The difficulties have been economic rather than tech-
nical and have been partly removed by recent economic developments.
The technical and engineering phases have advanced to a fairly satis-
factory state.

Present Status and Fields of District Heating

During the past decade the position of the district heating industry
has improved considerably; its service is now in great demand and it is
regarded as more likely to be profitable in properly selected territories
than formerly. Although the individual boiler plant is a competitor of
district heating service, nevertheless in cases where a building has
not yet been erected, the district heating service, by eliminating some
of the investment, generally can compete successfully with the indi-
vidual plant.

The improvement in the status of district heating has been due
principally to two causes. First there is the increased value or cost of
the space occupied by the individual heating plant in large buildings.
The increasing congestion of the central districts in large cities has caused the value of space, even in basements, to become very high. The unproductive space occupied by the boiler plant in the basement and by the chimney on each floor may be freed for rental purposes through the purchase of district steam service or a combination of steam and electrical service. When all of the items bearing upon the cost of steam service are taken into account and fairly evaluated the cost of the service compares favorably with the cost of producing steam in an isolated boiler plant, being usually less if the investment costs of the isolated plant are considered. The annual rental value of space released by the elimination of the boiler plant may equal the entire cost of district heating service for the building.

The second cause is a greater appreciation, on the part of the public, of the luxury value of steam service. The freedom from the dirt, smoke and annoyance which accompany the operation of the individual heating plant is attractive to the building owner. This is often of tangible value and consequently he has recently been more willing, and, because of the increasing prosperity in America, more able to pay for district heating service. His increasing desire to be relieved of the production of all classes of service which can be purchased warrants the paying of a price which, in some cases, may be somewhat higher than the bare tangible costs of furnishing his own heat supply. There is a real civic advantage, incidentally, in the elimination of smoke, and of the dirt and traffic obstructions caused by the handling of the fuel and ashes of the individual plant.

The overall thermal efficiency of district heating compares favorably with other methods of heating and is higher than appears in the case of the gas or electric utilities. The thermal efficiency of well designed district heating plants varies from 75 to 85 per cent. The efficiency of distribution varies from 80 to 90 per cent, depending upon the density of the load, in a system which is in a good state of repairs. The efficiency of utilization of the heat in the consumer's building is at least 90 per cent if the condensation, which contains some heat, is wasted and not returned to the boiler plant, and may reach 95 per cent. Assuming an average figure of 80 per cent for the district boiler plant, 85 per cent for the distribution system, and 93 per cent for the efficiency of utilization, the overall efficiency becomes 63 per cent. This exceeds the overall efficiency of an individual building heating plant which averages 50 per cent for a very small building and 60 per cent for a large building. District heating can thus be credited with an appreciable degree of saving in fuel consumption as compared with the operation of individual boiler plants, which may become an important consideration in the future.

It is interesting to compare the cost of supplying heat to a city district by means of the three methods which might be used, namely, district steam heating, gas or electricity. The price at which 1000 B. t. u.
are furnished to the consumer affords a basis of comparison of the economics of the production and distribution of heat by the three methods. In New York City the amounts of heat in B. t. u. which the consumer obtains for one cent in each case are as follows:

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<th>B.t.u. for One Cent</th>
<th>Cost Ratio</th>
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<td>Steam</td>
<td>$0.97 per thousand pounds</td>
<td>11,400</td>
<td>1.00</td>
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<tr>
<td>Gas</td>
<td>1.15 per thousand cu. ft.</td>
<td>4,780</td>
<td>2.38</td>
</tr>
<tr>
<td>Electricity</td>
<td>0.05 per kilowatt hour</td>
<td>680</td>
<td>16.76</td>
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The efficiency of utilization of the three forms of energy when applied to building heating differs, since gas must be burned under a boiler, while steam or electricity can be utilized with very little loss.

Fig. 2. Typical Large Buildings which are Supplied with Steam from a District Heating System.

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There are now three rather distinct fields in which district heating is employed, each involving different economic and engineering considerations. These are as follows:

A. Service to congested business and residential districts.
B. Service to districts of individual family residences.
C. Service to grouped industries.

Service to Congested Business and Residential Districts

District steam service in the congested business and residential districts of cities is by far the most important as to the amount of capital invested and the amount of building space heated. These districts constitute a particularly favorable field, first because of the high density of the load, making it possible to deliver large quantities of steam with a relatively small investment in distribution pipes and, second, because the service is in great demand.

In these districts are found office buildings, department stores, large apartment buildings and hotels. Office buildings use steam principally for heating and require service for periods of only a few hours longer than the normal working day. At other times, namely at night, and on Sundays and holidays, the service may be greatly reduced or shut off entirely. Large apartment buildings are somewhat similar to residences in the nature of their demand for steam, but take on in addition some of the requirements of hotels. The load factor of apartment dwellings that is, the ratio of the average load to the maximum load is considerably higher than office buildings. Hotels constitute a type of consumer which require steam for cooking, laundry, and operation of some machinery as well as heating.

Fig. 2 shows some typical buildings which are supplied with steam from a district steam supply system. Some of the largest office buildings in the world are thus heated.

Service to Districts of Individual Family Residences

There are a number of district heating systems supplying detached residences in America and the service is much in demand where it is available. There are several obstacles in the way of the general development of this form of district heating service. The high cost of the distribution pipes and the relatively small quantities of heat which are required in a residence area make the cost of district heating service rather high compared with other methods of heating. In America there have been developed in recent years quite satisfactory devices for burning fuel oil and artificial gas and it now appears that the use of these fuels in the future will supply the demand for automatic heating service. There are nevertheless several residential district heating systems in satisfactory operation, particularly in suburban areas and in the smaller cities. A few new installations are being made, usually in connection with housing and real estate developments.
Services to Grouped Industries

The supply of steam to industries for manufacturing uses as well as for heating is a service of rather recent growth but which gives promise of a great future development. Many industries have need for large quantities of heat in manufacturing processes and it often appears economically correct that their steam requirements as well as their electrical requirements be purchased from the Public Service Company. The development at Rochester, New York, which will be described later, is a typical illustration of a system established primarily for this purpose and is believed to be the forerunner of many enterprises of like nature.

