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STUDY OF BUILDING CONVERSION COSTS FOR THE ST. PAUL HOT WATER DISTRICT HEATING MARKET*

J. O. Kolb
Kevin Teichman**

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CAUTION

*Research sponsored by the Division of Buildings and Community Systems, Department of Energy

**Consultant, University of Minnesota

Prepared by the
OAK RIDGE NATIONAL LABORATORY
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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.

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. 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 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.

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.

In addition to the supply temperature characteristics described above, a cogeneration heat source district heating system requires the return water

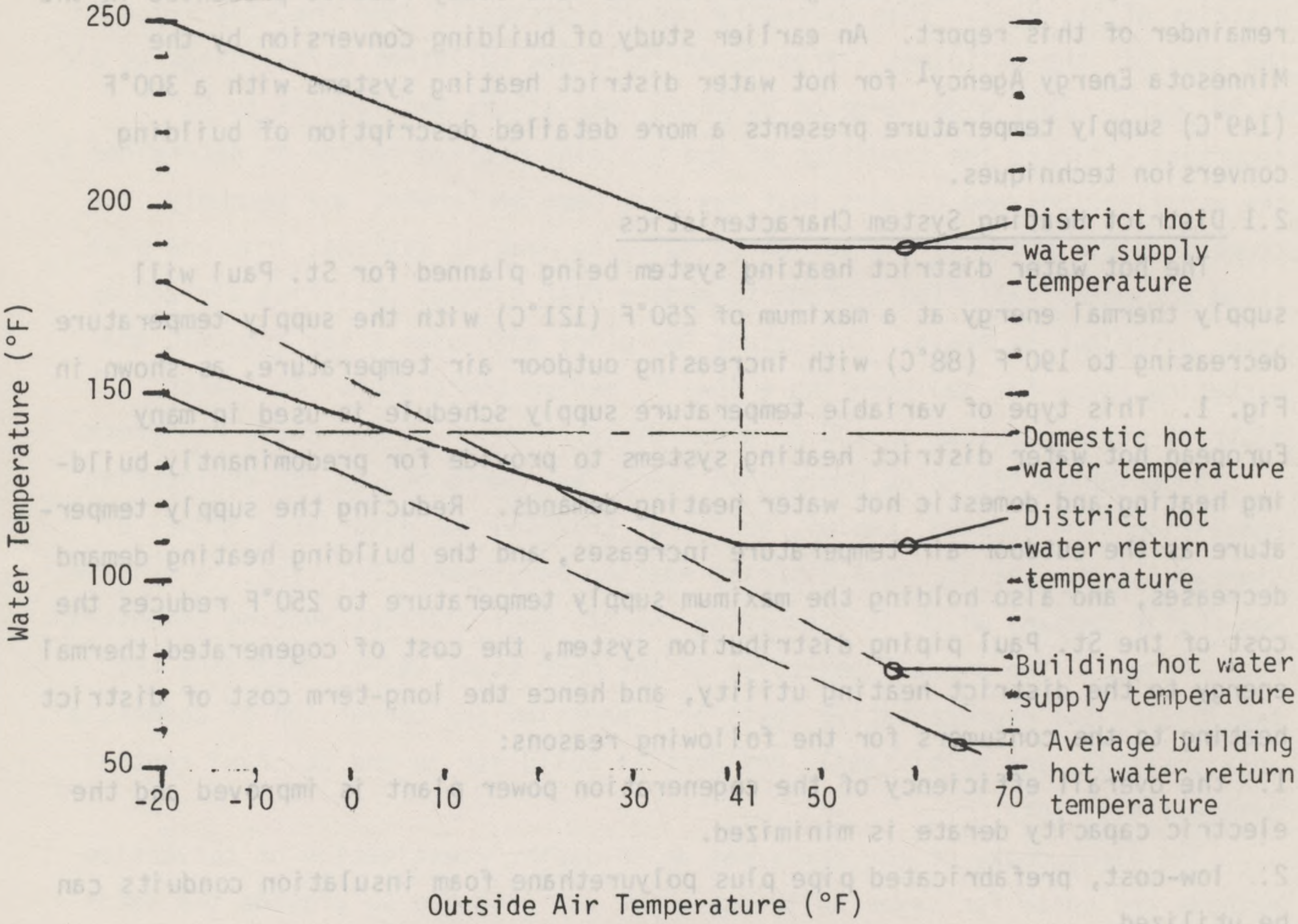

Fig. 1. Hot water temperatures for district heating system and hydronic building heating system as a function of outside air temperature.

