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District Heating/Cogeneration Application Studies for the Minneapolis–St. Paul Area

Building Conversion Costs and Economics for the St. Paul Hot Water District Heating Market

J. O. Kolb
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DISTRICT HEATING/COGENERATION APPLICATION STUDIES FOR THE MINNEAPOLIS-ST. PAUL AREA

BUILDING CONVERSION COSTS AND ECONOMICS FOR THE ST. PAUL HOT WATER DISTRICT HEATING MARKET*

J. O. Kolb
Kevin Teichman**

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Reports in This Series

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PREFACE

This report is one of a series of application studies of district heating/cogeneration for a U.S. metropolitan area. The technical, economic, environmental, and institutional studies in this series established the general feasibility and desirability of a hot water, district heating system using cogenerated thermal energy from utility power plants. St. Paul, Minnesota is proposing to replace a steam district heating system that serves its central business district with a modern hot water district heating system. The St. Paul District Heating Development Company, Inc., was established to develop an implementation plan for an economically feasible system as a demonstration project for a modern, hot water district heating system.

The St. Paul District Heating Development Company, Inc., has been funded by the Department of Energy, the State of Minnesota, the City of St. Paul, and the Northern States Power Company. The Oak Ridge National Laboratory has provided technical management for the Department of Energy as a part of the overall Twin Cities District Heating Application Studies.

Mr. Teichman served as a technical consultant to the District Heating Development Co. in the area of building conversion costs and economics prior to joining the Bloomington, MN office of Ellerbe Associates.

CONVERSION FACTORS

To convert from	To*	Multiply by
lb/h	kg/s	0.0001260
ft^2	m^2	0.09290
in.	cm	2.5400
MBtu or 10^6 Btu	GJ	1.055
Btu/h	kW(t)	0.0002931
MBtu/h or 10^6 Btu/h	MW(t)	0.2931
psi	kPa	6.895
°F	K	$T = [(T_{°F}-32)/18] + 273$
$/MBtu	$/GJ	0.9479

*Prefixes are used in the SI system to form decimal multiples of the base units (factors of 10^3): $k = 10^3$, $M = 10^6$, and $G = 10^9$.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the significant technical input during this study by Hans Nyman and Rudy Brynolfson of the St. Paul District Heating Development Co., Inc. We also wish to acknowledge the ORNL staff members Martin Broders and Gerald Pine for their review of the final report and Michael Karnitz and William Mixon for their support and review of this report. Finally, the assistance of Ms. Judy Taylor for preparation of the report manuscript is acknowledge.

ABSTRACT

The economic feasibility of supplying thermal energy from a 250°F (121°C) hot water district heating system to a wide range of building heating distribution types depends in large part on the cost of connecting and converting building heating systems to a hot water supply. This report summarizes a major study of building conversion methods and costs for the central business district of St. Paul, Minnesota, performed for the St. Paul District Heating Demonstration Project. Also, the general characteristics of an economic analysis are presented for a typical building with a current energy source of either steam district heat or natural gas.

In the study, an engineering consulting firm estimated conversion costs for 106 St. Paul buildings in the market area of a new hot water district heating system being developed by the St. Paul District Heating Development Co., Inc. (DHDC) Building heating systems were classified by the distribution media - steam, hot water, and air - and also by the heating system configuration - perimeter heating and/or air ventilation heating. The conversion cost results for hot water distribution system buildings are consistant with previous studies, averaging \$40/kW(t) of demand or \$0.3-0.5/ft^2 of heated area. In general, buildings with steam perimeter heating systems have much higher conversion costs than hot water heating systems. The unit conversion cost for the steam perimeter heating systems averages \$200/kW(t). The conversion cost for such heating systems includes a substantial cost for replacing equipment, in some cases up to 90 years old, and therefore represents the cost of renovating and upgrading old heating systems to efficient and modern hydronic heating system operation. Hence, the estimated conversion costs for steam perimeter heating systems have a wide variability - up to \$200/kW(t) of demand - and are subject to more uncertainty than the estimated conversion costs for other types of heating systems.

The economic analysis results were characterized by the time to achieve a positive cumulative cash flow after initiating hot water heating service, defined as the payback period. For the financing conditions being made available to potential customers in St. Paul and an assumed 1984 hookup year, payback periods are longer for current steam customers than natural gas customers. Acceptable payback periods of 5 to 6 years could be achieved for current natural gas customers with unit conversion costs up to ~$275/kW(t) of demand. The economic benefits of energy savings from converting steam heating systems to hydronic operation and improved tax benefits are also presented.

1. INTRODUCTION

As a part of the St. Paul District Heating Demonstration Project, a major study has been performed on the feasibility and the cost of converting building heating systems to be compatible with a 250°F (121°C) hot water district heating system. One of the main concerns in supplying building heating systems from a district system with a 250°F maximum supply temperature is the diversity in the building heating systems found in the initial market area, the central business district of St. Paul. This diversity results basically from the wide range in the ages of the buildings - from essentially new buildings to buildings as old as 90 years. This wide range of building ages allows two factors to be important - first, the condition of the building heating system as determined by the modifications and repairs that may have been performed; and secondly, the tremendous evolution in the design of building heating systems, from one-pipe steam perimeter radiation systems to modern HVAC systems utilizing air and/or water distribution media. This study therefore addresses a key economic and marketing issue for implementing a low- to medium-temperature, hot water district heating system in a U.S. urban market similar to St. Paul, Minnesota.

A two-phase "Building Conversion Study" was performed by the engineering consulting firm Michaud, Cooley, Hallberg, Erickson and Associates (MCHE) of Minneapolis for the St. Paul District Heating Development Co., Inc., a private, non-profit company which is conducting the St. Paul District Heating Demonstration Project. The overall objective of the MCHE study was to determine the feasibility and representative costs of connection and conversion of commercial, institutional, and multi-family residential buildings in the St. Paul central business district.

The first phase of the study was an in-depth investigation of conversion methods and costs for seven buildings which was intended to provide the basis for estimating the conversion cost for all buildings in the market area. However, after completing the first phase, the cost results proved to be too diverse to generalize for the entire market area. Therefore, a second study phase was conducted to provide a quick conversion cost estimate for 106 buildings of different specific heating types. The second study provides information on the range and variability of conversion costs for ten types of building heating systems. All conversion costs in this report are in mid-1980 dollars, and include only direct costs for material and labor; design fees or contingencies are not included.

In the following section, general principles are presented that affect the feasibility and cost of connection and conversion of existing building heating systems to a hot water district heating system.

2. GENERAL PRINCIPLES

The feasibility and cost of connection and conversion of existing building heating systems to a hot water district heating system involves consideration of several factors, such as (1) the district heating system characteristics, (2) the building's functional thermal energy requirements, (3) the types of building heating systems, and (4) the general guidelines for economic building connection and heating system conversion. These factors are discussed here briefly to provide a background for the MCHE study results presented in the remainder of this report. An earlier study of building conversion by the Minnesota Energy Agency[1] for hot water district heating systems with a 300°F (149°C) supply temperature presents a more detailed description of building conversion techniques.

2.1 District Heating System Characteristics

The hot water district heating system being planned for St. Paul will supply thermal energy at a maximum of 250°F (121°C) with the supply temperature decreasing to 190°F (88°C) with increasing outdoor air temperature, as shown in Fig. 1. This type of variable temperature supply schedule is used in many European hot water district heating systems to provide for predominantly building heating and domestic hot water heating demands. Reducing the supply temperature as the outdoor air temperature increases, and the building heating demand decreases, and also holding the maximum supply temperature to 250°F reduces the cost of the St. Paul piping distribution system, the cost of cogenerated thermal energy to the district heating utility, and hence the long-term cost of district heating to the consumers for the following reasons:

1. the overall efficiency of the cogeneration power plant is improved and the electric capacity derate is minimized.
2. low-cost, prefabricated pipe plus polyurethane foam insulation conduits can be utilized.
3. heat losses and corrosion are minimized.
4. the piping system design, fabrication and testing does not have to conform to the Minnesota Code for High Pressure Steam Piping and Appurtenances.

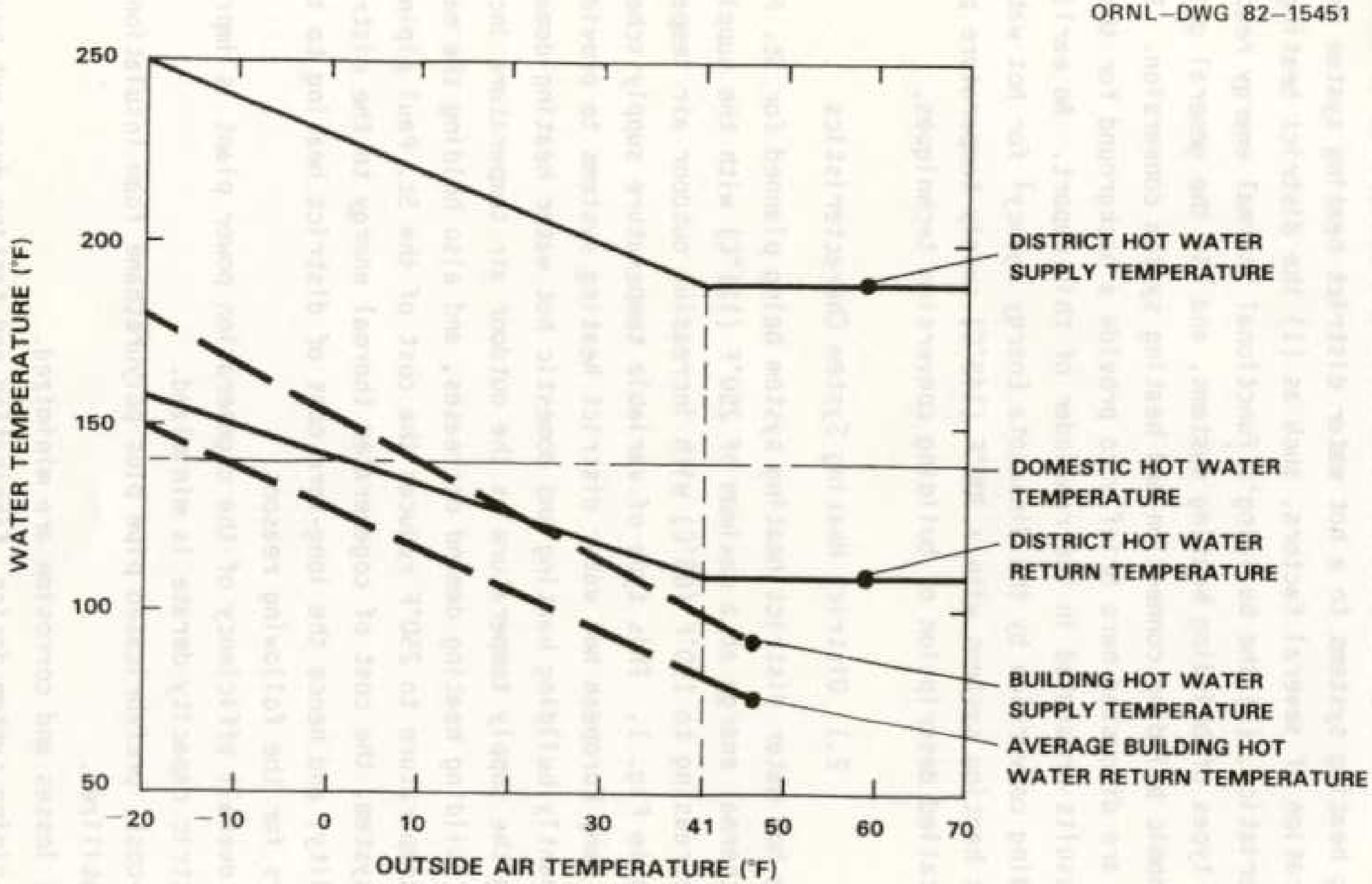

Fig. 1. Hot water temperatures for district heating system and hydronic building heating system as a function of outside air temperature.

In addition to the supply temperature characteristics previously described, a cogeneration heat source district heating system requires the return temperature to be reduced as much as practical for efficient operation of the power plant. The desired return water temperatures for the St. Paul system ranges from 110°F (44°C) to 160°F (71°C) as shown in Fig. 1. The desired return water temperatures and the supply temperature establish the criteria for the size and type of heat exchangers installed at each consumer location.

2.2 Building Functional Thermal Energy Requirements

The functional requirements of the various buildings in the St. Paul central business district for thermal energy are: (1) space conditioning - heating, cooling, humidification and dehumidification, (2) heating domestic hot water, (3) process heat - cooking, laundering, sterilization, etc. These end-use energy requirements, except for space cooling, are conventionally supplied by several types of energy - thermal energy as steam district heat, electrical energy, or gas and/or oil-fueled boilers or heaters.* Space cooling requires an additional energy conversion to produce the cooling effect through an electrical or absorption chiller.

The supply temperature of a district heating system for these various functions ranges widely, from 190°F for heating domestic hot water up to 400°F for sterilization and other relatively high temperature processes. Even the largest energy demand of space heating can require a hot water supply temperature of 270-300°F if the building heating system employs 5-15 psig steam as the distribution medium. Also space cooling when provided by an absorption chiller is usually supplied from steam or hot water in the temperature range of 270-400°F for commercially available chiller units. Therefore the choice of the hot water supply temperature for a district heating system determines the amount of thermal energy demand and types of end-uses that can be served in a given building market.

As was stated above, the St. Paul hot water district heating system will supply thermal energy between 190°F and 250°F to mainly provide for

*Other sources of energy for buildings include solar collectors and heat electric pumps which are found minimally in the St. Paul building market.

building space heating and domestic hot water heating. The main functional demand not accommodated by this approach is the space cooling demand that is presently provided by electric or absorption chillers. For the amount of existing absorption chiller capacity and the cooling load duration in St. Paul, the additional cost of a higher temperature distribution system (>270°F) to increase the summer supply temperature to serve the absorption chillers was not justified. The space cooling demand can either be supplied by replacing the absorption chillers with electric compressive chillers or by operating the absorption chillers on hot water at lower capacity than attainable with steam.

2.3 Types of St. Paul Building Heating Systems*

Building heating systems can be classified basically by the distribution medium used to deliver heat to the conditioned space - electricity, steam, hot water, air and combinations thereof. In a survey of 221 potential district heating customers, buildings representing 140 MW(t)** of peak thermal demand, the building heating systems in the St. Paul central business district were found to have the following types of distribution media: all steam, 132 buildings or 60% of the total number; all hot water, 34 buildings or 15%; steam and hot water, 18 buildings or 8%; all air, 37 buildings or 17%. The number of electrically heated buildings in the survey group was negligible. The reason for the preponderance of steam heating systems is twofold. First of all, steam was used extensively in heating systems until the 1950s, and most of St. Paul's central business district buildings were built prior to that time. Secondly, many St. Paul buildings are served from an existing steam district heating system.

A typical connection of a hot water distribution building system to the district heating system is shown schematically in Fig. 2. In general, three modes of heating are supplied - perimeter heating by radiation or induction units, ventilation air-handling circuits with preheat and reheat

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*This discussion is very general and is intended only as a brief background for this specific study. Detailed descriptions of building HVAC systems can be found in the ASHRAE Systems Handbook and the Handbook of Fundamentals.