Statistics

There are at present 161 district heating systems of all sizes in operation in America, of which nearly all are in the United States. In Canada there has been less attention paid to the subject, the system in the City of Winnipeg being the only one of any considerable size. The following table compiled from reports to the National District Heating Association illustrates some features of the industry at the present time.

Table 1
District Heating Statistics

| Number of Companies Reporting | 26 |
| Amount of Capital Invested | $80,000,000 |
| Revenue for 1928 | $17,000,000 |
| Number of Consumers Served | 9,322 |
| Steam Sold, Pounds | 18,900,000,000 |

These figures include the largest companies and many small companies. No hot water systems, of which there are sixteen, are included in the foregoing table. It is estimated that about two per cent of the total revenue of all companies is the revenue of the hot water systems.

The rate at which the industry is growing is well illustrated by Fig. 3, which shows the increase in number of consumers, boiler capacity and steam sold for twenty-two companies. The average growth for these companies has been approximately 11 per cent per year on a compound basis, but the growth in certain cases, notably in New York City, is even more rapid. The indicated average rate of growth is a high rate for a public utility and if maintained will cause district steam service to become in the future of basic importance nationally.

During the year 1929, eight of the larger companies invested a total of $9,361,000 for extensions to their distribution systems and boiler plants and they expect to add $10,200,000 more during 1930 (Fig. 3).

Type of District Heating Systems

The two types of systems are steam and hot water. Although hot water is used in a few systems it has the decided disadvantage of re-
quiring extremely high pressures in order to serve tall buildings whereas steam has many advantages in favor of its use. Steam can be used to supply buildings equipped either with a steam or a hot water heating system, and the quantity used can be satisfactorily metered. Steam can also be used to supply cooking apparatus, water heaters for domestic water supply, and laundry equipment. Because of the important advantages of steam service all recently installed systems are designed to use steam and no hot water systems have been installed for many years except to supply small groups of buildings, as in institutions. Of about thirty hot water plants originally installed only sixteen are now in operation and some of these are being converted to steam systems from time to time. The engineering features which will be discussed relate solely to steam systems unless otherwise stated.

Systems of steam distribution may be grouped into three classes as to steam pressures. Systems carrying 50 pounds per square inch or less (above atmosphere) are called low pressure systems. Systems carrying pressures of 100 to 200 pounds are called high pressure systems.
A third class has both high and low pressure pipes laid parallel to each other.

The design pressure is determined by the probable requirements of the consumers, the amount of space available below the streets for pipes and the policy of the company supplying the service. High pressure systems are necessary if laundry equipment is to be supplied or if pumps and other small power apparatus incidental to the operation of large buildings are to be served.

Usually the district heating plant is housed in a separate building, although there are cases where the steam is supplied from an electric generating station. The boiler plants in the basements of certain buildings are sometimes interconnected and used to supply several adjoining buildings. The Chicago development is an example of this method, which is termed the block system.

The following descriptions of typical district heating systems serve to illustrate the extent to which the service has been developed.

**New York City**

The New York Steam Corporation supplies steam to consumers on the Island of Manhattan for heat and power. At the present time the Corporation serves two districts, the downtown district and the uptown district, indicated on the map in Fig. 4.

The downtown district includes the area of large buildings constituting the financial and business center of lower Manhattan. The uptown district includes the rapidly developing business center as well as the area of large apartment and hotel structures adjacent to this center.

The Corporation serves a total of 2245 consumers occupying 1,265,974,00 cubic feet of building space. During the last fiscal year 7,731,487,000 pounds of steam were distributed from five boiler plants through 191,266 feet of pipe, ranging in diameter from 8 inches to 24 inches, to serve these consumers. The five boiler plants have an aggregate generating capacity of 6,000,000 pounds of steam per hour.

Consumers are served with steam at pressures ranging from 100 pounds to 150 pounds per square inch. In the downtown district a considerable portion of the steam is used for the generation of power, while in the uptown district the proportion of power service is much less. The sale of steam for power increases the summer load but as existing isolated power plants using this service are discontinued from time to time the amount of steam thus used is decreasing. Summer loads are improved to a small extent by the sale of steam to construction operations which, in New York, are in progress to a great extent continuously.

The tremendous concentration of business forces the use of high pressures and large pipes to supply the demand for steam service. The subsurface space is crowded with water, sewer, gas and electric services so that the generation of district heating supply in any one
Fig. 4. District Heating Systems of the New York Steam Corporation.
location is limited by the inability to distribute steam from one point in excess of 4,000,000 pounds per hour.

The pipe is of extra heavy steel with welded flanges and is laid with multiple-corrugation copper expansion joints to provide for expansion. Concrete and tile conduit is used above tide water level while a specially designed waterproof cast iron housing is used at the lower levels. Two inches of insulation surrounded by a layer of rubberoid roofing material together with a filling of mineral wool in all the remaining space between the pipe and the conduit constitute the insulation. Drain stations are provided at low points of the mains to remove the condensation. Main valves and expansion joints are enclosed in vaults. Distribution feeders are usually 24 inches in diameter.

Expansion of the service has required during each of the past several years the installation of about three miles of pipe, and an increase in station capacity of 300,000 to 600,000 pounds of steam per hour.