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 150°F (66°C) to 160°F (79°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 180°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 180°F and 250°F to mainly provide for building space heating and domestic hot water heating. The main functional demand not accommodated by this approached is the space cooling demand that is presently provided by electric or absorption chillers. For the amount of existing absorp-

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

tion 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 reduced 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 coils in the air-handling duct work, and domestic water heating. The most predominant space heating mode in the St. Paul buildings is with steam or hot water perimeter heating. If buildings have both steam and hot water, steam is usually supplied

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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.

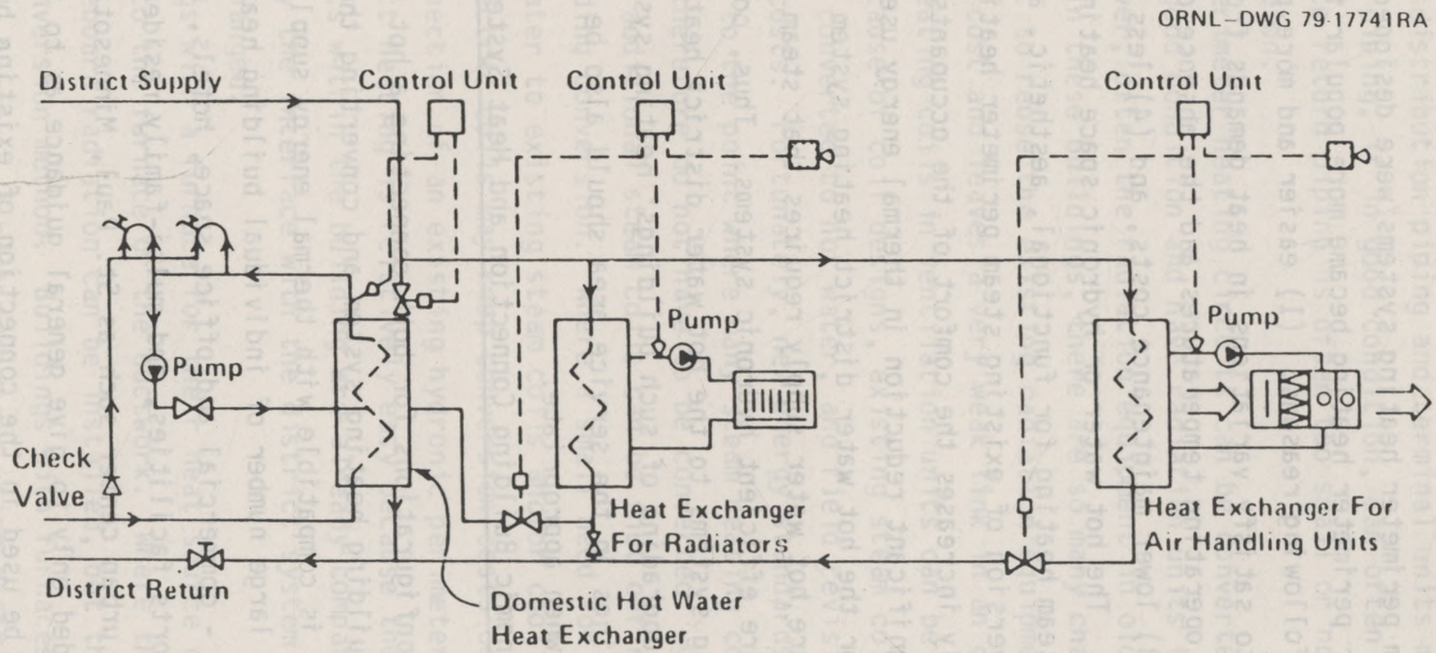

Fig. 2. Building heating system connected to district heating emphasizes low return temperature.

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 are required for buildings 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 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 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.