**The (t) notation denotes thermal energy as opposed to electrical, mechanical, or chemical energy.

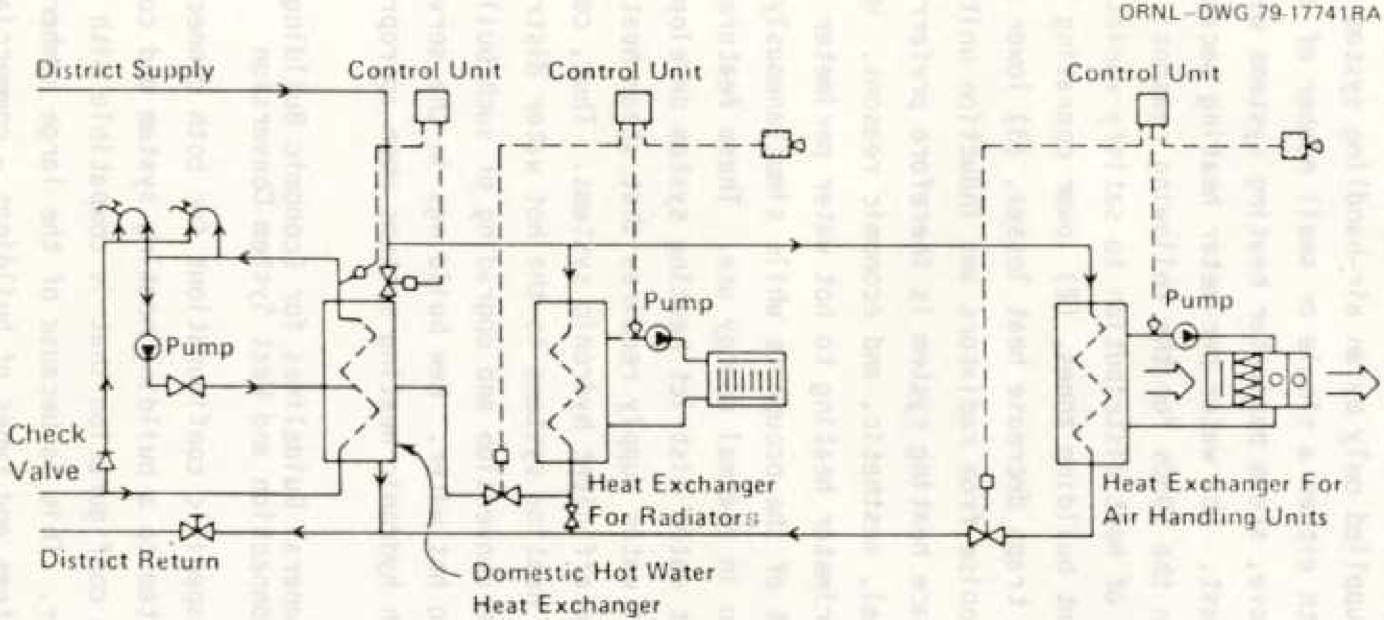

Fig. 2. Building heating system connected to district heating emphasizes low return temperature.

coils in the air-handling duct work, and domestic water heating. The predominant space heating mode in the St. Paul buildings is with steam and hot water perimeter heating. If buildings have both steam and hot water, steam is usually supplied to the air-handling ventilation heating coils and hot water to perimeter heating units. In the St. Paul market, buildings with space heating supplied only by an air-handling system are usually smaller buildings with either a single or small number of individual zones.

As was noted above, steam perimeter heating systems were designed extensively in the past. Hot water perimeter heating became more popular than steam heating in the 1950s for the following reasons: (1) easier and more precise control of heat distribution to satisfy variations in heat demands from different building zones, (2) lower operating temperatures and the absence of steam traps decrease heat losses, (3) lower maintenance costs, and (4) less noise from radiators and induction units. The hot water or hydronic space heating system is therefore preferred over steam heating for functional, aesthetic, and economic reasons. Hence, conversion of existing steam perimeter heating to hot water perimeter heating usually increases the comfort of the occupants while simultaneously providing a significant reduction in thermal energy use. These features are also important for the hot water district heating system development because a 250°F temperature hot water supply requires that steam heating systems be converted to the more efficient hydronic systems. Thus, connection of buildings with steam heating systems to the hot water district heating system encourages the conversion and upgrading of such buildings' heating systems from steam to hot water. New buildings in the service area should also be designed with hydronic heating systems when appropriate.

2.4 General Guidelines for Economic Building Connection and Heat System Conversion

There are many specific configurations for both connecting a hot water district heating system to a building heating system and converting the building system to a configuration that is compatible with thermal energy supplied by hot water. This is because of the large number of individual building heating systems and types of buildings - commercial and office space, hotels, restaurants, schools, museums and sports facilities, and multi-family residential units - that exist in a mature urban center such as St. Paul, Minnesota. The comments that follow are intended only to give general guidance as to the conversion approaches that can be used in the connection of existing buildings to a hot water district heating system.

The most extensive heating system modification is required for a building with steam perimeter heating that must be converted to hot water (or hydronic) operation. Conversion of an existing steam perimeter system is difficult because both distribution piping and terminal units may need to be changed. Steam supply piping, if in good condition, can often be reused for hot water, but condensate return piping is often too small or not routed for return to a central location.

Steam perimeter heating circuits can be converted to hot water service if they are in good condition and have radiation units that are compatible with hot water. However, often the radiation equipment in older buildings is not in good condition. In these buildings, there are so many changes involved in piping and controls that to reuse the existing radiation equipment may save little in installation cost and leaves a very weak link in an otherwise like-new system.

Steam heating coils in ventilation units can be an expensive conversion element. Because of coil designs, existing steam coils may provide insufficient heating when converted to hot water, and field revision costs are comparable to replacement costs. Fortunately, new energy standards have reduced outdoor air requirements to the point where many steam heating coils have been shut off. These coils therefore do not have to be converted. Using the same philosophy of design, many additional steam coils can be shut off rather than converted at the time of building conversion. Where a small need for ventilation heat remains, piping hot water to existing steam coils and/or cooling coils or the addition of auxiliary electric coils may keep conversion costs down.

The connection of an existing hydronic perimeter heating system to hot water district heating is relatively easy because the distribution systems and terminal units within the building are already compatible with a hot water supply. Only the interface with the district system and some control elements need to be changed.

Buildings with a furnace for their heat source can generally have hot water coils added to the furnace or the ductwork. Where this is not possible, new hydronic baseboard radiation can be installed, but this is a more difficult and expensive conversion method. Buildings with furnaces usually have a gas-fired domestic hot water heater. A heat exchanger using district heating water can be installed before the water heater to change the heat source from gas to district heated hot water and to retain the storage capacity in the existing water heater. This conversion method, of course, applies to any building with a gas-fired or electric water heater.

Buildings with electric baseload perimeter radiation or induction units generally do not adapt well to hot water district heating. However, where ventilation systems have electric heating coils and where domestic water is heated by electricity, the conversion methods described previously apply. Also, electrically supplied hot water perimeter heating circuits can be easily converted to a hot water supply.

Steam domestic water heaters are generally converted to hot water by replacement of a steam tube bundle with a hot water tube bundle.

Michaud, Cooley, Hallberg, Erickson and Associates applied these principles in each of the two study phases described below. Study of these systems was intended to provide generic data for buildings with similar characteristics.

A more detailed description of the standards and guidelines for designing new building heating systems and converting existing heating systems for service from the hot water district heating system planned for St. Paul appears in Appendices A and B. These reports were developed for the St. Paul District Heating Development Co. as a part of the marketing phase of the new St. Paul hot water system.

3. PHASE I STUDY

The first phase of the MCHE study analyzed the conversion of seven buildings which were specified as typical buildings within the market area. The seven buildings heating demands range from 700-3500 kW, as shown in Table 1. This table also presents a brief description of each building's heating system. Each of the buildings has a different building mechanical system which was studied for hot water district heating connection.

Conversion costs and suggested conversion methods were developed for each of the buildings. After in-person surveys were made of each of the building heating systems by MCHE engineers, drawings of the systems were made or obtained from building engineers. Schematic designs showing proposed piping and instrumentation were then drawn in accordance with accepted European hot water district heating system design methods. A local mechanical contractor was then able to prepare a cost estimate for each building conversion.

The conversion methods developed depended on an evaluation of the physical condition and operating requirements for some of the building heating system's equipment. Since retention of some of the equipment, such as preheat coils in the air-handling subsystems, could not always be definitely determined, conversion methods and costs were prepared for several options of system conversion ranging from a minimum to a maximum cost of conversion. Of the options considered, one conversion cost and method was recommended; these recommended costs are presented in Table 2 along with the range of unit conversion costs [$/kW(t)] estimated in the Phase I study. Table 3 breaks down the resulting cost data and characteristics for the seven buildings. Analysis of the conversion methods for each building demonstrated that it was technically feasible to connect the buildings to a district hot water system.

Phase I also demonstrated that lower costs may be feasible if certain heating system equipment, i.e., preheat coils, could be used as is or excluded and not converted to hot water. A large potential for energy savings was also projected due to the energy conservation related to the modernization of existing steam perimeter heating subsystems from conversion to hydronic operation.

Table 1. Phase I Building Information

Building	Demand [kW(t)]	Building Heated Area (ft^2)	System* Age (Years)	Building Heating System Characteristics
Pioletti Hi-Rise (public housing)	750	127,000	?	Hydronic radiation and ventilation heating.
Empire Building (commercial)	750	62,000	?	Two-pipe steam radiation and ventilation heating.
Hamm Building (commercial)	2635	312,000	61	Two-pipe steam + part hydronic radiation heating; two-pipe steam ventilation heating with preheat and reheat.
YWCA (apartment + athletic facilities)	1230	118,000	18	Hydronic radiation heating + two-pipe steam ventilation heating with preheat and reheat.
St. Paul Companies (commercial)	2920	443,000	30	Two-pipe steam radiation + ventilation heating with preheat.
Dayton's (commercial)	3370	388,000	18	Hydronic radiation and ventilation heating.
Centennial Office Building (commercial)	3010	323,000	22	Hydronic radiation and two pipe steam ventilation heating with steam preheat and hydronic reheat.

*Age relative to 1980.

Table 2. Phase I Building Conversion Cost Results

Building	Recommended Conversion Cost	Recommended Unit Conversion Cost $/kW(t)	Range of Unit Conversion Cost $/kW(t)	Recommended Conversion Cost/ Unit Area ($/ft^2)
Pioletti Hi-Rise	$ 47,300	63	32.4 - 63	0.372
Empire Bldg.	$ 28,950	38.6	38.6 - 79.7	0.468
Hamm Bldg.	$151,700	57.5	57.5 - 85.1	0.486
YWCA	$ 92,500	75.2	52.8 -103.2	0.784
St. Paul Co.	$ 93,000	32.0	27.7 - 53.1	0.210
Dayton's	$104,000	30.9	30.9	0.268
Centennial Office Bldg.	$145,900	48.5	26.9 - 73.4	0.452

Table 3. Phase I - Recommended Conversion Cost Breakdown

Building	Service Piping within Building	Radiation	Domestic Hot Water Heater	Hot Deck & Reheat Coils	Preheat Coils	Misc. Piping, Controls & Related Equip.	TOTAL
Pioletti Hi-Rise	$ 3,200	$19,700	$23,000	--	--	$ 1,400	$ 47,300
Empire Building	$ 2,850	$ 8,725	$ 8,650	--	$ 8,725	--	$ 28,950
Hamm Building	$26,850	$68,850	$13,900	$22,000	$14,650	$ 5,500	$151,750
St. Paul YWCA	$ 3,300	$16,600	$21,400	$11,900	$27,505	$11,750	$ 92,455
St. Paul Co.	$12,265	$33,185	$20,295	--	$12,205	$15,070	$ 93,020
Dayton's	$28,500	$38,300	$26,200	$11,000	--	--	$104,000
Centennial Office Bldg.	$17,280	$11,150	$10,175	$10,450	$64,995	$31,850	$145,900

The results of this relatively in-depth study were encouraging in terms of the unit conversion cost results. However, it was decided that additional buildings should be studied in order to specify conversion cost estimates for a wider variety of market area buildings.

4. PHASE II STUDY

The second study phase by MCHE was organized on the basis of ten types of building heating systems which were categorized by the types of perimeter and air-handling ventilation heating subsystems employed. The ten types of heating systems are described in Table 4. While the Phase I study was detailed in nature, the Phase II study provided a less detailed and quicker analysis of a larger sampling of buildings. This approach was deemed advisable expecially for the significant number of older buildings in the market area.

4.1 Approach

The approach used for this study phase was based on the experience gained in the Phase I study. First, an on site survey of the building heating system was made by an MCHE engineer and a cost estimator from a mechanical contractor firm. On the basis of the survey and available drawings of the existing heating system, a cost estimate for the conversion work was prepared by the mechanical contracting firm. Since less time was spent developing the cost estimate in the Phase II study, a single conversion design and cost estimate was developed for each building based on the best judgement of the engineer concerning replacement and reuse of existing equipment such as piping and heating coils. Since many of the buildings studied have heating systems that have been in service for more than forty years, some of the conversion costs developed in this study include costs for upgrading the building heating systems to efficient, easily controlled hydronic systems. This is especially true for the heating systems with steam perimeter heating.

4.2 Results

Results from Phase II of the MCHE study are presented in three areas -- building heating system characteristics, conversion costs, and equipment/labor cost distribution. The building heating system characteristics are summarized in Table 5 for the 106 buildings surveyed. Overall, the survey population covers a wide range of types of building heating systems involving practically all combinations of perimeter radiation and air handling subsystems. The energy sources for these buildings are predominately oil,

Table 4. Description of Building Heating Systems for Phase II Study

System Group No.	Description
1	Hot Water Radiation-Hot Water Air Side: Hot water is delivered to radiators and/or induction units within the heated space. In addition, hot water is supplied to heating coils in air handling units which pass air over the coils and deliver warm air to the space.
2	Steam (Two Pipe) Radiation - No Air Side: Steam in a two pipe configuration is supplied to radiators and/or induction units within the heated space.
3	Hot Water Radiation - No Air Side: Hot water is supplied to radiators and/or induction units within the heated space.
4	Steam (One Pipe) Radiation - No Air Side: Steam in a single pipe configuration is supplied to radiators and/or induction units within the heated space.
5	Steam (Two Pipe) Radiation - Steam Air Side: Steam in a two pipe configuration is supplied to radiators and/or induction units within the heated space. Steam is also supplied to heating coils in air handling units which pass air over the coil and deliver warm air to the space.
6	No Radiation - Gas Fired Air Side: Gas is burned to directly heat air which is delivered to the space.
7	Steam (One Pipe) Radiation - Steam Air Side Steam in a single pipe configuration is supplied to radiators and/or induction units within the heated space. In addition, steam is supplied to heating coils in air handling units which pass air over the coils and deliver warm air to the space.
8	No Radiation - Steam Air Side: Steam is supplied to air handling units which pass air over the coils and deliver warm air to the space.