The consumers use the service for heat, power, cooking, laundry and process work.

A total of 6200 kilowatts of electricity is generated in the boiler plants all of which is used for supplying some of the boiler plant auxiliaries. Coal is brought to the stations by barges on the East River and hoisted directly to the bunkers except for the downtown station to which the coal is carried by trucks. The greater part of the ashes are sold at the stations for construction purposes.

The New York Steam Corporation is the largest district heating organization in America and a statement of its earnings, expenses and charges for the year ending June 30, 1929 is appended to indicate how large such a heating service may become in a fertile field.

1. Gross Earnings:

| Operating Revenues          | $7,711,065.12 |
| Non-Operating Revenues      | 75,687.71     |
| Total Gross Earnings        | $7,786,752.83 |

2. Operating Expenses and Taxes:

| Operation                  | 3,920,149.69  |
| Maintenance                | 651,639.70    |
| Taxes                      | 571,447.19    |
| Total                      | 5,143,236.58  |

3. Net Earnings Before Provision for Retirement Reserve

   | 2,643,516.25 |

4. Deductions:

| Interest on Funded Debt     | $956,936.18   |
| General Interest            | 139,248.53    |
| Amortization of Bond Discount Expense | 64,756.65 |
| Miscellaneous Amortization  | 3,900.00      |
| Total Deductions            | $1,164,841.36 |
Detroit, Michigan

The district heating system in Detroit is operated by The Detroit Edison Company. This system serves about 2000 customers with a distribution system consisting of 168,810 feet of pipe and 10,742 feet of tunnel. The buildings which are served include large office buildings, department stores, hotels, restaurants and residences, as shown in Figure 5. The steam is used for building heating and domestic water heating and some steam is used for cooking and miscellaneous purposes. In 1928, 2,455,052,000 pounds of steam were sold.

There are four boiler plants located at different points of the system with an aggregate maximum output 2,815,300 pounds of steam per hour. The system is fed by means of high velocity feeders feeding into important points of the distribution network. Pressure at the consumer’s service ranges from 5 to 30 pounds.

In three of the four plants electricity is generated, there being a total electric generating capacity of 6,650 kilowatts, part of which is used for supplying the boiler plant auxiliaries. Coal and ashes are handled by motor trucks.

The heating service in Detroit is very popular and nearly all buildings within the district where service is available purchase steam (Fig. 5).

Chicago, Illinois

In Chicago the Illinois Maintenance Company operates a block system of district heating. In this type of system a group of several buildings is heated by a boiler plant located in the basement of one of the buildings. Pipes are run through building basements to connect the heating systems of the several buildings. There are several of these groups which are interconnected as shown in Figure 6.

The company serves eighty consumers with about 1,250,000 square feet of radiator surface heating 125,000,000 cubic feet of space. The distribution system contains 15,000 feet of pipe. In 1928, 720,679,000 pounds of steam were sold.
There are two principal disadvantages to the block system, first the inefficiency of the small basement plants and second the distribution of steam by means of an insecure right of way through consumer's premises. However, if a large system were contemplated in Chicago some of the elements of the block system would be retained. The location of the boilers in basements has some advantage because the
plants are located at various points of the distribution system and the pipe sizes may therefore be kept relatively small (Fig. 6).

![Diagram of the Block Heating System of the Illinois Maintenance Company in Pittsburgh, Pennsylvania]

**Pittsburgh, Pennsylvania**

The Allegheny County Steam Heating Company operates a district heating system in the downtown district of the city. There are two steam generating plants having a total of seven boilers.

The company has 219 customers with 2,500,000 square feet of radiator surface heating 218,000,000 cubic feet of space. In 1928 1,217,616,000
pounds of steam were sold. In general consumers are served with steam at 10 pounds pressure but in a few cases the pressure is 125 pounds per square inch.

The principal steam pipes are installed in tunnels along with the condensation return piping. The buildings served are mainly large office buildings, large department stores and hotels. No industrial business is served but a number of customers operate restaurants and laundries with steam taken from the district heating system.

Rochester, New York

The Rochester and Gas Electric Corporation operates three separate systems in the city of Rochester. One system serves the commercial district and the other two serve industrial districts.

This company serves altogether approximately 300 consumers and has about 63,550 feet of underground steam pipes. The steam sold in 1928 totalled 1,060,000,000 pounds. Steam pressure at the consumer's point of supply ranges from 5 to 140 pounds per square inch.

Steam service to industrial users was begun several years ago in Rochester in the vicinity of the Company's electric generating station which happened to be located in close proximity to an industrial district. The station is a condensing plant and steam is bled from the turbines at two different pressures to supply the high and low pressure steam distribution systems. A general district heating service is carried on in the vicinity in addition to the industrial service.

In the Lincoln Park district there is a group of varied industries using large amounts of process and heating steam. A plant was established nearby for the purpose of supplying steam service and to generate electricity.

The initial installation was placed in operation in November 1927. It consisted of two 9,580 sq. ft. Bigelow Hornsby boilers burning powdered coal. A 3000 kw extraction non-condensing turbine was installed and placed in operation as soon as the load justified it, which was in January 1929.

Steam pipes in the industrial district are laid in split tile conduits and the nature of the district permits burying them only two or three feet underground. Many extensions to mains and additions to the equipment were made last year to care for increased demand for steam.

Boiler Plants

Since some of the district heating projects are controlled by the operators of electric power plants it is but natural that the boiler plant practice should follow rather closely that of electric generating stations. There are however a few fundamental conditions which are peculiar to district heating and which affect the design of heating plants.