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 sub systems, 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 coals, 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.

The results of this relatively in-depth study was 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.

Table 1. Phase I Building Information

Building	Demand [KW(t)]	Building Heated Area (ft^2)	System* Age	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	$ 47,000
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	$151,700
St. Paul YWCA	$ 3,300	$16,600	$21,400	$11,900	$27,505	$11,750	$ 92,455
St. Paul Co.	$12,265	$33,300	$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

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 in-person 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 area -- 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, 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

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

System Group No.	
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 $(KW/ft^2) \times 10^3$
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.

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.

The individual cost data have been segregated by system age -- less than 10 years, 10 to 50 years, and greater than 50 years -- and also be systems requiring special treatment. These are systems usually in older buildings which either require essentially complete replacement because of degraded condition or

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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		

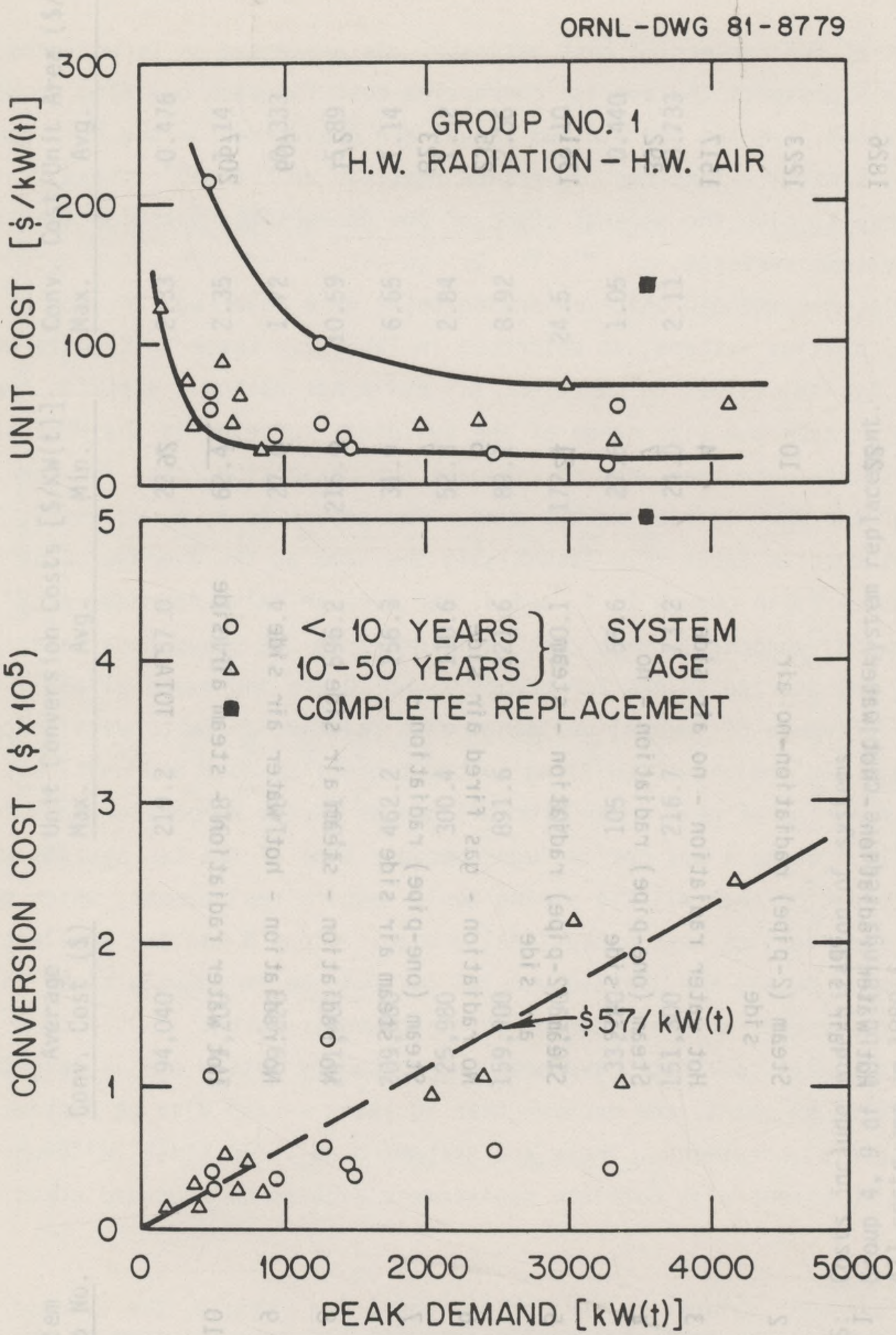

Fig. 3. Conversion cost and unit conversion cost (1980 $) for group No. 1 buildings served by 250°F hot water system.

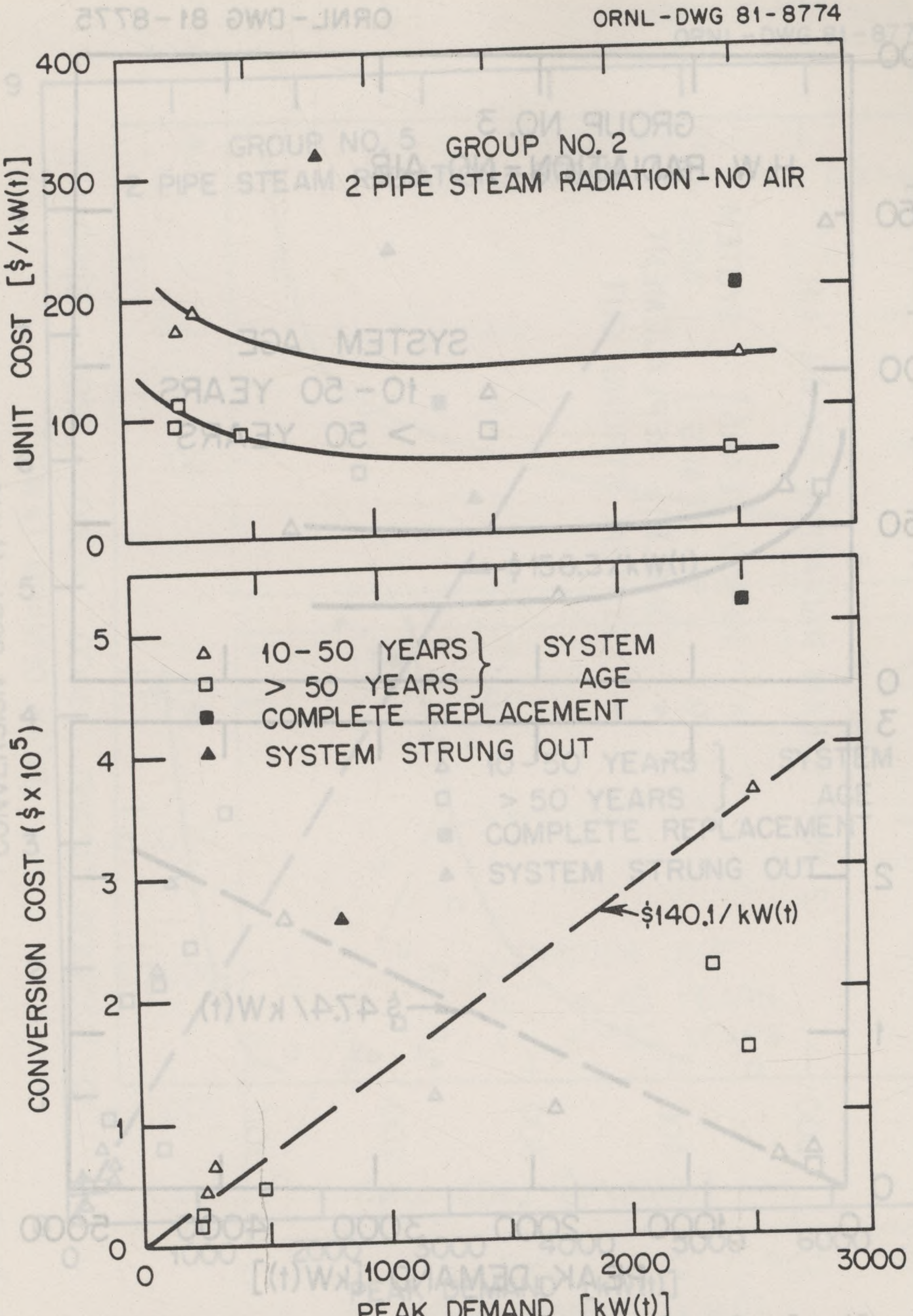

Fig. 4. Conversion cost and unit conversion cost (1980$) for group No. 2 buildings served by 250°F hot water system.