Table 4. (CONTD)

9 No Radiation - Hot Water Air Side

Hot water is supplied to heating coils in air handling units which pass air over the coils and deliver warm air to the space.

10 Hot Water Radiation - Steam Air Side:

Hot water is delivered to radiators and/or induction units within the heated space. In addition steam is supplied to heating coils in air handling units which pass air over the coils and deliver warm air to the space.

Table 5. Summary of Building Heating System Characteristics

System Group No.	No. of Bldgs.	Avg. Peak Demand [kW(t)]	Avg. System Age (Years)	Avg. Demand/Unit Area (W/ft^2)
1	24	1,650	11	8.35
2	10	1,222	43	8.13
3	5	1,248	27	7.03
4	10	405	58	9.89
5	24	1,343	41	7.29
6	6	235	13	17.3
7	8	722	60	11.5
8	7	85	17	8 79
9	5	607	22	7.92
10	7	2,067	10	10.0
	106			

NOTES: Total peak demand of surveyed buildings = 119.6 MW(t).
Groups 1, 3, and 9 use hot water piping.
Groups 2, 4, 5, 7, and 8 use steam piping.
System age relative to 1980.

gas or steam district heating; electric heat and heat pumps are used in only a few buildings in the St. Paul market area. The average peak demand and system age vary widely between the groups. The groups with the highest average system ages -- numbers 2, 4, 5, and 7 -- all have steam distribution piping. Groups 6 and 8 have the lowest average peak demands and both use only air-handling systems (no perimeter radiation).

Results of the conversion cost estimates are presented in three forms. First, Table 6 presents the average conversion cost for each building group; also the maximum, average and minimum values are presented for the unit conversion cost -- \$/kW(t) -- and the conversion cost per unit area.* These tabulated results give the general trend of the conversion costs for the ten groups of systems surveyed.

Secondly, recommended unit conversion costs were selected for each of the ten types of heating systems, as described in Table 7. These unit costs were selected as typical values to represent all buildings having a specific type of heating system over the size range of the buildings surveyed in the MCHE study. These cost values were then used to estimate the conversion costs for the remainder of the DHDC initial market area. For groups 2, 3, 6, 7, and 9, the average unit cost in Table 7 is essentially the same as the average value in Table 6. However, in groups 1, 4, and 8, the average value is reduced by removing several abnormally high cost buildings from the group data base; conversely, the average values for groups 5 and 10 are increased slightly to reduce the influence of several buildings with relatively low conversion costs.

Thirdly, the individual building system conversion cost and unit cost are shown as a function of peak demand for all groups except numbers 4 and 8 in Figs. 3 to 11. Group 4 was not included because nine of the ten systems were of an age or condition that all the piping would require replacement, which makes this group's conversion cost exceptionally high. Group 8 has the smallest sized buildings which causes the unit conversion costs to be relatively high; this group also represents a small segment of the customer market.

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*The "average" values are "group" averages; for example, the average unit conversion cost is the total conversion cost for the group divided by the total kW(t) demand of the group.

Table 6. Summary of Building Conversion Costs for 250°F (121°C) Hot Water Supply

System Group No.	Average Conv. Cost ($)	Unit Conversion Costs [$/kW(t)] Max.	Avg.	Min.	Conv. Cost/Unit Area ($/ft^2) Max.	Avg.	Min.
1	94,040	219.2	57.0	22.6	2.33	0.476	0.032
2	171,200	318	140.1	62.4	2.35	1.14	0.56
3	59.220	148	47.4	27.6	1.72	0.333	0.28
4	241,400	1,301	596.2	216.4	10.59	5.89	2.38
5	209,800	462.2	156.3	31.9	6.65	1.14	0.21
6	25,980	300.4	110.6	52.8	2.84	1.92	1.37
7	159,900	891.6	221.6	89.1	8.92	2.56	0.84
8	20,290	708	240.1	172.4	24.5	2.10	0.97
9	33,720	105	55.6	27.6	1.05	0.440	0.19
10	151,300	216.7	73.2	24.0	2.11	0.733	0.45

NOTES: Costs include modernization of systems.
Group 4, 9 of 10 buildings require complete system replacement.
All costs are in 1980 $.

Table 7. Recommended Building Conversion Costs - Phase II

System Group No.	Heating System Type	No. Buildings	Avg. Peak Demand kW(t)	Unit Cost $/kW(t)
1	Hot water radiation - hot water air side	22	1826	40
2	Steam (2-pipe) radiation no air side	10	1223	140
3	Hot water radiation - no air side	4	1517	44
4	Steam (one-pipe) radiation - no air side	7	392	403
5	Steam (2-pipe) radiation - steam air side	21	1351	181
6	No radiation - gas fired air side	6	235	110
7	Steam (one-pipe) radiation - steam air side	7	823	220
8	No radiation - steam air side	3	172	198
9	No radiation - hot water air side	5	607	56
10	Hot water radiation - steam air side	7	2067	107
	TOTAL	92		

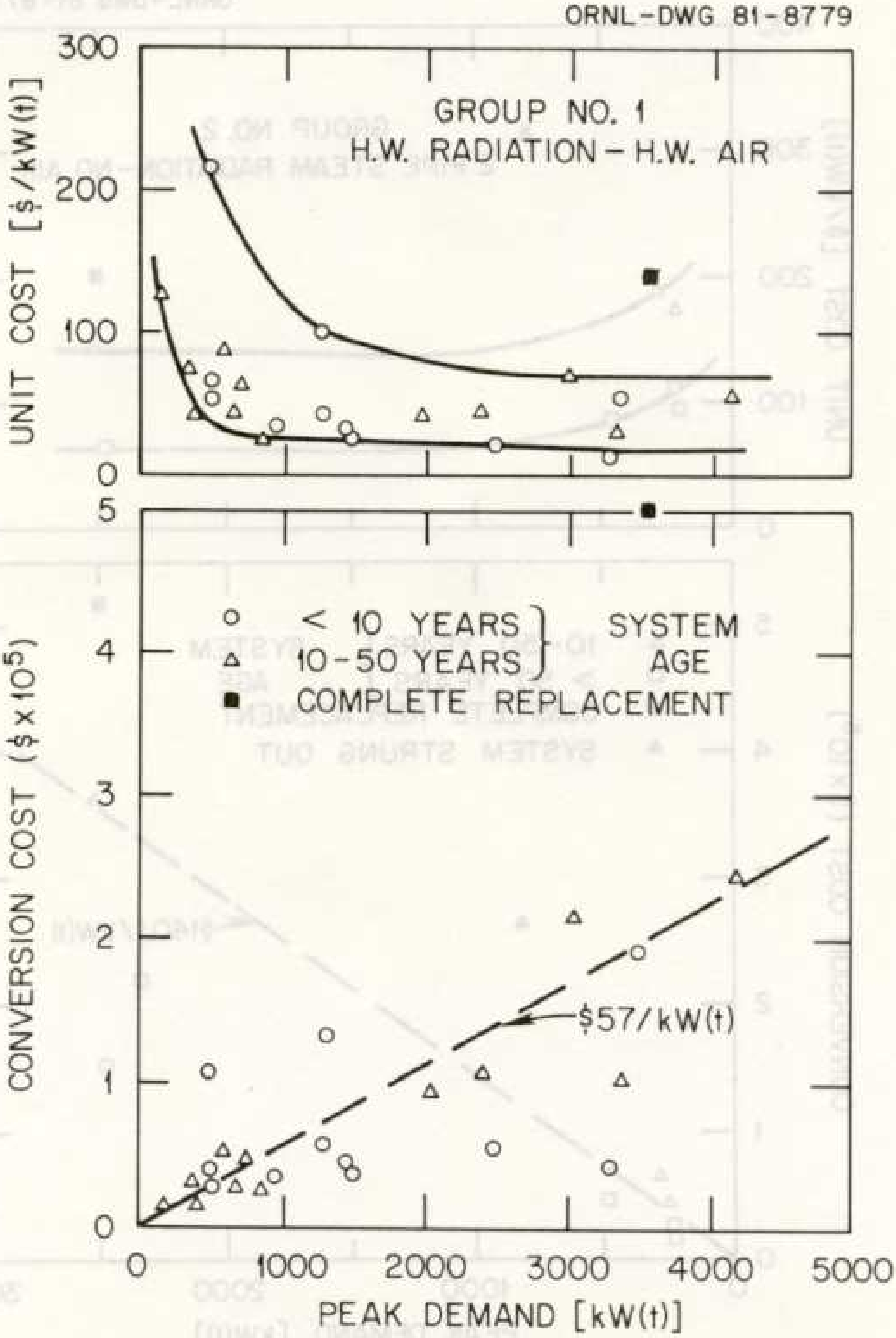

Fig. 3. Conversion cost and unit conversion cost (1980 $) for group No. 1 buildings served by 250°F hot water system.

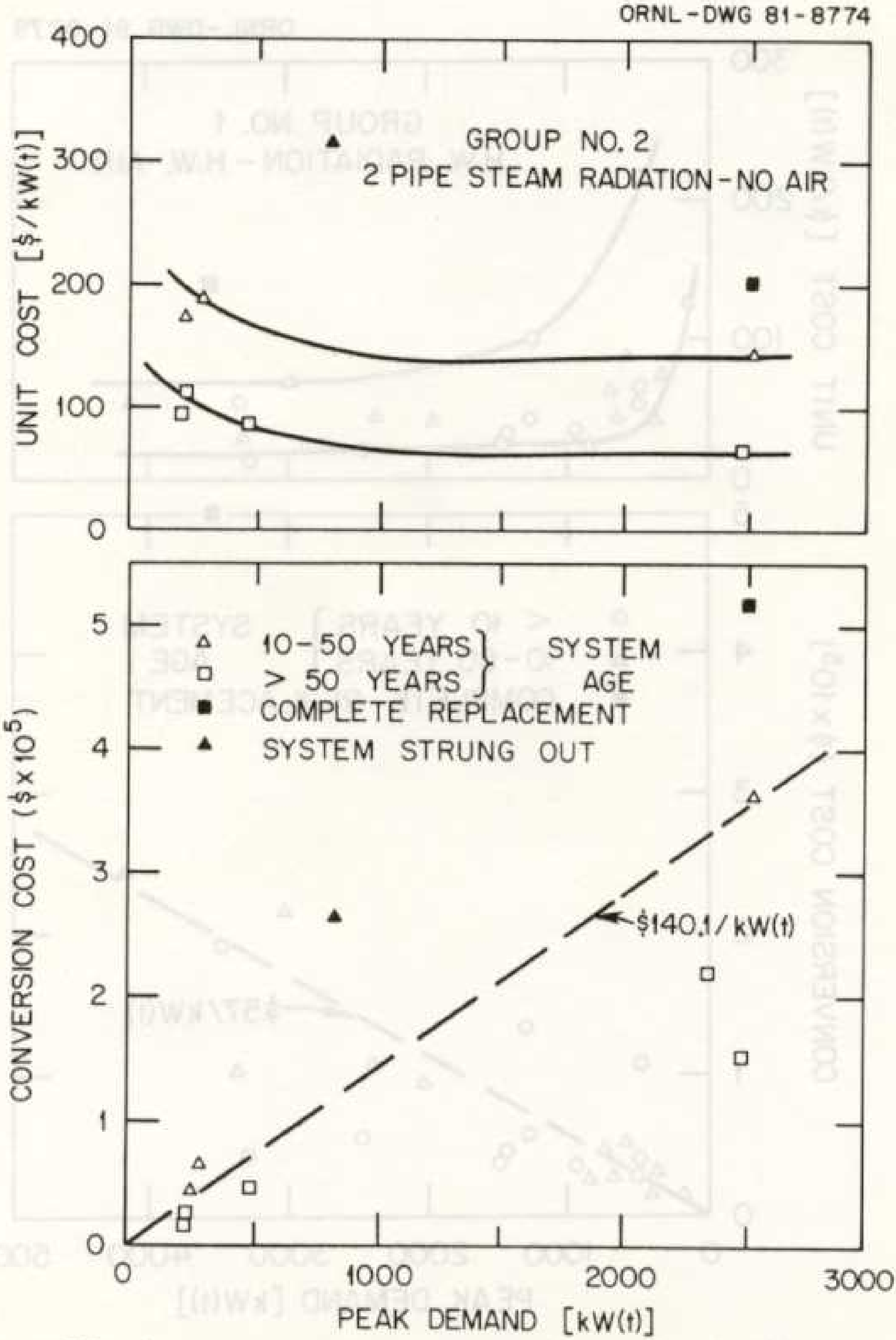

Fig. 4. Conversion cost and unit conversion cost (1980$) for group No. 2 buildings served by 250°F hot water system.

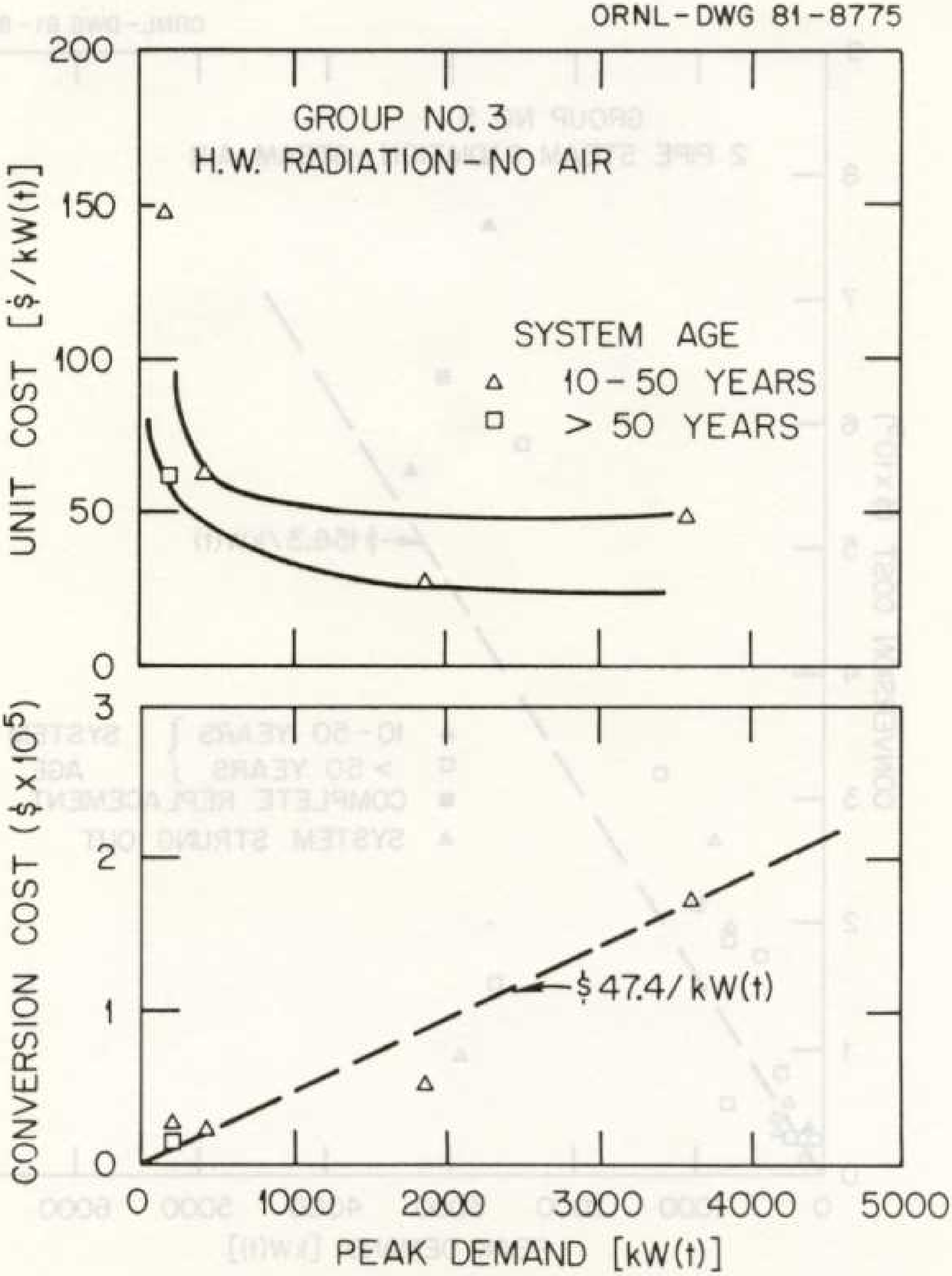

Fig. 5. Conversion cost and unit conversion cost (1980 $) for group No. 3 buildings served by 250°F hot water system.