The most important of these is the comparatively low average load which they carry as compared with the maximum load. In many
instances it is not considered economical to install apparatus for removing heat from the chimney gases, such as economizers which heat the boiler feedwater or heaters which preheat the air used for combustion. The monthly load conditions are shown in Fig. 7 for a typical district heating system (Detroit) and in Fig. 8 are shown the variations of the load throughout the day.

Another condition that affects the design of district heating plants is that they are usually located near the centers of cities, where land is costly and the area of the site is consequently restricted. The plant must therefore be designed with due regard to economy of land. Other peculiar features are the necessity in many instances of transporting the coal and ashes by motor truck because of the lack of nearby railroad
or water transportation facilities; and the necessity of elaborate feedwater treatment. The latter is made necessary by the fact that it is seldom economical to return the water of condensation from the consumer's heating apparatus and raw water from the city supply must therefore be used and requires chemical treatment.

![Graph of temperature and load curves for Detroit's district heating plant throughout the day.]

Fig. 8. Variation of District Heating Plant Output Throughout the Day (Detroit).

As to methods of fuel burning there is no decided tendency toward the use of either underfeed stokers or pulverized fuel, either method having been employed in recently constructed plants.

The trend of heating plant design is illustrated by the following descriptions of recently built plants.
During the year 1925 the rapid development of the uptown district served by the New York Steam Corporation made it necessary to construct a large new station to supply the service. After a detailed study of operating requirements, fuel cost and availability, load concentration possible with different methods of firing with especial reference to available area, and local nuisance ordinances the station was designed for the use of pulverized fuel. (Fig. 9).

At present there are four boilers installed, each containing approximately 17,000 square feet of heating surface. The furnaces are almost completely water cooled having about 3000 square feet of heating surface of the fin-tube type. The arrangement of boiler surface is such that the hot gases from the furnace are divided into two streams, each
passing through one boiler section. The gases from each boiler section pass through an economizer of the expanded surface type, there being two per boiler with about 5000 square feet of heating surface each. The gases leaving each economizer pass through an air heater of the plate type, each having approximately 30,000 square feet of heating surface. There are two air heaters per boiler.

Air is forced through the air heaters by two forced draft fans above each boiler. Gases are removed from the system and delivered to the common stack by two induced draft fans above each boiler.

The plant is located on the East River so that coal is brought to it in barges from which it is hoisted by an electric tower to the main coal bunker which has a capacity of 10,000 tons (2000 pounds). The coal is fed from the main bunker through dryers to the pulverizing mills. After pulverization it is transported to the boiler bins by air transport through pipes. Each boiler has bin capacity sufficient for 100 tons of pulverized coal. From the boiler bins the coal is fed by screw feeders through pipes into the furnaces. There are twelve burners in each furnace.

Water is supplied from the city mains, heated by exhaust steam from the auxiliaries and pumped to the boilers. Because there are no returns from the consumers and because of the high rates of evaporation it is necessary to treat the water chemically which in this case is accomplished by feeding the chemicals directly to the boilers.

Most auxiliaries are driven electrically by current furnished from three 3000 kw non-condensing turbines.

Steam is generated at a pressure of 285 pounds gauge and throttled through reducing valves or a high back pressure turbine to distribution pressure.

The four boilers are normally operated to generate a total of 1,580,000 pounds of steam per hour continuously and in cases of emergency may be called upon for a maximum total steam production of 1,700,000 pounds per hour.

Operation of the auxiliaries is largely by remote manual control from the firing floor.

The Beacon Street Plant of The Detroit Edison Company

Fig. 10 shows a cross section of the Beacon Street plant of The Detroit Edison Company. This plant contains four boilers designed to operate at 160 pounds pressure and to deliver 400,000 pounds of steam per hour each. A 3000 kw turbine exhausts partly into the feedwater heater and partly into the distribution system. The plant is designed to contain ultimately twelve boilers.

The boilers are fired by automatic stokers which were chosen in preference to pulverized coal since, at the time the choice was made, no method of removing ash from the flue gases had been perfected.

Water cooled furnace walls were not installed as the maintenance of refractory walls is less in this case than investment costs for water.
cooled walls, and preheaters were not used as the increased cost was not justified due to the high maximum hourly load as compared to the average load. The boilers are equipped with forced and induced draft fans and most of the auxiliaries are motor driven.

Fig. 10. The Beacon Street Plant of The Detroit Edison Company.

*The Lawn Street Plant of the Rochester Gas and Electric Corporation*

Coal is prepared at a coaling station on a railroad siding and hauled to the plant by motor trucks, where the truck bodies filled with coal are hoisted by crane to the bunkers. Ashes are dumped from the furnace directly into trucks and hauled away.

About 20 per cent of the feedwater is condensation returned from consumers' heating systems, the balance being city water which is treated by a zeolite system with an acid after-treatment. There is a three hour storage of water in the plant.
The Lawn Street Plant of the Rochester Gas and Electric Corporation has two 1122 horsepower Bigelow-Hornsby boilers, designed to operate with a pressure of 375 pounds per square inch with a total output of 240,000 pounds of steam per hour. Allowance was made in the building for one additional boiler. These boilers, which burn powdered fuel, are capable of operating at 400 per cent of rating.

Each boiler is equipped with 4707 square feet of economizer surface using induced draft fans and a superheater which gives a steam temperature of 540 degrees Fahrenheit.

Fig. 11. The Lawn Street Plant of the Rochester Gas and Electric Corporation.

The Generation of Electricity in District Heating Plants as a By-Product

One Curtis General Electric Company turbine with a capacity of 3000 kw designed to exhaust into the distribution system with a back pressure of 5 to 10 pounds is installed.