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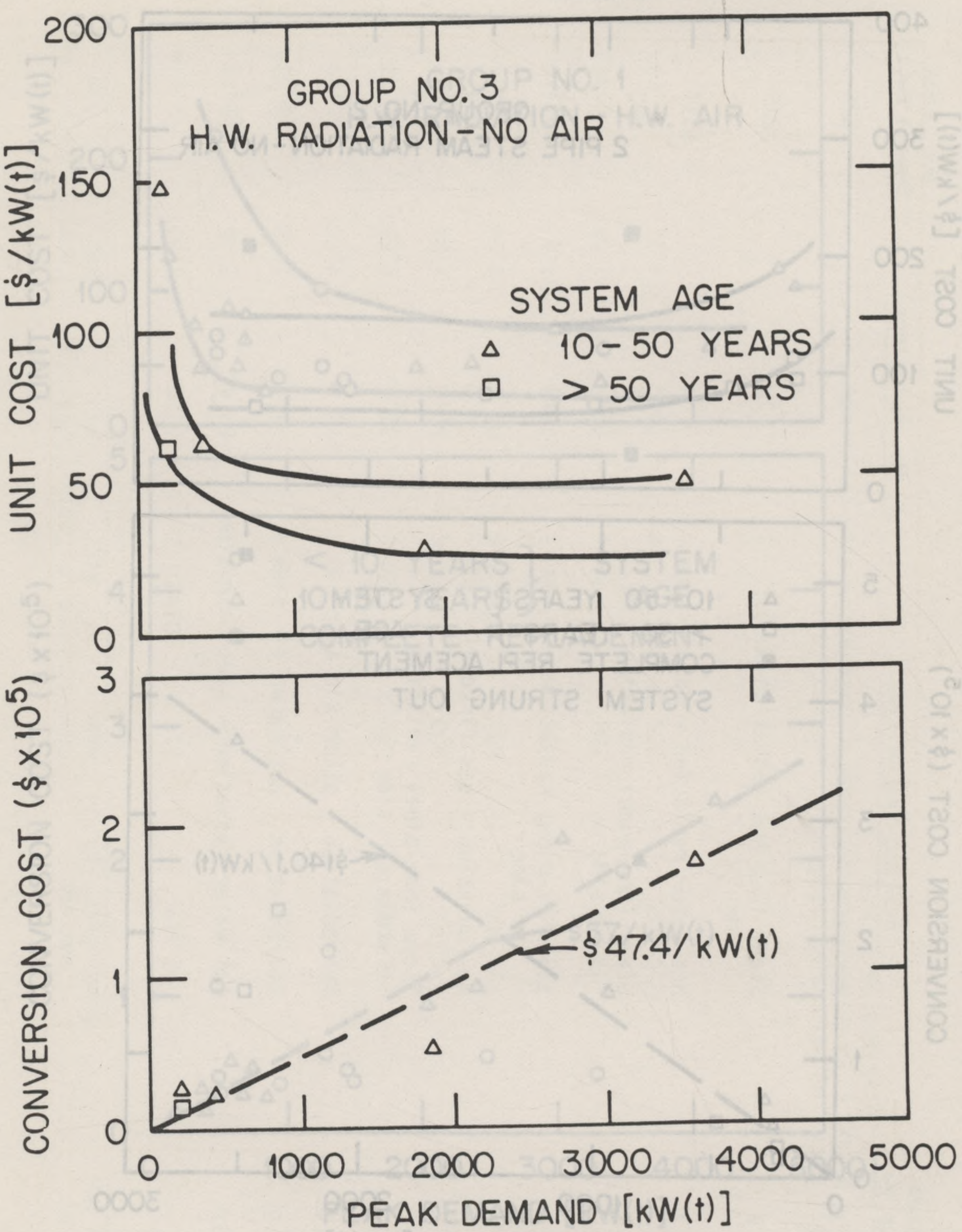

Fig. 5. Conversion cost and unit conversion cost (1980 $) for group No. 3 buildings served by 250°F hot water system.