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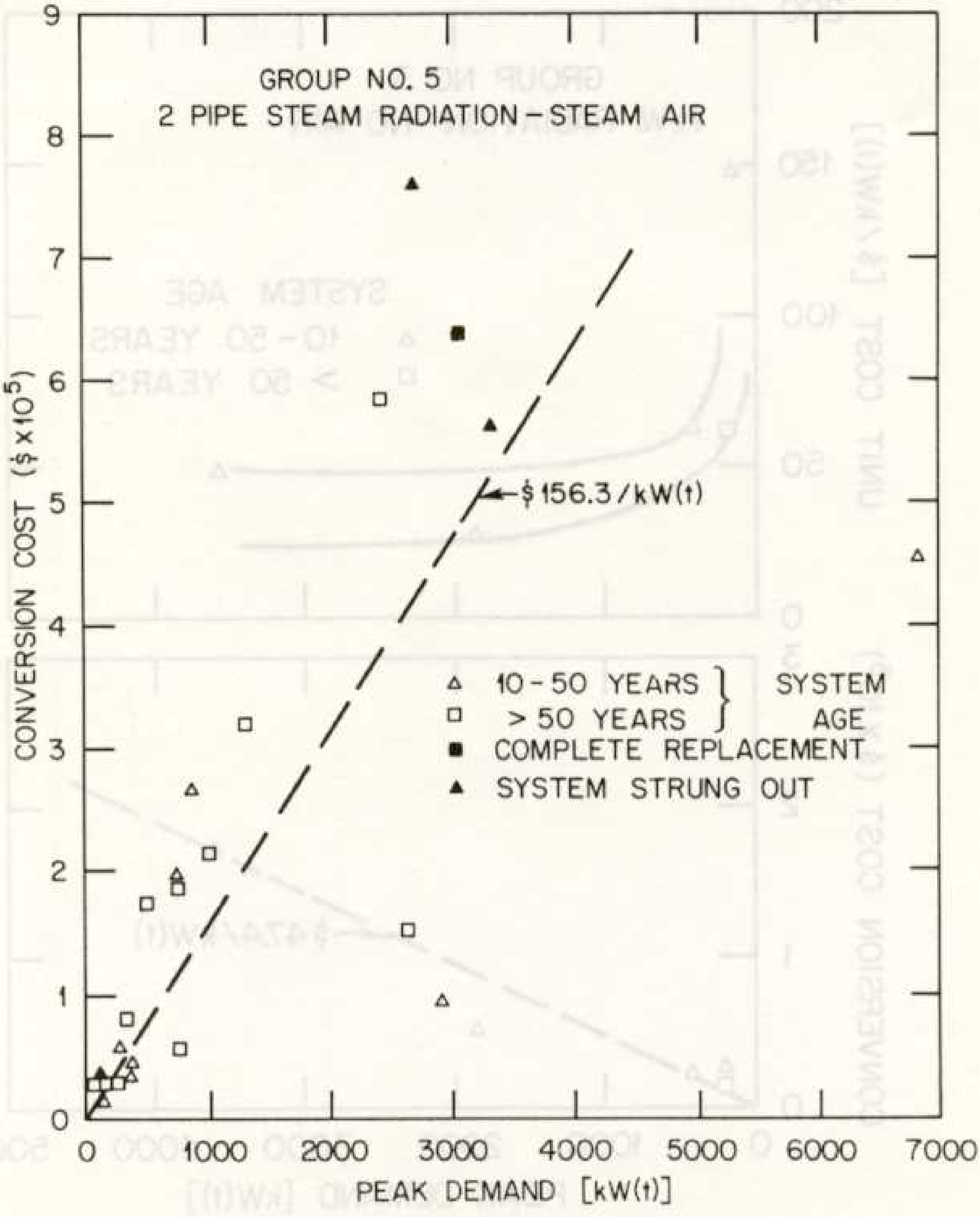

Fig. 6. Conversion cost (1980 $) for group No. 5 buildings served by 250°F hot water system.

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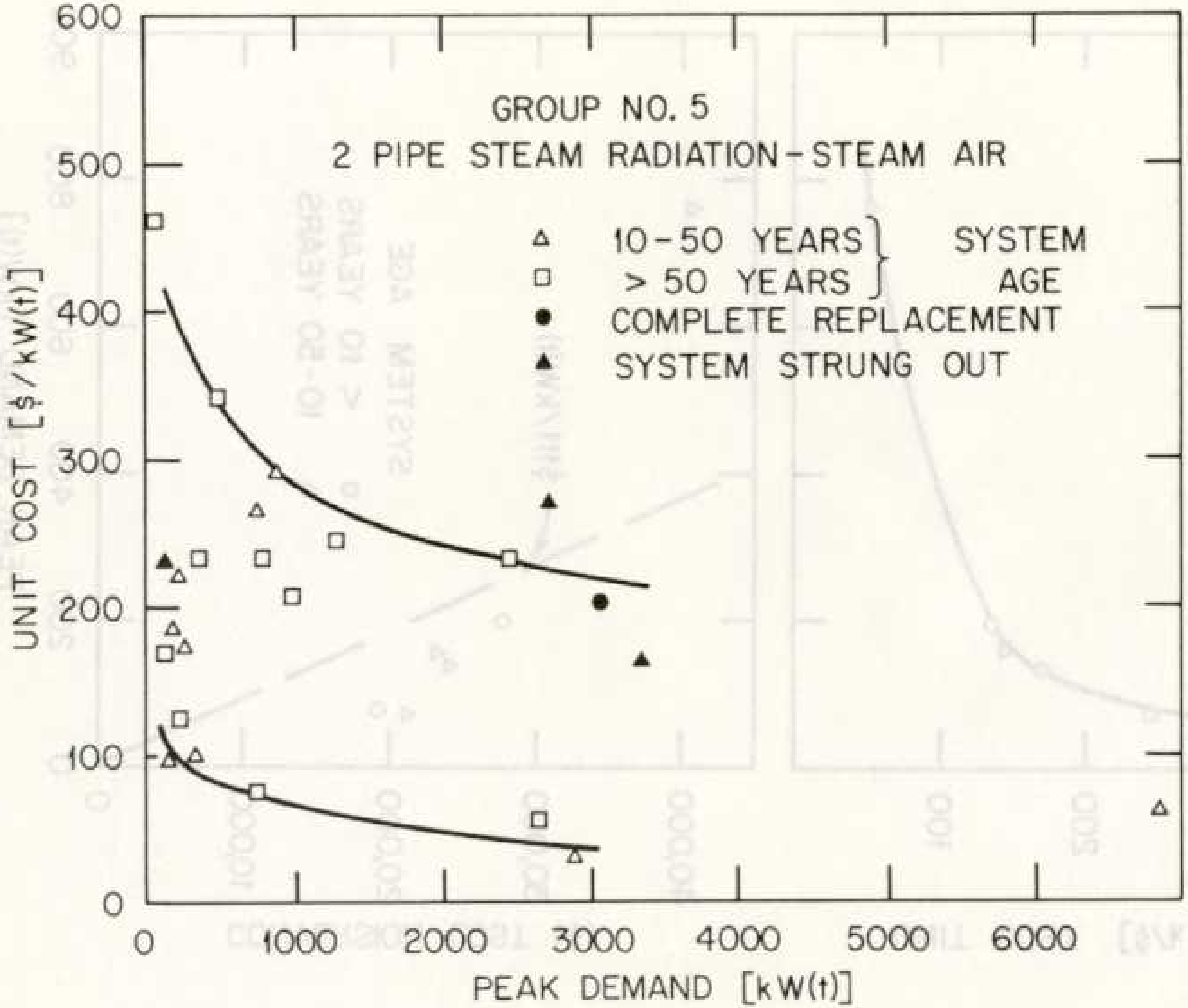

Fig. 7. Unit conversion cost (1980 $) for group No. 5 buildings served by 250°F hot water system.

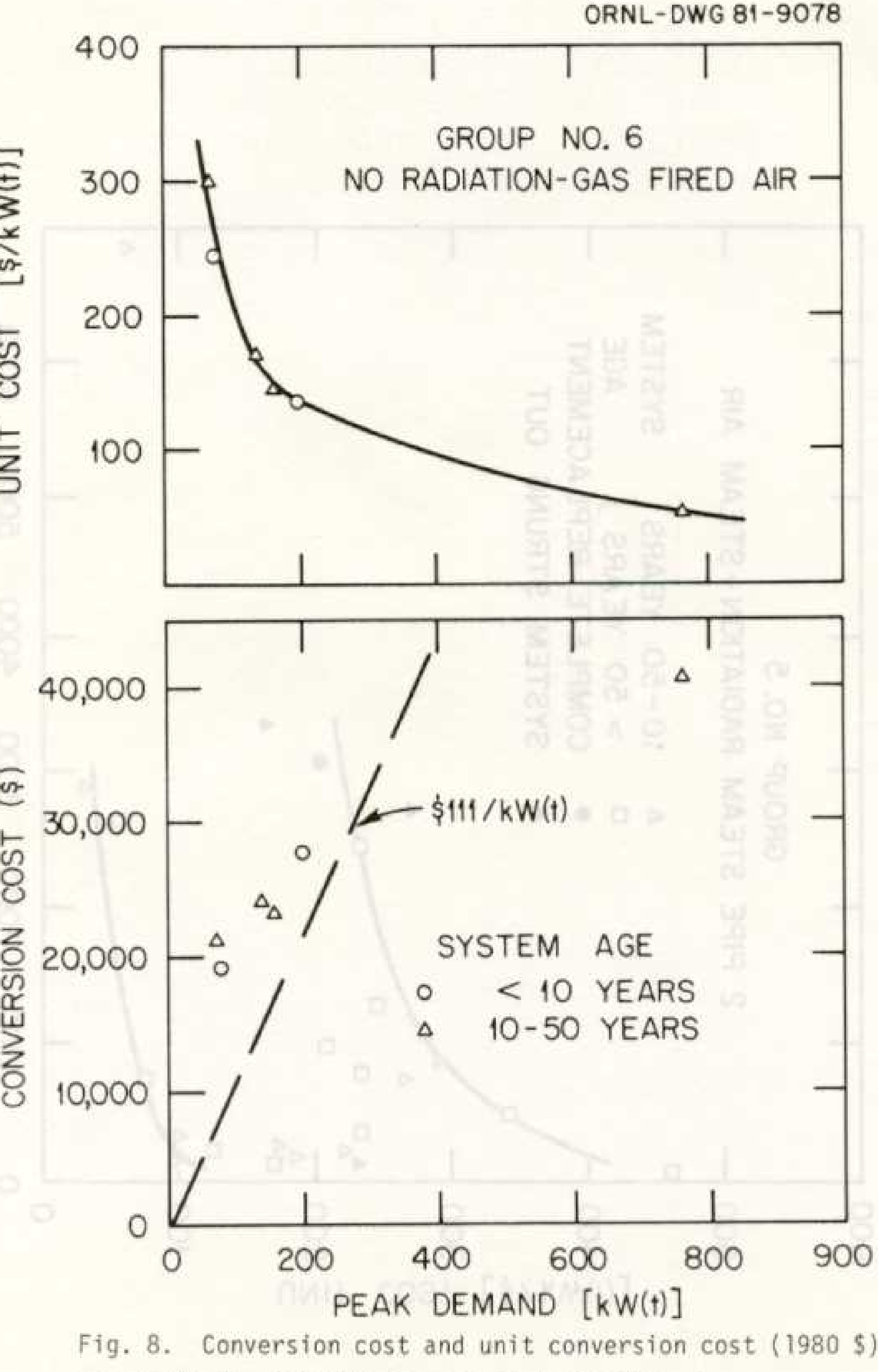

Fig. 8. Conversion cost and unit conversion cost (1980 $) for group No. 6 buildings served by 250°F hot water system.