As shown in Fig. 11, coal is delivered by truck to the bunkers in the basement and conveyed to the bunkers over the boilers. Each boiler has two 7000 pounds per hour pulverizing mills driven by 75 horsepower motors and one 2000 pound per hour mill driven by a 25 horsepower motor. There are two burners for each large mill and one burner for each small mill. Ashes are disposed of by a vacuum ash handling system.
In some district heating plants electric generating units are installed, through which the steam is passed before being distributed for heating purposes, the electricity being delivered to the system of the electricity supply company. In other plants steam is delivered to the distribution pipes direct from the boilers, without passing through a turbine. The question as to whether or not the generation of electricity as a by-product is economical or otherwise desirable cannot be given a general answer but must be decided in each individual case on the basis of local considerations.

In a few cases an electric generating plant serving a city happens to be so located that exhaust steam bled from the turbines can be distributed for district heating but ordinarily the electric generating plant is located some distance away and the heating service is supplied from a plant built for that particular purpose, close to the district where heat is to be distributed. The question then is whether turbo-generators should be installed in such a heating plant or whether the steam should be taken direct from the boilers and distributed for heating.

The gain in overall thermal economy which results from generating electricity from steam which is subsequently used for heating, as compared with generating an equivalent quantity of electricity in a condensing plant is well appreciated; but there are other economic and financial considerations which have in some instances led engineers to believe that the use of steam direct from the boilers for heating is the most desirable method. The correct answer in any particular case depends upon the value of a kilowatt hour of electricity at the location of the heating plant as compared with the total cost of producing it in the heating plant. The relation of fuel cost in America to investment and labor costs is such that the method which is much more wasteful of fuel is sometimes found to be the more economical. Unless steam driven auxiliaries are installed, the use of a small turbo-generator, delivering exhaust steam to a feedwater heater is usually justified on economic grounds.

The use of boiler pressure of 400 pounds per square inch and higher by making possible the generation of large quantities of electricity, renders byproduct generation more attractive and this method is receiving considerable attention at the present time.

Steam Distribution

There are two methods of distribution in use. One is the method shown in Fig 12. The distribution system consists of a trunk pipe whose size decreases as the quantity of steam decreases, and a number of lateral pipes laid in the intersecting streets and forming a more or less interconnected network. This is the simplest form of distribution system and is used in the majority of cases.

The second method is illustrated in Fig. 13. This system consists of a network of mains to which steam is supplied by feeders which extend from the boiler plant to selected points in the network.
tional feeders can be constructed to supply a district which becomes heavily loaded. The method of operation consists in maintaining, at the point where the feeder connects to the network of pipes, a constant pressure by adjusting the amount of steam flow. The pressure at the remote end of the feeder is recorded at the heating plant by an electrically operated long distance pressure gauge.

Very high velocities of flow are perfectly feasible and in many cases a velocity of flow of 50,000 feet per minute exists, while velocities as high as 75,000 feet per minute have been observed. This is to be compared with a velocity of 10,000 to 12,000 feet per minute which is common practice in steam power plants in America. The use of high velocities and large drops in pressure makes it possible to use relatively small diameter pipes and materially reduces the investment costs.

The distance over which steam can be transmitted has been found to be very great, depending only upon the pressure drop and the pipe diameter. The greatest distance over which steam is actually being transmitted to a consumer is approximately 15,000 feet. The limi-
tations of the areas which are covered by district heating systems are not due to any difficulties in steam transmission but to the size of the districts which can profitably be served.

The steam pressure which is carried has a marked effect upon the pipe diameters with either of the two types of systems shown in Figures 12 and 13. This effect is twofold. The density of the steam at higher pressures is greater and the permissible pressure drop is greater both of which considerations make smaller pipes possible. The size of pipe required for pressures below 10 pounds increase very rapidly with decreasing pressure. It would be physically impossible to distribute the quantities of steam required in the largest cities at pressure below 10 pounds per square inch although in small systems this method is feasible.

When water is costly or requires elaborate purification it is found economical to return the condensate from consumers' buildings to the plant, but usually the cost of the pipes for this purpose is not warranted.

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Fig. 14. Various Forms of Pipe Conduits.

a. Segmental Wood Casing  
b. Vitrified Clay Tile Conduit Enclosing Three Pipes  
c, d, e. Vitrified Clay Tile Conduits  
d. Cast Iron Conduit, Used in Very Wet Ground

Underground Pipe Construction

In Fig. 14 are shown several of the forms of pipe conduit in common use. The wood casing has been widely used and is satisfactory where
the soil is well drained but deteriorates rapidly in wet soil. In large cities the more permanent forms of construction employing concrete or vitrified clay tile are used and under reasonably favorable conditions have a life of at least 30 years.

Fig. 15. Expansion Devices.

a. Slip Joint  b. Variator with Copper Diaphragm  c. Corrugated Copper Expansion Joint
Heat Losses

Although the heat loss from the underground pipes is an important item it is not as serious as might be supposed. It was previously stated that the efficiency of distribution in a well designed system is 80 to 90%. This loss of 10 to 20 per cent includes not only the condensation loss in the pipes but loss from steam leaks and other causes.

The heat loss can be approximately measured by measuring the condensation which is drained from the pipes. Tests which have been conducted in this way on portions of district heating systems have indicated that the heat loss varies from 50 to 75 B.t.u. per square foot of pipe surface per hour for pipes laid in dry soil and fairly well insulated.

The linear expansion of the pipes is provided for by some one of the three devices shown in Fig. 15. The slip joint which is quite widely used has the advantage of being able to take care of several inches of expansion travel. It must however be so located as to be accessible for the renewal of the soft packing. The so-called variators which depend upon the flexure of copper diaphragms are capable of taking care of 2½ inches of movement and are located at intervals of 100 to 200 feet. They require no attention and need not be accessible. The corrugated expansion joint is capable of taking care of ½ inch of movement for each corrugation. The corrugated portion is made of copper. In general the trend is toward the use of the slip joint or the corrugated joint, the former for any pressure used and the latter for pressures between 50 and 150 pounds per square inch.