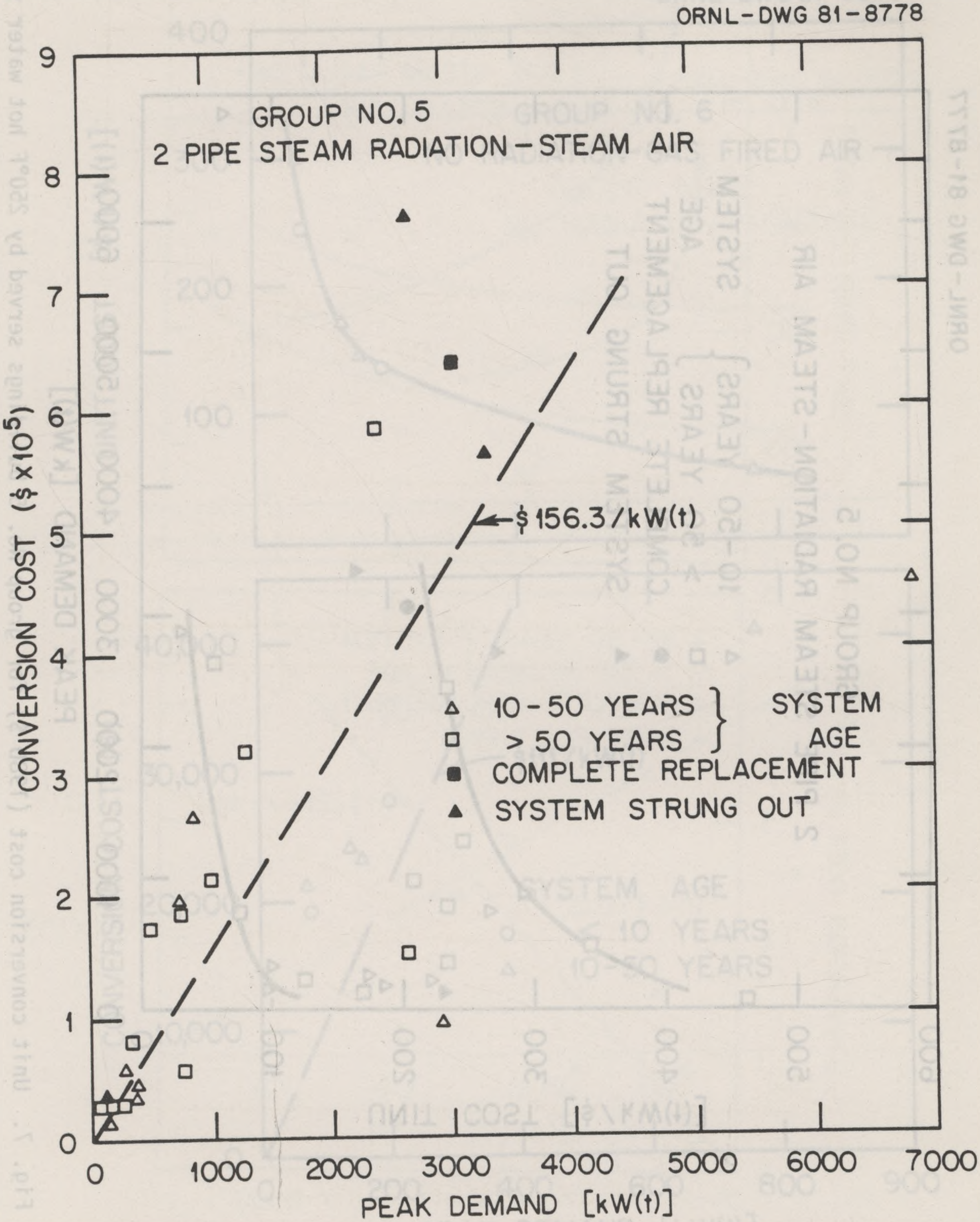

Fig. 6. Conversion cost (1980 $) for group No. 5 buildings served by 250°F hot water system.