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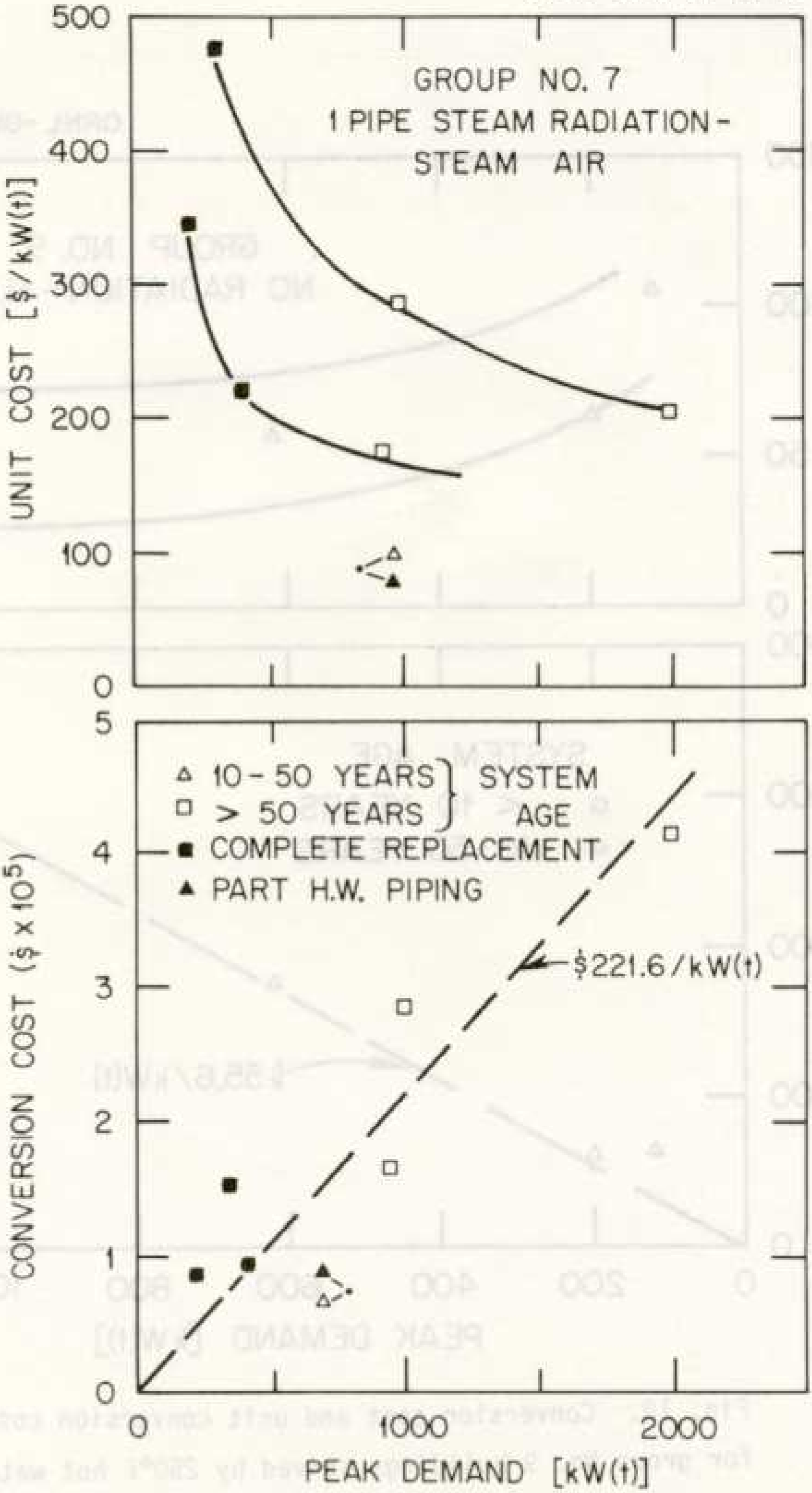

Fig. 9. Conversion cost and unit conversion (1980 $) for group No. 7 buildings served by 250°F hot water system.

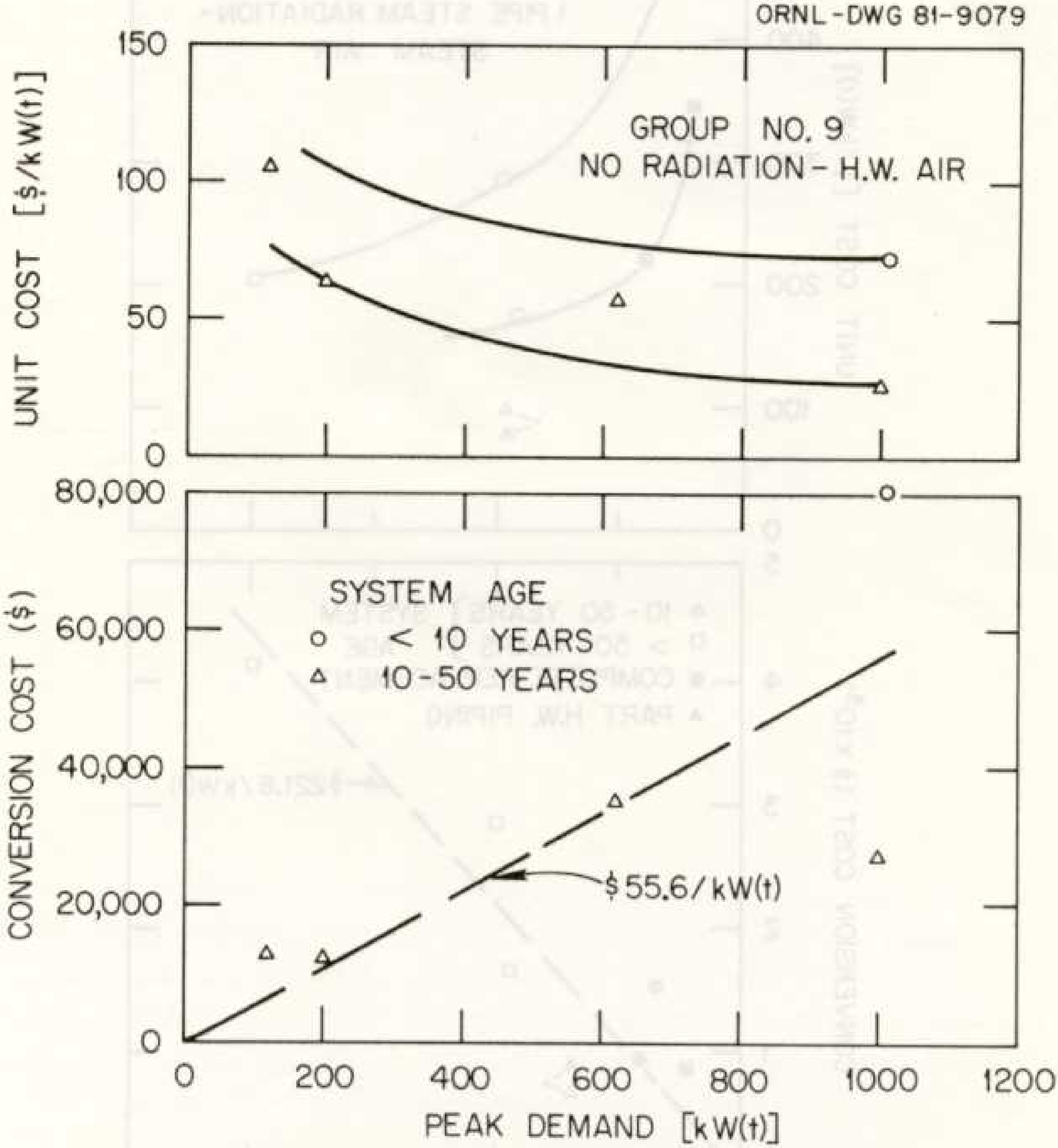

Fig. 10. Conversion cost and unit conversion cost (1980 $) for group No. 9 buildings served by 250°F hot water system.

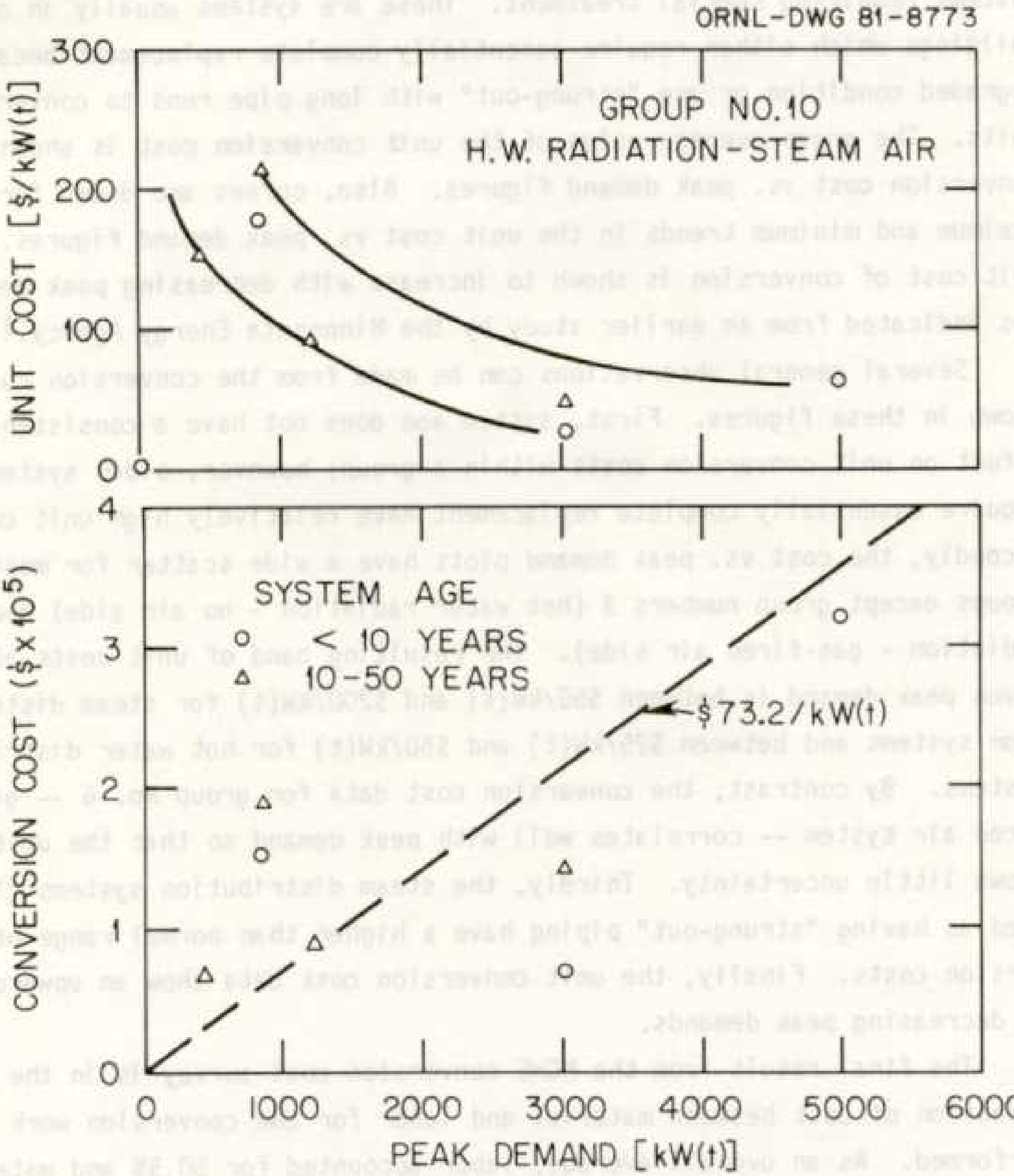

Fig. 11. Conversion cost and unit conversion cost (1980 $) for group No. 10 buildings served by 250°F hot water system.

The individual cost data have been segregated by system age -- less than 10 years, 10 to 50 years, and greater that 50 years -- and also by systems requiring special treatment. These are systems usually in older buildings which either require essentially complete replacement because of degraded condition or are "strung-out" with long pipe runs to converter units. The group average value of the unit conversion cost is shown on the conversion cost vs. peak demand figures. Also, curves are drawn for the maximum and minimum trends in the unit cost vs. peak demand figures. The unit cost of conversion is shown to increase with decreasing peak demand as was indicated from an earlier study by the Minnesota Energy Agency.[1]

Several general observations can be made from the conversion cost data shown in these figures. First, system age does not have a consistent effect on unit conversion costs within a group; however, older systems that require essentially complete replacement have relatively high unit costs. Secondly, the cost vs. peak demand plots have a wide scatter for most groups except group numbers 3 (hot water radiation - no air side) and 6 (no radiation - gas-fired air side). The resulting band of unit costs at a given peak demand is between \$50/kW(t) and \$200/kW(t) for steam distribution systems and between \$25/kW(t) and \$50/kW(t) for hot water distribution systems. By contrast, the conversion cost data for group No. 6 -- gas-fired air system -- correlates well with peak demand so that the unit cost shows little uncertainty. Thirdly, the steam distribution systems classified as having "strung-out" piping have a higher than normal range of conversion costs. Finally, the unit conversion cost data show an upward trend at decreasing peak demands.

The final result from the MCHE conversion cost survey is in the distribution of cost between material and labor for the conversion work to be performed. As an overall average, labor accounted for 50.5% and material 49.5% of the total cost. When classifying the systems by steam and hot water systems, the labor component rose to 52% for steam systems compared to 48% of the total cost for hot water systems.

4.3 Discussion of Results

This study covers a broad range of characteristics of building types -- in terms of (1) thermal end-uses [HVAC system, domestic hot water and process uses], (2) building ages [affecting the type, condition and configuration of the internal distribution system], and (3) building sizes and heat demands [from 900 to 900,000 ft^2 and 9 to 6835 kW(t)]. Also, the treatment of costs to both convert and simultaneously modernize a building system for connection to a 250°F (121°C) hot water district heating system adds a large degree of complexity to establishing building conversion costs. The modernization and upgrading of the building systems is especially important in the St. Paul central business district because a significant fraction (~30%) of the building systems surveyed in this study are 50+ years old. A concomitant factor with building age is the high percentage of buildings using low pressure steam distribution systems.

The overriding philosophy guiding this study was not to minimize the "first cost" of connection to a hot water supply system but rather to optimize the life-cycle cost of the energy supply and the building distribution systems. The minimum "first cost" strategy would dictate a hot water supply temperature in the 270-300°F (132-149°C) range operated year around to supply the existing steam distribution systems. However, a 270-300°F system supplying steam from a water-to-steam heat exchanger, would require almost an order of magnitude increase in water flow and have a higher return water temperature than would be the case with a 250°F supply to a water-to-water heat exchanger. The higher temperature strategy leads to a lowest initial cost for "adapting" a building system to a hot water heat supply, as is presented in the Minnesota Energy Agency study,[1] but leaves the older steam distribution buildings with a system that is less efficient, more difficult to regulate, has higher maintenance costs, requires more pumping energy and larger piping, and lowers the cogeneration system efficiency.

Therefore, the strategy followed in this study is based on three principles: first, the hot water supply temperature would be limited to 250°F (121°C) to reduce the construction and operating costs of the district heating system; secondly, steam distribution systems should be adapted to hot water district heating or converted to hot water distribution in an economical fashion; thirdly, when necessary, degraded or out-moded equipment should be replaced and an overall system modernization should be included with connection to the hot water district heating supply.

This strategy is restated here because it has a major impact on the results of the building conversion cost survey for buildings with steam perimeter heating. For such systems, a significant part of the conversion cost can be for system modernization and upgrading. This result is illustrated most dramatically by building group No. 4 which contains the largest percentage of the older steam systems and has the highest unit conversion costs of the groups surveyed. For the other steam distribution systems - groups 2, 5, 7, and 8 - the average unit conversion costs are from \$40 to \$190/kW(t) higher than for hot water distribution systems - groups 1, 3, and 9. These differences in unit conversion costs between steam and hot water building systems are higher than the \$10 to 20/kW(t) unit cost difference estimated in the MEA study[1] The earlier study analyzed relatively newer buildings supplied by 300°F (149°C) hot water for which system modernization and upgrading changes were not included.

The difference in building conversion costs for hot water and steam distribution systems can also be compared with previous estimates of conversion cost based on the conversion cost/unit area ($\$/ft^2$). The average conversion cost/unit area for the hot water distribution systems - groups 1, 3, and 9 - ranges from 0.333 to 0.476 $\$/ft^2$ which is consistent with the range of 0.32 to 0.76 $\$/ft^2$ reported for hot water distribution system buildings in Ref. 2. The steam distribution systems - groups 2, 5, 7, and 8 - have average conversion cost/unit area ranging from 1.14 to 2.56 $\$/ft^2$, which are 0.8 to 1.8 $\$/ft^2$ higher than for hot water distribution systems. Also, the all-air distribution system - group 6 - has an average conversion cost/unit area of 1.92 $\$/ft^2$, approximately 1.5 $\$/ft^2$ higher than for hot water distribution systems. This information for conversion costs/unit area for steam and air distribution systems is the first published data of this type to the authors' knowledge.