The use of fusion welding employing either the oxygen-acetylene or the electric arc method for joining underground pipes is quite general and has many advantages in district heating work. The branch pipes which supply the individual buildings can thus be joined to the main pipe without the insertion of a fitting.

Tunnels

It is sometimes found desirable to install the pipes in tunnels large enough to be entered by a man. When several large pipes must be placed in the same street it is often not much more costly to construct a tunnel than to lay the pipes in separate trenches, and in a tunnel the pipes are readily accessible for inspection. Also when there is a great congestion of other pipes immediately below the pavement, as is frequently the case in narrow streets, a tunnel bored at a lower elevation to carry the steam pipes is often the best solution.

The question as to the desirability of tunnel or trench construction depends upon local conditions and particularly upon the nature of the soil. The trenching method is so much less costly that it is almost universally used.

In Fig. 16 is shown one form of tunnel construction which has proven satisfactory in a clay subsoil. Except for the concrete floor it is built
of brick and is so shaped that it will withstand earth pressures when located 25 to 60 feet below the surface.

The Consumer's Heating Apparatus

Experience has conclusively demonstrated that in order to supply heating service that will be satisfactory to the consumer, both as to quality and cost, the operators of a district heating system must assist him in designing a suitable heating system and in operating it economically. Complaints made about the quality of the service are usually due entirely to defective equipment in the consumer's building and consequently the proper design and maintenance of the consumer's equipment are very important in the rendering of satisfactory and economical heating service. Engineering practice in the design of heating apparatus in America has reached a fairly satisfactory stage of development but there are certain peculiar principles which should be observed when heating service is to be supplied by the district heating system.

The special apparatus which is necessary to adapt a consumer's heating system to the use of steam from a district heating system consists of

(a) A pressure reducing valve. The pressure carried in the district heating pipes is usually higher than is desirable for use in the radiators and should be reduced to the desired pressure.

(b) A trap which will permit the drainage of condensation from the pipes and radiators without leakage of steam.

(c) An economizer (not always provided) to utilize the heat in the condensation.

(d) A meter (supplied by the district heating company) to measure the amount of steam used.
The Economical Use of Heat

It became evident several years ago that district heating service was often regarded as costly because of the wastefulness with which the heat was used by many consumers. In order to compete more successfully with individual boiler plant, district heating companies have in recent years expended considerable effort in determining the most
economical methods of heating and in assisting the consumer in employing those methods.

There is an essential difference between the operation of a heating system in which fuel is burned and one which uses steam from a district heating plant. In the former case the amount of heat used is governed by the amount of fuel fed to the boiler and is therefore under direct control. In the latter case the supply of heat is practically unlimited and carelessness in the control of it results in excessive consumption.

There are many ways in which the consumption of heat in a building can be reduced, but the two most important ways are (a) by shutting off the heat supply during the night and at other times when it is
not required, and (b) by regulating the heat supply according to the outside temperatures.

It is especially important that heat be shut off at night or whenever a building is unoccupied. Fig. 17 illustrates the great decrease in the amount of steam consumed which can be made by shutting off the heat at night and permitting the building to cool down. The heat consumption is slightly higher than normal for a short time after the steam is turned on in the early morning but the net saving is very large.

Although the shutting off of the heat supply in a building when heat is not required is the most fruitful means of saving steam, the regulation of the supply during the periods of occupancy is also important. The steam heating system, in its simplest form, does not give a heating effect which is graduated in accordance with heating requirements, but delivers from each radiator the maximum amount of heat if the supply valve is open and none at all when the valve is closed. Buildings are therefore frequently overheated and the occupants are inclined to keep windows open unnecessarily. Means of adjusting the heat supply which are independent of the occupant are therefore desirable.

Automatic temperature control, operated by compressed air and with a controlling element in each room, has been brought to a fairly satisfactory state of development but is not widely used chiefly because of its rather high cost. There are two other methods, both of which permit the amount of heat to be controlled at the central point of supply in the building. They are (a) the orifice method and (b) the intermittent method.

In the former an orifice plate is inserted in the pipe which supplies each radiator and the amount of steam which enters the radiators may be controlled by adjusting the pressure of the steam at the main supply point. The other method is made possible by an automatic device known as the Pendleton Control, which is attached to the main supply valve and opens and closes it at predetermined intervals so as to give the desired average heating effect. The method of operation is shown in Fig. 18.

This device is well adapted to buildings of fairly large size and is particularly desirable for hotels and apartment buildings.

Another important point in the economical utilization of heat is the extraction of the heat in the condensation. The recoverable heat is about 10 per cent of the original heat of the steam. The usual method is to pass the condensate through a heat exchanger in which the water supplying lavatories is partially heated, the final heating taking place in a separate heater supplied with steam. The arrangement of an economizer of this kind is shown in Fig. 19.

There are various other ways in which the cost of heating buildings can be reduced. District heating companies have learned that the instruction of consumers in these methods is a sound commercial policy because it lowers the consumer’s cost of heating and therefore renders the purchase of heat from the district heating company more attractive.
in comparison with the operation of his own boiler, besides cultivating his good will.

The satisfactory use of district heating service requires that the various pieces of apparatus be kept in perfect working order and most district heating companies provide free inspection service. Periodic inspections of consumers' piping and equipment are quite generally conducted.
The use of steam varies in different kinds of buildings because of the differences in building construction, hours of occupancy and indoor temperatures. Between individual buildings of the same kind there is also considerable variation due largely to the degree of care used in controlling the heat supply. Table 2 gives the consumption of several classes of buildings in two cities.