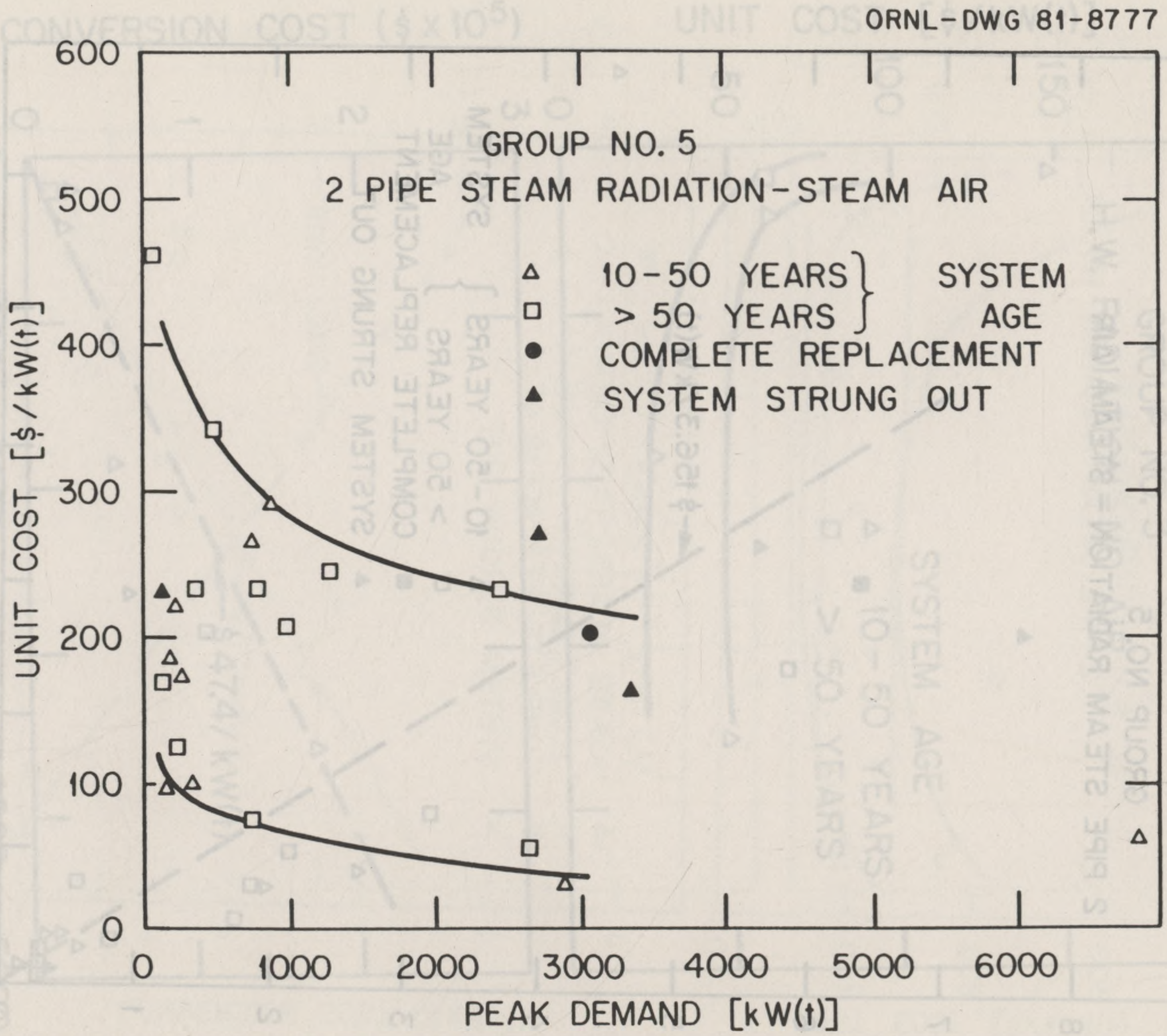

Fig. 7. Unit conversion cost (1980 $) for group No. 5 buildings served by 250°F hot water system.