The higher conversion costs for the steam distribution systems are caused by extensive replacement of existing converter units, perimeter radiation units, and the installation of piping and controls required to operate such systems as hot water distribution systems. In addition to generally higher conversion costs, the modernization and upgrading of the steam systems contributes to the wide variability in the unit conversion costs, as evidenced by the \$200/kW(t) range in unit conversion cost at a given peak demand for group No. 5. This wide range of unit costs is caused by the wide diversity of systems that were developed over an 80 year time period. Also, the physical condition of the system components and insulation varies greatly and contributes to the diversity in conversion and modernization costs for steam distribution systems.

To a certain extent, the conversion costs for individual steam distribution buildings developed in Phase II of this study are higher than the costs developed in Phase I. In Phase I, a building was chosen to represent typical conversion techniques and costs, so equipment replacement for upgrading and modernization for that building system was not completely included to prevent distorting the results to be applied to a number of buildings. Since Phase II was based on a survey of a much larger number of buildings, the upgrading and modernization costs were included on an individual, case-by-case basis. One building, the Empire Building in group 5, was analyzed in both phases of the study. The conversion costs estimated in Phase I and Phase II for this building were \$28,950 and \$56,000 and unit costs of \$38.6 and \$74.7/kW(t), respectively. The additional cost in the Phase II estimate was for replacing all existing return piping as opposed to just the return loop in the equipment room for the Phase I estimate. This case is an example of additional costs for system upgrading and modernization.

For steam distribution buildings served by the existing steam district heating system or local steam boilers, steam-to-steam converter units were replaced when considered necessary by new hot water-to-hot water units in the Phase II study. This procedure may replace existing converter units that could be usable as hot water-to-hot water units because excessive capacity was often provided in the original design. Therefore, additional information and experience with steam converter units in hot water applications could result in their continued use, thus reducing the conversion cost materially.

5. ECONOMIC ANALYSIS OF BUILDING CONVERSION INVESTMENT

The cost of converting a building heating distribution system to a hot water supply is an important concern in marketing a new district heating service to potential customers. This concern is particularly significant for owners of older buildings equipped with a high conversion cost, one-pipe, steam perimeter radiation heating system - such as building group numbers 4 and 7 in Table 4. In this section, the basis is presented for a cash flow analysis for a building conversion assuming connection to the proposed St. Paul hot water district heating system. Results of cash-flow analyses are presented in terms of the payback period based on the "years to positive cumulative cash flow" for a specific building size with a range of representative conversion costs to cover most of the conversion techniques required to modify a building's heating system for a hot water supply.

5.1 Approach

A computer program (Appendix C) to analyze the annual cash-flows and the investment payback for building conversion costs was developed by the St. Paul District Heating Development Co. (DHDC) as a marketing tool for the planned, new, hot water system in St. Paul. In essence, the program calculates the net annual cost or savings to a customer from the difference in the hot water heating service cost and the building owners' current heating and conversion costs, including a tax credit for depreciation and interest expense, and accumulates the annual cash flows from the year of assumed initial hookup to the system. Generally, the savings from the district heating service increase with time, overcoming the cost of amortizing a loan to repay the conversion cost. After some period of time - the payback period - the cumulative cash flow becomes positive indicating the customer has recovered his investment costs to that time with future years yielding increasing positive cash flows. The analysis is performed in current dollars with inflation and escalation of costs included in the year-by-year values input to the program. A discount factor can also be applied to the annual cash flow to allow for the risk in future return on investment, although, for most of the results reported here, a zero discount rate was used.

5.2 Energy Prices

A key input to the analysis of building conversion cost pay-back is the projected price to customers for thermal energy in St. Paul beginning in 1982 through the year 2000.

5.2.1 Hot water district heating prices

The average* price of hot water district heating, projected for the St. Paul system, has been developed by the DHDC to be competitive with all energy supply alternatives (see Ref. 3 for a detailed discussion of the district heating pricing policy). To meet the lowest alternative end-use price from firm natural gas, the average district heating price was based on a price of $6.50/MBtu in 1980 with price escalation set at the assumed general inflation rate out to 1988. Beginning in 1989, the hot water price is cost-based for the assumed system operation. The average hot water price, shown on Fig. 12, escalates at 12%/year for 1981-82, 10%/year for 1983-84, and 8%/year for 1985-88.

5.2.2 Alternative energy prices

Retail prices to commercial customers for the conventional heating fuels, natural gas and No. 2 and No. 6 fuel oils, were based on projections by the Minnesota Energy Agency in 1980 out to the year 2000 for the St. Paul area. These fuel prices were converted to end-use energy prices using an annual average end-use conversion efficiency of 65% for both natural gas and heating oils. The resulting projected end-use prices for natural gas and fuel oils to the year 2000 are shown in Fig. 12. The price escalation rates projected for natural gas are 18.5%/year averaged between 1981 and 1989 and 11%/year between 1990 and 2000. For the heating oils, the average escalation rates over the 1981 to 2000 period are 11.2%/year and 12.1%/year for No. 2 and No. 6 oils, respectively.

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*The hot water price includes an energy charge and a demand charge, the latter being dependent on the annual peak demand of the individual customer. The "average" price represents the energy charge and the average demand charge estimated for all customers of the system.

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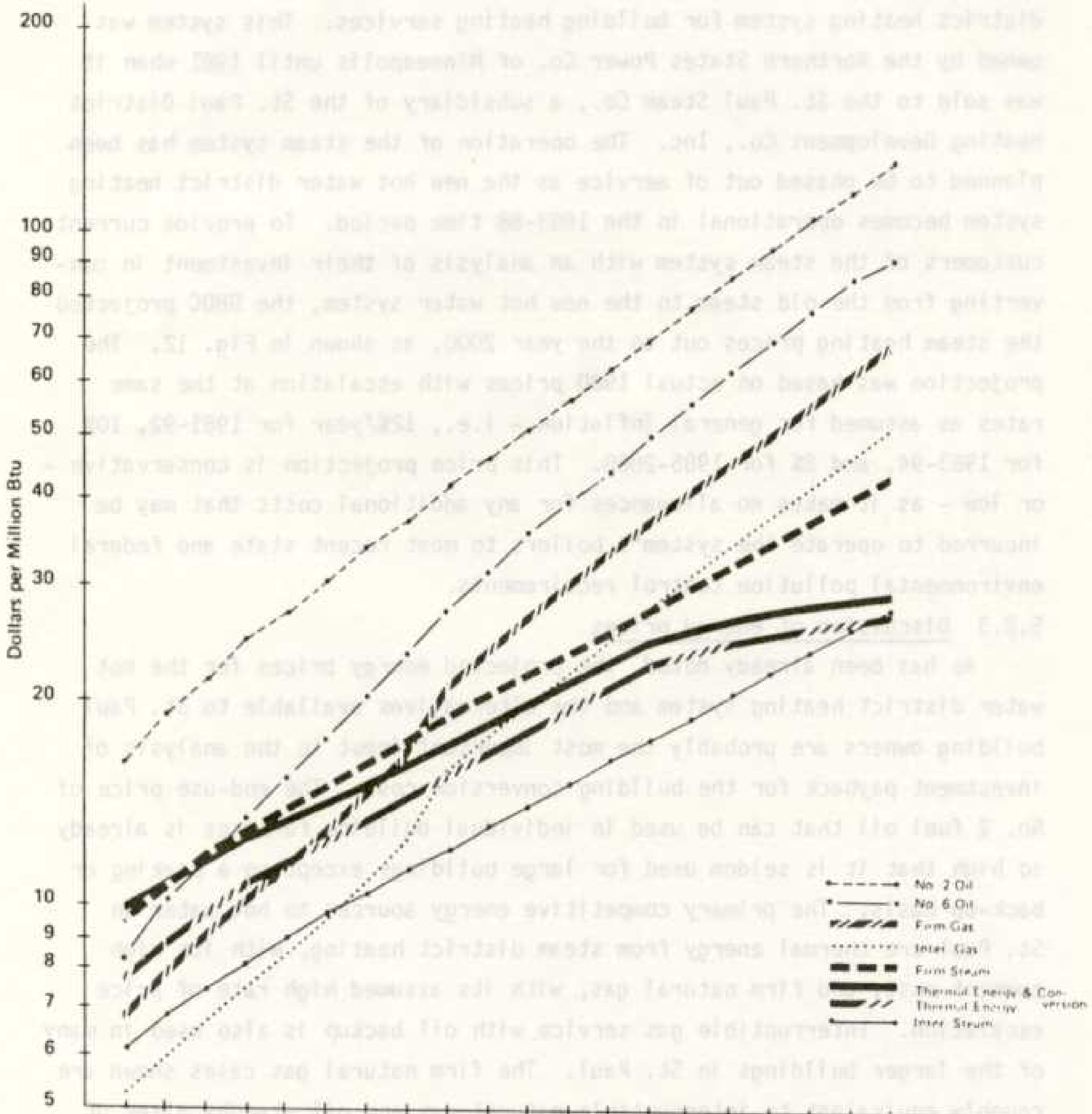

Fig. 12. Projected end-use prices for hot water thermal energy and alternatives in St. Paul in current $/million Btu.

In addition to conventional combustible heating fuels, St. Paul central business district building owners have had access to a steam district heating system for building heating services. This system was owned by the Northern States Power Co. of Minneapolis until 1981 when it was sold to the St. Paul Steam Co., a subsidiary of the St. Paul District Heating Development Co., Inc. The operation of the steam system has been planned to be phased out of service as the new hot water district heating system becomes operational in the 1983-88 time period. To provide current customers of the steam system with an analysis of their investment in converting from the old steam to the new hot water system, the DHDC projected the steam heating prices out to the year 2000, as shown in Fig. 12. The projection was based on actual 1980 prices with escalation at the same rates as assumed for general inflation - i.e., 12%/year for 1981-92, 10% for 1983-94, and 8% for 1985-2000. This price projection is conservative - or low - as it makes no allowances for any additional costs that may be incurred to operate the system's boilers to meet recent state and federal environmental pollution control requirements.

5.2.3 Discussion of energy prices

As has been already noted, the projected energy prices for the hot water district heating system and the alternatives available to St. Paul building owners are probably the most important input to the analysis of investment payback for the building conversion cost. The end-use price of No. 2 fuel oil that can be used in individual building furnaces is already so high that it is seldom used for large buildings except on a peaking or back-up basis. The primary competitive energy sources to hot water in St. Paul are thermal energy from steam district heating, with its high current cost, and firm natural gas, with its assumed high rate of price escalation. Interruptible gas service with oil backup is also used in many of the larger buildings in St. Paul. The firm natural gas cases shown are roughly equivalent to interruptible natural gas and oil standby mixes of 90% interruptible gas/10% #2 oil and 67% interruptible gas/33% #6 oil.

The prices for hot water and steam district heat are both projected to escalate at the assumed inflation rate out to at least 1989, so that these prices are level on a constant dollar basis. As shown in Fig. 12, beyond 1994 the hot water price begins to decrease relative to the general inflation-rate based price of steam district heat. Therefore, for a current customer of the steam system, an immediate savings in direct heating cost can be realized regardless of when the conversion from steam to hot water is made.

The price escalation of natural gas was projected by the MEA in 1980 to be much higher than the general inflation rate, especially out to 1990. With the 18.5% escalation rate, the end-use price of natural gas passes the price of hot water in about 1985, as seen in Fig. 12. Recent price increases of natural gas have been close to the MEA projection even though the inflation rate in 1982 has decreased below the 10-12% rate projected for the 1981-1984 period. However, the continued high rate of esclation of gas prices though the 1980's is the important condition that is required to provide the economic incentive for a building owner to switch from natural gas, with its historically low price, to another source of thermal energy.

Since well-head prices for new natural gas are increasing rapidly to reflect the true cost of developing new supplies, and "old" interstate gas prices are being deregulated, most analyses of future gas prices have results comparable to the projections of the MEA used in this study. Therefore, the continued and rapid increase in natural gas prices will most likely occur through the 1980's to properly value this important energy source in comparison with other fuel types.

5.3 Scope of Analysis

The scope of the results presented is for a single building heating load with conversion to hot water heating service in a specific year and with a narrow range of financing options. The major parameters treated are three levels of conversion cost, two types of current energy source - firm natural gas and firm steam district heat - and reductions in energy use up to 40% resulting from energy conserving measures implemented during conversion. The reason for narrowing the scope of the customer conditions is to clearly illustrate the general features of the results of the investment pay-back analysis, rather than to present results for a wide range of conditions from which general conclusions would be difficult to obtain. A general discussion of the effect of various assumed conditions is included in Section 5.5 following the presentation of the specific results.

5.3.1 Base-case assumptions

A set of assumed customer conditions was chosen to represent a typical owner of a moderately-sized building in the St. Paul central business district in 1981. These "base case assumptions", listed in Table 8, include the data required as input to the DHDC computer program, described in Appendix C.

Building energy use

The building energy use assumptions specify an annual thermal energy use of 3481 MBtu and a 600 kW(t) peak thermal demand; these conditions represent an existing multi-story, commercial building with approximately 60,000 ft^2 of heated floor area, based on a peak thermal demand per unit area of 10 $W(t)/ft^2$ (see Table 5). The annual energy use is equivalent to 1700 hours per year at the peak thermal demand, a typical relationship for existing commercial buildings in the Twin Cities.

The base case assumes no energy savings result from the building conversion. However, several building conversion design studies conducted by the DHDC concluded that thermal energy use and demand could be reduced by up to 40% for existing buildings with one-pipe, steam perimeter heating systems - Group numbers 4 and 7 in Table 4 - that convert to a hydronic building heating system and also incorporate additional energy conservation features such as night set-back controls.[4] The energy savings from building conversion was also treated as a parameter to examine its effect on system payback; for such cases, the same percentage reduction was applied to both the peak demand and the annual energy use.

Building conversion financing

The choice of financing the cost of building conversion would be at the option of the building owner. However the high financing costs or interest rates existing during the last several years has severely dampened the economic incentive for long-term financing of investments in any energy conservation features without substantial subsidies through federal tax credits or government secured, low interest loans. Therefore the city of St. Paul has developed a source of tax-exempt financing for building owners who wish to finance their conversion cost when becoming customers of the hot water system. This financing will provide loans through the St. Paul Port Authority at an estimated rate of 12% per year for up to 30 years.

Therefore these financing conditions were used in the "base case assumptions" listed in Table 8.

Tax effects

Any tax effect is a positive contribution to annual cash flow by reducing the customer's income tax payment. An income tax rate of 35% was chosen to represent "for-profit" businesses in St. Paul. The depreciation allowance was based on a 15 year, straight line schedule; also, no investment tax credit was included in the "base case" assumptions. A faster depreciation schedule or any investment tax credit would both add to the tax effect and shorten system payback. Therefore the "base-case" tax effects were calculated conservatively for a profit-making business so that the investment pay-back results would not be jeopardized by future tax law revisions.