Table 2
Steam Consumption for Heating, Hot Water Supply and Cooking, for Various Kinds of Buildings

<table>
<thead>
<tr>
<th>Type of Building</th>
<th>Average Annual Steam Consumption Pounds per year per Cubic Foot of Space Heated.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Detroit¹</td>
</tr>
<tr>
<td>Office Buildings</td>
<td>5.0 to 8.0³</td>
</tr>
<tr>
<td>Banks</td>
<td>7.9</td>
</tr>
<tr>
<td>Apartment Buildings</td>
<td>11.0</td>
</tr>
<tr>
<td>Hotels</td>
<td>9.0 to 15.0</td>
</tr>
<tr>
<td>Large Department Stores</td>
<td>4.7</td>
</tr>
<tr>
<td>Small Retail Stores</td>
<td>6.1</td>
</tr>
<tr>
<td>Moving Picture Theatres</td>
<td>5.5 to 7.5</td>
</tr>
<tr>
<td>Garages, All Buildings</td>
<td>3.0 to 5.0</td>
</tr>
</tbody>
</table>

Methods of Charging for District Heating Service.

Early in the development of the industry it was found that the charge for heating service should be based upon the amount of heat actually used by each consumer. Any method of charging which assesses a fixed sum, regardless of the quantity used, is quite wrong, because it leads to a great waste of heat by the consumer. The use of such a method for hot water service due to the lack of a satisfactory meter has been one of the major reasons why it has given way to steam for district heating. The use of meters for steam heating service is universal, and steam is sold in units of 1000 pounds.

A typical schedule of charges is as follows:

For the first 50,000 pounds each month $1.90 per M 1lb.

| "" "" next 100,000 "" "" "" | 1.35 "" "" "" |
| "" "" 300,000 "" "" "" | 1.10 "" "" "" |
| "" "" 550,000 "" "" "" | .90 "" "" "" |
| "" "" 1,000,000 "" "" "" | .85 "" "" "" |
| "" "" 2,000,000 "" "" "" | .80 "" "" "" |
| "" "" excess over 4,000,000 "" "" "" | .75 "" "" "" |

¹ Average outdoor temperature for the heating season of 8 months was 36 deg. F.
² Normal average outdoor temperature for heating season 43 deg. F.
³ The higher figure is for buildings in which less care is used in operating the heating system.
The charge is often subject to adjustment for changing prices of coal. The schedule of charges given above is based on a bituminous coal price of $3.80 per ton (2240 pounds). For each 14 cents increase or decrease per ton above or below the base price of $3.80 an adjustment of one cent per thousand pounds of steam is made.

It is well known that a schedule of charges similar to the one given above does not assess every consumer exactly in proportion to the true cost of rendering him service and a more refined method of charging is sometimes desirable. The items comprising the cost of the service may be divided into two groups. In one group are those items which are dependent upon the maximum amount of steam which the system may be called upon to deliver. Most of the capital costs and labor costs are included here. In the second group, are those items which are dependent upon the total amount of steam delivered including principally the fuel and water costs. It is desirable that the method of charging take this principle into account as otherwise the consumer who uses heat for many hours during the day may be assessed an unduly large amount.

A method of charging has therefore been developed and is used in a few cities, by which the consumer is assessed partly on the basis of his maximum rate of use of steam and partly on the basis of the total steam which he uses.

The use of such a method of charging assesses each consumer approximately in proportion to the true cost of serving him. It is not a new theory but is well known and widely used in other forms of public utility service. Applied to district heating service it tends to lower the charges for service to those classes of consumers which use heat during many hours of the day, such as the hotels, clubs and apartment buildings, and therefore makes it possible for district heating service to compete more successfully with the cost of operating individual plants.

Another method developed to distribute the cost of service among consumers in accordance with load factor, recognizes the advantage of high average monthly use during the summer and establishes a price based on this summer use. This price constitutes a material reduction from the normal heating charge.

Meters

The art of metering the heat supply has been developed to a satisfactory state. One method is to measure the condensation at its point of discharge from the consumer's piping. In order to accomplish this it is necessary that the condensation be collected at one point, that the pipes be free from leaks and that the condensate be drained to the meter without the escape of steam, which upsets its operation and causes incorrect registration.

One form of condensation meter is illustrated in Fig. 20. It consists of a drum having six compartments which are filled in succession from the central inlet spout, the drum being caused to revolve slowly by the
unbalanced weight of water in it. The revolutions are transmitted through a gear train to a dial which shows the accumulated consumption.

Another form of condensation meter is the tilting meter shown in Fig. 21. It consists of a pan divided into two compartments and supported on trunnions. The compartments fill and discharge alternately.

Fig. 20. Rotary Condensation Meter, Cross Section of Drum Shown at Right.

Fig. 21. Condensation Meter of the Tilting Type.

These meters record the total quantity of steam used. In order to make use of a method of charging which takes into account the maximum rate of consumption it is necessary to have a meter which will show the hour-by-hour use. This is accomplished in the case of the meter illustrated in Fig. 20 by an attachment which traces on a chart the hour-by-hour consumption.

The metering of the condensation is impracticable in some cases, particularly where it is not possible to return the condensation, as
when steam is used in engines or processes in which it is mixed with liquids. Some form of steam flow meter is necessary in such cases and the St. John meter shown in Fig. 22 is the one most commonly used, although there are many other forms, most of which employ the Venturi

Fig. 22. Steam Flow Meter-Displacement Type.
As the valve V opens to pass steam, the action is transmitted to the dial and recording chart. The valve is so tapered that the rising is in direct proportion to the flow of steam.

Fig. 23. Steam Flow Meter-Venturi Type.
principle as does the one shown in Fig. 23. In some cities the steam flow meter is used almost exclusively. This is the case in New York City where much steam is sold for power purposes and the collecting of the condensation for metering would be impossible. Steam flow meters are generally used on high pressure systems where there is a reasonably constant delivery pressure to the consumer.

The accuracy of condensation and steam flow meters compares favorably with that of meters used in other utility services.

**Economics**

The cost of heating service includes many items of which the fuel cost, while the largest single item is less than one third of the total cost. Investment costs play a large part and the expenses of distribution and of maintaining the consumers equipment are not inconsiderable. The approximate relative importance of the items comprising the total cost of service are shown in Table 3.

<table>
<thead>
<tr>
<th>Items Which Comprise the Cost of Heating Service</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel cost</td>
<td>30 per cent</td>
</tr>
<tr>
<td>Other steam generation costs</td>
<td>15 &quot;  &quot;</td>
</tr>
<tr>
<td>Cost of distribution</td>
<td>5 &quot;  &quot;</td>
</tr>
<tr>
<td>Cost of caring for consumer's equipment</td>
<td>2 &quot;  &quot;</td>
</tr>
<tr>
<td>Selling expense</td>
<td>1 &quot;  &quot;</td>
</tr>
<tr>
<td>General expense, including taxes</td>
<td>7 &quot;  &quot;</td>
</tr>
<tr>
<td>Capital costs — Boiler plants</td>
<td>25 &quot;  &quot;</td>
</tr>
<tr>
<td>Capital costs — Distribution system</td>
<td>15 &quot;  &quot;</td>
</tr>
<tr>
<td></td>
<td>100 per cent</td>
</tr>
</tbody>
</table>

While the investment required for a district heating system naturally varies considerably, depending upon local conditions, the ratio of investment to income is $4.00 to $5.00 investment per dollar of annual income, which is a slightly larger ratio than that required for electrical service. The investment is divided between the boiler plant and distribution system, sometimes in nearly equal proportions but more often with a larger amount invested in the boiler plant in a ratio of 1 1/2 or 2 to 1.

The financial success of a district heating enterprise depends largely upon the following factors:

(a) The plant investment per pound of steam output.

(b) The density of the load, which may be expressed as the amount of steam sold annually per foot of distribution pipe. This figure averages throughout the country 16,000 pounds per foot, while the figure for New York City where many tall buildings are served is 40,000 pounds per foot.

(c) The selling price per thousand pounds. This varies in different cities from $.60 to slightly over $1.00 and has until recently been

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1 Does not include heat loss from distribution pipes. This item is included in the fuel cost.
much too low in many cases. In the larger cities a selling price of from 
$.90 to $1.00 per thousand pounds is necessary if the business is to be 
profitable.

Conclusions

The results of the combined experience of many district heating 
companies permit the forming of some fairly definite conclusions regard­
ing the engineering and economic status of district heating in America.

The distribution of the quantities of steam required for heating 
even in the largest cities can be successfully accomplished and the 
distances which can be covered are fixed by economic and not by engineer­
ing limitations. The service must be limited to favorable areas if it is 
to be profitable and there is no prospect of a city-wide district heating 
service in its present form.

The use of hot water for commercial district heating has been defin­
etly abandoned in favor of steam.

The generation of electricity in district heating plants is desirable in 
some cases and to some degree, and the complete application of the 
thermodynamic possibilities in this respect is being considered in some 
plants.

A district heating system is desirable as an auxiliary to an electric 
supply service as a means of eliminating the individual plant.

District heating has its most profitable and most popular field in the 
business districts of large cities and there is an increasing demand for 
the service. It depends for its success upon certain climatic, economic 
and physical conditions which are to some extent peculiar to America. 
It is not as profitable in residence districts, made up of detached single 
family dwellings, and except for certain types of community developments 
it appears that other methods are satisfying the demand for automatic 
heating.

The supply of steam to manufacturing industries for heating and for 
manufacturing processes affords a promising field for future develop­
ment.

The district heating industry is on a sound basis and its future expan­
sion in the fields in which it is profitable is assured.

Zusammenfassung

Das amerikanische Klima und die Methoden der Häuserbeheizung sind für die 
Entwicklung der Fernheizung von großem Einfluß. In den Vereinigten Staaten 
und in Kanada ist die Außentemperatur im Winter ziemlich niedrig und relativ 
hohe Innentemperaturen werden verlangt. Die benötigten Wärmemengen sind 
also verhältnismäßig groß.

Fernheizwerke bedienen mit gutem Erfolg Wohnquartiere und Geschäfts­
viertel; der letztere Fall ist das aussichtsreichere Geschäft hinsichtlich Absatz­
und Gewinnmöglichkeiten. Die Konkurrenz der Einzelheizanlage ist stark, doch 
behauptet sich die Fernheizung besonders durch ihre nicht direkt in Zahlen aus­
drückbaren Vorteile. In einigen Städten wird Dampf neben Heizzwecken auch 
zur Fabrikationszwecken an Industrieunternehmungen abgegeben; nach dieser 
Richtung öffnet sich der zukünftigen Entwicklung ein weites Gebiet.

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In einigen Fällen benutzt man den Dampf vor der Verteilung zur Erzeugung von elektrischer Energie, welche jedoch gänzlich als Nebenprodukt behandelt wird. Auf diese Weise könnten große Elektrizitätsmengen erzeugt werden, besonders wenn sehr hohe Kesseldrücke zur Anwendung gebracht würden, doch lassen es kaufmännische Gesichtspunkte oft unangebracht erscheinen, zu dieser Methode überzugehen.

Verteilung, Messung und Ausnutzung des Heizdampfes sind ziemlich gut entwickelt, doch sind noch viele weitere Verbesserungen möglich.