Table 8. Base Case Assumptions for Typical Customer

Building Energy Use	
Annual thermal energy use	3481 MBtu
Peak thermal demand	600 kW(t)
Savings from building conversion	0%
Conversion Financing	
Loan interest rate	12%
Loan period	30 years
Type of payment	level, principal + interest
Tax Effects	
Income tax rate	35%
Depreciation schedule	15 years
Investment tax credit	0%
Miscellaneous	
Hookup year	1984
Discount rate	0%

Miscellaneous

The assumptions for the "base case" analyses specified 1984 as the hookup year for conversion of the building heating for hot water service. The earliest hookup year could realistically be 1983 and the latest could be beyond 1986. The later the hookup year, the larger the difference between the price for hot water service and competitive fuels effecting larger customer heating cost savings. Therefore, the 1984 hookup year is a relatively conservative assumption.

Finally a zero discount rate was used in the "base case" assumptions. Although this assumption probably decreases the pay-back time for most situations, its effect is of secondary importance as discussed in Section 5.4.

5.3.2 Conversion costs

As was noted earlier, three levels of conversion cost were used with the single-sized building for the results presented in this report. The lowest cost of \$45,000 - in 1980 \$'s - corresponds to a unit conversion cost of \$75/kW(t) of peak demand which is adequate for converting an existing hydronic heating system - group numbers 1,3, and 10 in Table 4. A medium cost of \$105,000 corresponds to a unit cost of \$175/kW(t) for conversion of two-pipe, steam perimeter heating systems - such as for group numbers 2 and 5; finally, a high cost of \$165,000 corresponds to a unit cost of \$275/kW(t) for conversion of one-pipe, steam perimeter heating systems - groups 4 and 7. Therefore these three conversion costs cover all but the extremely high or low conversion costs for this size building.

5.4 Results

The results of the cash flow analyses are presented in tabular form to show all the assumed conditions and the numerical results for the calculated "payback period" or "years to positive cumulative cash flow" The calculated cases were all for a 1984 hookup year and represented either a current firm steam customer or a firm natural gas customer.

5.4.1 General

Before presenting the tabulated case-by-case results, the general result for the cumulative cash-flow vs. time behavior is of interest. The cumulative cash flow behavior for the medium conversion cost of \$105,000 - in 1980 dollars - and the "base case" assumptions are shown in Fig. 13.

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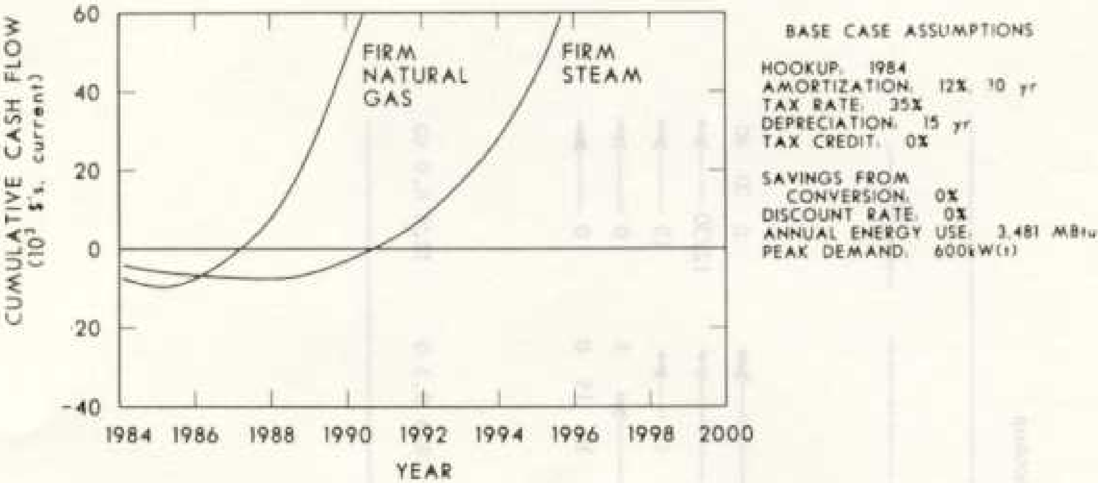

Fig. 13. Cumulative cash flow vs. time for $105,000 (1980 $'s) conversion cost and current steam district heating and natural gas energy sources.

With 1984 as the initial year of hot water service, the time to achieve a positive cumulative cash flow - or the payback period - is 3.2 years for the current firm natural gas customer and 7.5 years for the current firm steam district heating customer.

It should be noted that once a positive cumulative cash flow is achieved, the positive cash flow accelerates rapidly. This behavior is caused by the rapidly increasing price difference with time between the current energy source and hot water thermal energy. Also the minimum cumulative cash flow is approximately a negative $5000-$7000 for this medium cost conversion case with the "base case" assumptions. For a relatively high conversion cost of $165,000 in 1980 dollars, the maximum negative cumulative cash flow increases substantially to $20,000-$40,000, while the corresponding value for a relatively low conversion cost of $45,000 is very small (<$2000).

5.4.2 Case results

The customer conditions and case results for the firm steam and firm natural gas current energy sources are presented in Tables 9 and 10, respectively. Cases were run for the three levels of conversion cost and several levels of energy savings from conversion for both current energy sources. In addition, the following customer conditions were varied from

Table 9. Cases analyzed for current firm steam source, 1984 hookup

Conversion cost (10^3 1980 $'s)	45	105								165		
Customer conditions												
Conversion savings (%)	0	0	10	20	0	→	→	→	→	0	20	40
Loan amortization (%, yrs.)	12/30	12/30	→	→	12/20	12/30	→	→	→	12/30	→	→
Depreciation period (yrs.)	15	15	→	→	→	10	15	→	→	15	→	→
Tax credit (%)	0	0	→	→	→	→	→	→	5	0	→	→
Discount rate (%)	0	0	→	→	→	→	10	15	0	0	→	→
Result												
Years to positive cash flow	<1	7.5	1.7	<1	10.3	2.5	8.4	9.3	0	12.4	6.0	<0

Table 10. Cases Analyzed for Current Firm Natural Gas Source, 1984 Hookup

Conversion cost (10^3 1980 $'s)	45		105			165		
Customer conditions[a]								
Conversion savings (%)	0	20	0	10	20	0	20	40
Result								
Years to positive cash flow	0.4	<1	3.2	1.7	0.8	5.4	3.3	1.3

[a]Discount rate = 0%, depreciation period = 15 years, and loan amortization is at 12% and 30 years for all cases.

the base case assumption for the current firm steam source: loan amortization, depreciation period, tax credit, and discount rate.

The resulting "years to positive cumulative cash flow" or payback period for these cases is listed in Tables 9 and 10. These values were taken from plots of cumulative cash flow vs. time, similar to Fig. 13. For several cases, the cash flow was positive in the first year (1984), so the payback period was less than one year.

5.5 Discussion of Results

In this section, the general parametric behavior of the investment risk in terms of the payback period are presented relative to the level of conversion cost and energy savings from conversion. Also, the general effect of other assumed customer conditions on the payback period are discussed. Conditions for which the payback period is about five years or less are emphasized as desirable from the customer's point of view.

5.5.1 Effect of conversion cost

From the results in Tables 9 and 10, the effect of conversion cost in 1980 dollars, on the payback period was plotted in Fig. 14 for the "base case" assumptions.

The payback period is seen to increase more rapidly with increasing conversion cost for the current steam customer than for the current natural gas customer. The payback period is very short (<1 year) for low conversion costs of about $50,000 and is no greater than five years for 1980 conversion costs of $150,000 and $80,000, for natural gas and steam customers, respectively.

5.5.2 Effect of energy savings from conversion

The payback period results in Tables 9 and 10 were also plotted in Fig. 15 to show the effect of energy savings for the $105,000 and $165,000 conversion costs - in 1980 dollars. Again the high payback periods at zero energy savings decrease more rapidly with the current steam source than for the current natural gas source. To reduce the payback period for the current steam customer to five years or less requires an energy savings of 25% at the $165,000 conversion cost level and a savings of only 5% at the $105,000 cost level. However, the payback period for the current natural gas customer is 5 years or less for essentially all three levels of conversion cost and energy savings.

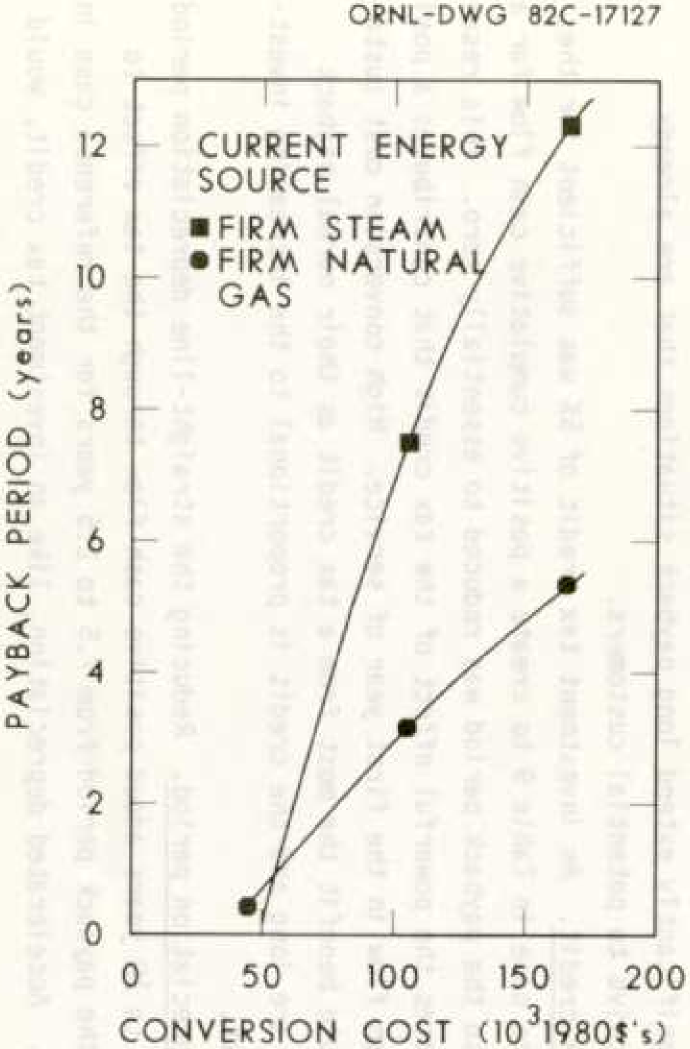

Fig. 14. Payback period vs. conversion cost for current steam district heat or natural gas energy sources, base case assumptions.

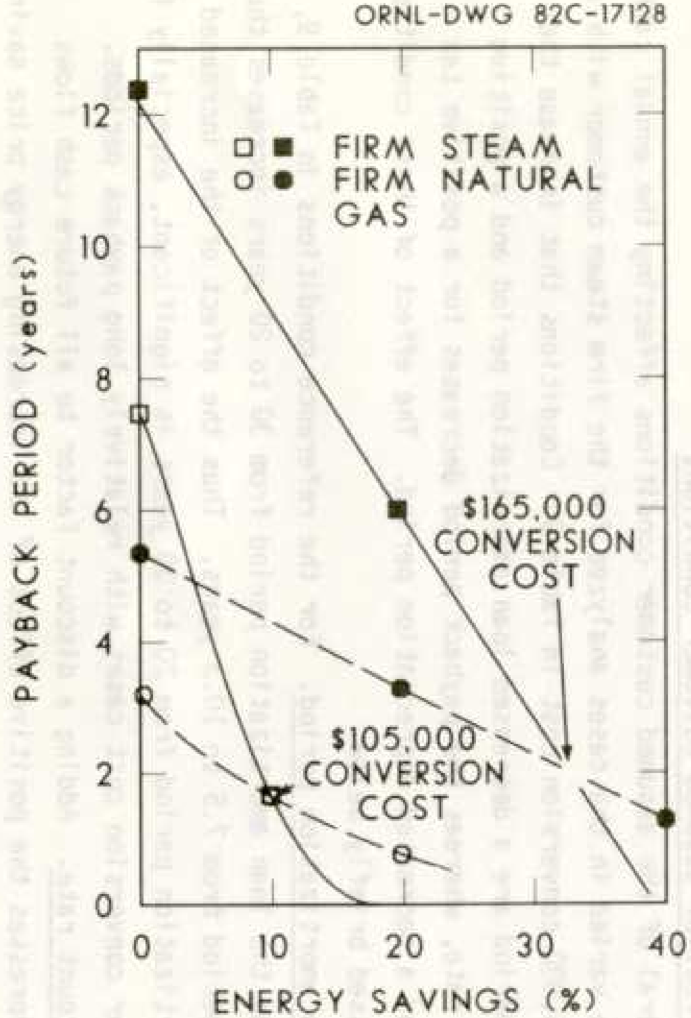

Fig. 15. Payback period vs. relative energy savings for high and medium cost building conversions-base case financing assumptions.

5.5.3 Effect of assumed customer conditions

Several of the assumed customer conditions affecting the annual cash flow were varied in the cases analyzed for the firm steam customer with a 1980 $105,000 conversion cost in Table 9. Conditions that increase the payback period are a decreased loan amortization period and a positive discount rate, whereas the payback period decreases for a positive tax credit and a decreased depreciation period. The effect of these conditions is discussed briefly below.

Loan amortization period. For the reference conditions in Table 9, decreasing the loan amortization period from 30 to 20 years increases the payback period from 7.5 to 10.3 years. Thus the effect of the increased loan amortization period from 20 to 30 years is significant, especially for the higher conversion cost cases with relatively long payback periods.

Discount rate. Adding a discount factor to all future cash flows mainly depresses the positive effect of the increasing energy price savings in later years. The 10 and 15% discount rates increase the payback period only a moderate amount for the $105,000 level of conversion cost cases in Table 9, from 7.5 years to 8.4 and 9.3 years, respectively. In general, discounting will affect short payback investment situations minimally but will significantly extend long payback situations that are already unattractive to potential customers.

Tax credit. An investment tax credit of 5% was sufficient for the reference case in Table 9 to create a positive cumulative cash flow for all years, so the payback period was reduced to essentially zero. This result illustrates the powerful effect of the tax credit that contributes a positive cash flow in the first year of service. High conversion cost customers would benefit the most from a tax credit as their normal payback periods are long and the credit is proportional to the increasing investment cost.

Depreciation period. Reducing the straight-line depreciation period from 15 to 10 years added positive cash flow through the tax effect to reduce the payback period from 7.5 to 2.5 years for the reference case in Table 9. Accelerated depreciation, like an investment tax credit, would contribute most to reducing the payback period for high conversion cost customers, and turn many building conversion investment situations from long payback, high risk type ventures to a venture with an acceptable payback and risk.

6. SUMMARY AND CONCLUSIONS

6.1 Building Conversion Costs

The study of building conversion costs in St. Paul by Michaud, Cooley, Hallberg, Erickson and Associates has produced a wealth of information, especially in the survey of 106 buildings in Phase II. The results of this survey, presented in Table 7, have been used by the DHDC to develop general conversion cost estimates for unsurveyed buildings in the DHDC market area. In addition, the results of the survey are the basis for several conclusions relating to the combined effort of system connection, upgrading, and conversion for a 250°F (121°C) hot water supply system.

The results of Phase II of this study indicate that buildings that have hot water supplied to the perimeter heating systems, air side systems or both are the most economical to convert to a hot water district supply system. The average unit conversion cost for such systems is $40/kW(t) with lower costs in the $15 to 30/kW(t) range possible for newer systems requiring little or no upgrading.

By contrast, heating systems with one- or two-pipe steam supplied to perimeter systems -- groups 2, 4, 5, and 7 -- have the highest unit conversion costs, averaging from $140 to 400/kW(t). Also in the case of group 5, the highest range of unit cost occurs, up to $200/kW(t) (Fig. 7), at a given peak demand. These high conversion costs are caused by significant upgrading and modernization required to provide for a hydronic heating system. The additional investment to modernize some of the existing steam heating systems may require incentives to encourage the building owner to make such an investment if a clear economic pay-back is not evident. However, this investment in modernizing existing steam heating systems would benefit from the reduced energy consumption of the more efficient hydronic system and also from the reduced long-term energy costs of the hot water district heating system.

The uncertainty in the conversion cost for such buildings, as evidenced by the range of costs found in this survey, indicates that an individual building system survey and cost estimate is desirable to establish the conversion cost for a specific building or potential customer.

Therefore, design assistance to potential customers should be considered in the marketing phase of implementing a district heating system to provide an incentive for owners of buildings that require significant upgrading and modernization.

Finally, the use of existing steam-to-steam converter units after conversion to a hot water heating system could result in significant cost reductions for many steam heating systems.

6.2 Building Conversion Economics

The results of the cash flow analyses presented in this report give general guidelines on the payback period for a customer's building conversion cost investment. The payback period is treated as the time to establish a positive cumulative cash flow after connecting to the hot water district heating system in 1984 as a source of thermal energy. The basic scenario treats a medium-sized building with either firm steam district heat or firm natural gas as the current energy source. The reference cash flow analysis assumes realistic loan amortization conditions for potential customers in St. Paul - 12% financing, 30 year repayment period - and conservative tax effects from the depreciation schedule (15 year, straight line) and tax credits (none). Energy prices for natural gas, steam district heat and hot water district heat were based on current values of end-use prices with escalation rates for natural gas from the Minnesota Energy Agency, and for hot water or steam district heat from the St. Paul DHDC.

In terms of an acceptable investment criterion for a building owner choosing whether to modify his building heating system for hot water service, a five to six year payback period was chosen to represent the limit that most for-profit building owners would accept. This payback period was not selected on a "rate of return" basis, since the rate of return over the greater than twenty year life of the equipment would be well above the 12% financing rate if the cumulative cash flow became positive after only five to six years. Rather, one of the primary factors affecting this particular investment decision for current natural gas customers is the time period over which the real prices of the current energy sources are assumed to escalate. A payback period of five or six years therefore requires acceptance of projected gas prices through 1989 to 1990 with a 1984 hookup year assumption.

An additional - and not insignificant - consideration for many potential customers relative to an acceptable payback period is the general state of the economy. With the recession continuing through 1982 and no dramatic improvement expected, a more conservative than normal investment attitude results. Therefore, many businesses may require a two-three year maximum payback period to minimize their risk period until a more positive economic condition returns.

The results of the payback period analysis show that a five to six year payback period criterion is met for all current natural gas customers even if unit conversion costs are as high as \$275/kW(t) of demand (1980 \$'s). For current steam customers, the payback period criteria is met if (1) a high unit conversion cost of \$275/kW(t) of demand results in 25% or greater energy savings, or (2) a medium cost of \$175/kW(t) results in a 5% or greater energy savings.

It is obviously important to hold the actual cost of the system conversion and connection as low as possible to reduce the financing costs and decrease the payback period. Other techniques to reduce the payback period are a shorter depreciation period to increase the income tax effect and any tax credit that might be available. These techniques would be especially important for high conversion cost buildings which would otherwise have excessive payback periods, and also for potential customers who require a relatively short, two-three year payback period.

7. REFERENCES

1. R. E. Sundberg and H. O. Nyman, "Methods and Cost Estimates for Converting Existing Buildings to Hot Water District Heating," Oak Ridge National Laboratory Report ORNL/TM-6830/P4, December 1979.

2. W. Pferdehirt and N. Kron, Jr., "District Heating from Electric Generating Plants and Municipal Incinerators: Local Planner's Assessment Guide," Argonne National Laboratory Report ANL/CNSV-12, Table 6, November 1980.

3. H. O. Nyman et al, "Market Assessment and Economic Analysis of the St. Paul District Heating System," ORNL/TM-6830/P10, Vol. 1, Ch. 5 (November 1982).

4. Ibid, Ch. 4.

APPENDIX C

COMPUTER ANALYSIS EXPLANATION

ST. PAUL DISTRICT HEATING DEVELOPMENT COMPANY, INC.

COMPUTER ANALYSIS EXPLANATION

Attached is a sample output from the computer program with explanation of how the various numbers are derived. The numbers which are circled on the output come from the building data base and are unique for each building. Numbers with squares around them come from the utility data base. All are entered at the time of the run and are the same for all buildings in a run.

All numbers which do not have a circle or square around them are computed by the program. The attached sheet shows how each number is computed. The number before each formula corresponds to the hand written number beside each printed number on the output.

Also attached is a section of the utility data base showing the energy prices which are used. The specific numbers used in the formulas attached are circled with the number of the formula indicated.

EXPLANATION OF COMPUTED NUMBERS*

(1) $$\frac{\text{1980\$}}{621{,}545} \times \frac{\text{Escal. factor}}{1.25} = \frac{\text{1982\$}}{776{,}931}$$

(2) $$\frac{\text{1982\$}}{776{,}931} \times \frac{\text{Amort. factor}}{.117460} = \frac{\text{Annual pmt.}}{91{,}258}$$

(3) $$\frac{\text{1982\$}}{776{,}931} \Big/ \frac{\text{Years}}{15} = \frac{\text{\$/yr. depreciation}}{51{,}795}$$

(4) $$\frac{\text{MMBtu}}{9{,}000} \Big/ \frac{\text{Conv. factor}}{3.413} \Big/ \frac{\text{Utilities}}{1700} \times \frac{\text{Conv. factor}}{1000} = \frac{\text{KW}}{1551.16}$$

(5) $$\left(\frac{\text{DH MMBtu}}{9000} \times \frac{\text{DH Energy Rate}}{5.01}\right) + \left(\frac{\text{KW}}{1551.16} \times \frac{\text{DH Demand Rate}}{23.67}\right) = \frac{\text{DH Cost}}{81806}$$

$$\frac{\text{DH Cost}}{81806} \Big/ \frac{\text{MMBtu}}{9000} = \frac{\text{Avg. \$/MMBtu}}{9.09}$$

(6) $$\frac{\text{Current MMBtu}}{15000} \times \frac{\text{Fuel Rate}}{10.94} \times \frac{\text{Franchise Fee}}{1.087} = \frac{\text{Current fuel cost}}{178377}$$

(7) $$\frac{\text{DH Cost}}{81806} \times \frac{\text{Franchise fee}}{1.087} = \frac{\text{DH cost incl. fee}}{88923}$$

(8) $$\frac{\text{Annual amort.}}{91258} - \left(\frac{\text{Int. rate}}{.10} \times \frac{\text{Unpaid Conv. balance}}{(776931 - 13565)}\right) = \frac{\text{Principal amt. for year}}{14921}$$

(9) $$\frac{\text{Int. rate}}{.10} \times \frac{\text{Unpaid conv. balance}}{(776931 - 13565)} = \frac{\text{Int. amt. for year}}{76337}$$

(10) $$\frac{\text{DH Cost}}{88923} + \frac{\text{Principal amt.}}{14921} + \frac{\text{Int. amt.}}{76337} = \frac{\text{Total DH Cost}}{180181}$$

(11) $$\left(\frac{\text{DH Cost}}{88923} + \frac{\text{Int. amt.}}{76337} + \frac{\text{Depreciation}}{51795}\right) \times \frac{\text{Tax rate}}{0} -$$

$$\left(\frac{\text{Current fuel cost}}{178377} \times \frac{\text{Tax rate}}{0}\right) = \frac{\text{Tax effect}}{0}$$

(12) $$\frac{\text{Current fuel cost}}{178377} - \frac{\text{Total DH Cost}}{180181} + \frac{\text{Tax effect}}{0} = \frac{\text{DH savings for year}}{-1804}$$

(13) $$\frac{\text{DH savings to date}}{(-8745)} + \frac{\text{Current year savings}}{(-1804)} = \frac{\text{Cumulative savings to date}}{-10549}$$

*Note: Throughout this section, "MM" should be read as "10^6."

1 105 60 33 May 7, 1982

ST. PAUL DISTRICT HEATING DEVELOPMENT COMPANY

SAMPLE

CUSTOMER INFORMATION FOR CITY HALL

YEAR OF HOOKUP: 1982
TOTAL CONVERSION COSTS(1980 DOLLARS): $ 621545 (INCLUDES 12% DESIGN FEE)
TOTAL CONVERSION COSTS(1982 DOLLARS): $ 776931. (1)
LEVEL AMORTIZATION PAYMENT: $ 91258 (2) OVER 20 YEARS AT 10% PER ANNUM
TAX RATE: 0%
STRAIGHT LINE DEPRECIATION: 15 YEARS AT 51795 (3) $/YR
TAX CREDIT IN FIRST YEAR: 0 %
ENERGY COSTS INCLUDE: 8.7% FRANCHISE FEE EXCEPT OIL
PEAK LOAD: 1551 (4) KW
ESTIMATED UTILIZATION HOURS: 1700
ENERGY SAVING FROM CONVERSION: 40%

	PRIMARY	BACKUP	TOTAL
	----------FUEL USE----------		
	NSP STEAM	NONE	
ANNUAL HEATING CONSUMPTION(MILLION BTU)	15000.	0	15000.
ESTIMATED DH CONSUMPTION(MILLION BTU)			9000.

YEAR	CURRENT FUEL RATE $/MMBTU	DH FUEL RATE $/MMBTU	CURRENT ENERGY COSTS	I------DISTRICT HEATING------I ENERGY COSTS	CONVERSION AMORTIZATION PRINC	INTER	TOTAL COSTS	TAX EFFECTS ($)	DISTRICT HEATING SAVINGS ($)	CUMU-LATIVE SAVINGS ($)
1982	8.95	8.15	132235	79722	13565	77693	170980	0	-8745	-8745
1983	10.54	9.08 (5)	178377 (6)	88923 (7)	14921 (8)	76337 (9)	180181 (10)	0 (11)	-1804 (12)	-10545 (13)
1984	12.04	10.34	196312	101137	16414	74844	192395	0	3917	-6632
1985	13.00	10.73	211965	104534	18055	73203	196152	0	15773	9141
1986	14.04	11.54	228922	112604	19860	71398	204162	0	24781	33901
1987	15.17	12.56	247347	122629	21846	69412	214037	0	33260	67161
1988	16.36	13.56	267076	132894	24031	67227	223922	0	43154	110315
1989	17.69	14.41	288435	140886	26434	64824	232247	0	56185	166504
1990	19.10	15.14	311426	148156	29078	62180	239414	0	72011	238515
1991	20.63	16.13	336372	157756	31985	59273	249014	0	87358	325873
1992	22.28	16.73	363275	163915	35184	56074	255177	0	108099	433972
1993	24.07	17.84	392461	174550	38702	52556	265808	0	126853	560825
1994	25.99	18.55	423787	181486	42573	48685	272754	0	151013	711837
1995	28.07	19.34	457681	189225	46830	44428	280483	0	177199	888836
1996	30.32	20.22	494388	197834	51513	39745	289092	0	205276	1094112
1997	32.74	21.20	533828	207421	56664	34594	298679	0	235148	1329258
1998	35.36	22.25	576545	217693	62330	28928	308951	0	267593	1596851
1999	38.19	23.39	622689	228846	68564	22695	320104	0	302584	1899435
2000	41.24	24.67	672418	241368	75420	15838	332626	0	339792	2239227

○ = in building database
□ = in utility database or entered for each run

THE FOLLOWING NUMBERS ARE THE FUEL PRICES AND COST FACTORS USED BY THE PROGRAM. FOR EACH ITEM, THERE ARE TWO LINES OF DATA: 1981-90 AND 1991-2000. THE ORDER IS:

1. FIRM NSP STEAM
2. INTERRUPTIBLE NSP STEAM
3. FIRM NATURAL GAS
4. INTERRUPTIBLE NATURAL GAS
5. ELECTRICITY
6. #2 OIL
7. #6 OIL
8. HOT WATER DISTRICT HEATING (AVERAGE)
9. BUILDING ESCALATION RATES
10. DISTRICT HEATING DEMAND RATES
11. DISTRICT HEATING ENERGY RATES

6.88	9.95	10.94	12.04	13.00	14.04	15.17	16.36	17.69	19.10
20.63	22.28	24.07	25.99	28.07	30.32	32.74	35.36	38.19	41.24
5.89	6.37	7.01	7,71	8.33	8.99	9.71	10.49	11.33	12.24
13.21	14.27	15.41	16.65	17.98	19.42	20.97	22:65	24.46	26.42
4.06	4.89	5.71	6.52	8.44	10.32	11.51	13.22	15.74	17.50
19.55	22.14	25.07	28.61	32.14	35.93	40.09	44.55	49.35	55.06
4.06	4.89	5.71	6.52	8.44	10.32	11.51	13.22	15.74	17.50
19.55	22.14	25.07	28.61	32.14	35.93	40.09	44.55	49.35	55.06
8.63	9.20	9.58	10.15	10.62	11.78	12.73	13.37	14.83	16.00
17.26	18.88	20.15	21.70	23.53	25.40	27.43	29.63	31.96	34.55
8.85	10.76	12.37	14.06	15.82	17.17	19.01	21.02	23.29	25.70
29.84	32.33	36.45	41.10	45.70	50.56	55.81	61.51	67.53	74.80
5.35	6.60	7.70	8.84	9.83	10.99	12.20	13.66	15.27	16.93
18.99	21.69	24.65	28.34	31.76	35.27	39.16	43.33	47.66	52.97
7.28	8.15	8.97	9.87	10.66	11.51	12.43	13.42	14.26	14.74
15.94	16.83	17.93	18.51	19.20	19.62	21.01	22.05	23.14	24.39
1.12	[illegible]	1.38	1.52	1.64	1.77	1.91	2.06	2.23	2.41
2.60	2.81	3.03	3.28	3.54	3.82	4.13	4.46	4.81	5.20
20.00	21.52	23.87	26.04	28.64	31.51	35.54	38.82	41.03	42.38
43.76	45.23	47.59	47.59	47.59	47.59	47.59	47.59	47.59	47.59
4.00	4.44	[illegible]	5.85	5.75	6.11	6.43	6.87	7.34	7.84
6.58	8.96	9.64	10.35	11.14	12.02	13.00	14.05	15.19	16.47

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BUILDING CONVERSION COSTS AND ECONOMICS FOR THE ST. PAUL HOT WATER DISTRICT HEATING MARKET

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Microfiche enclosed