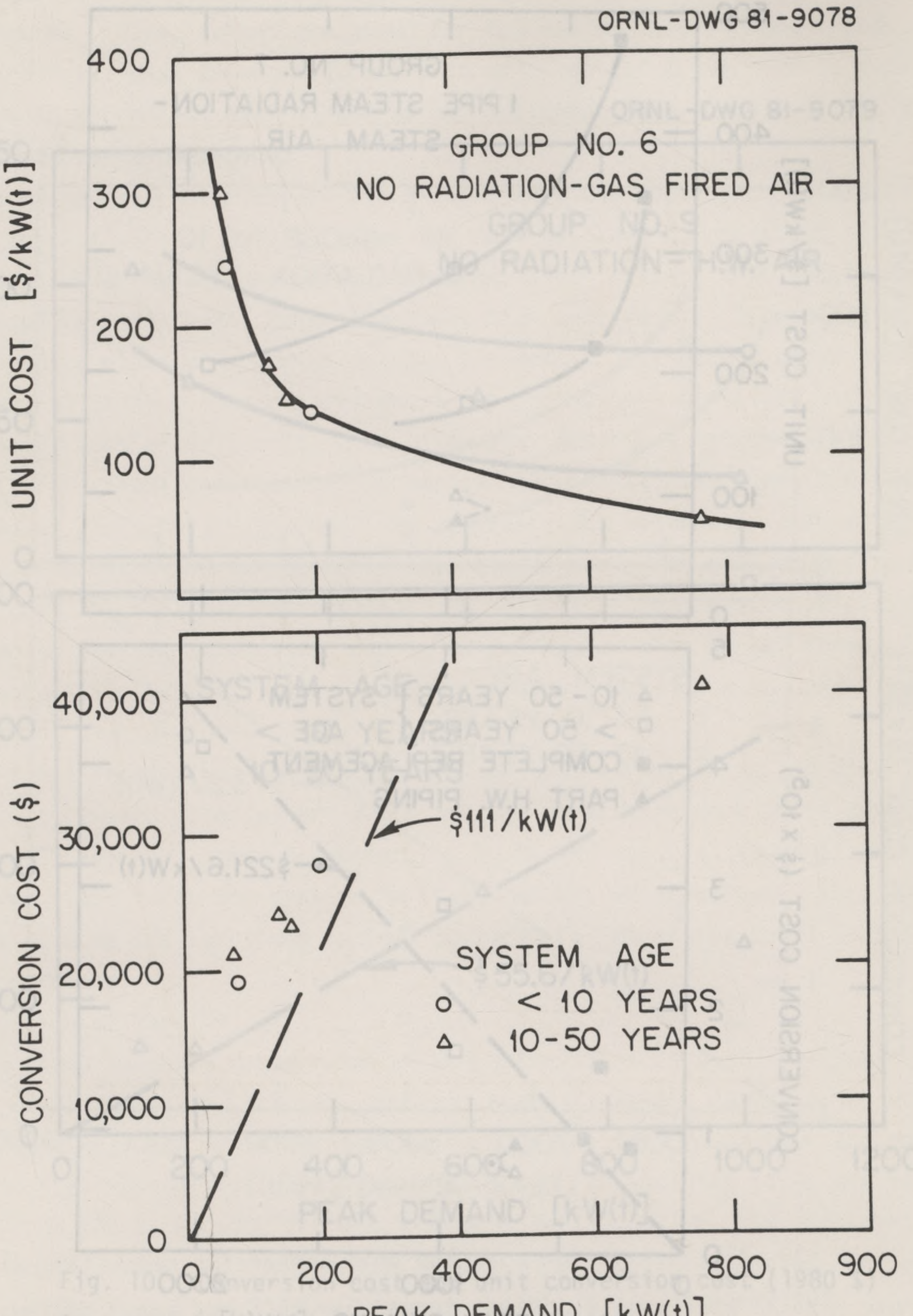

Fig. 8. Conversion cost and unit conversion cost (1980 $) for group No. 6 buildings served by 250°F hot water system.

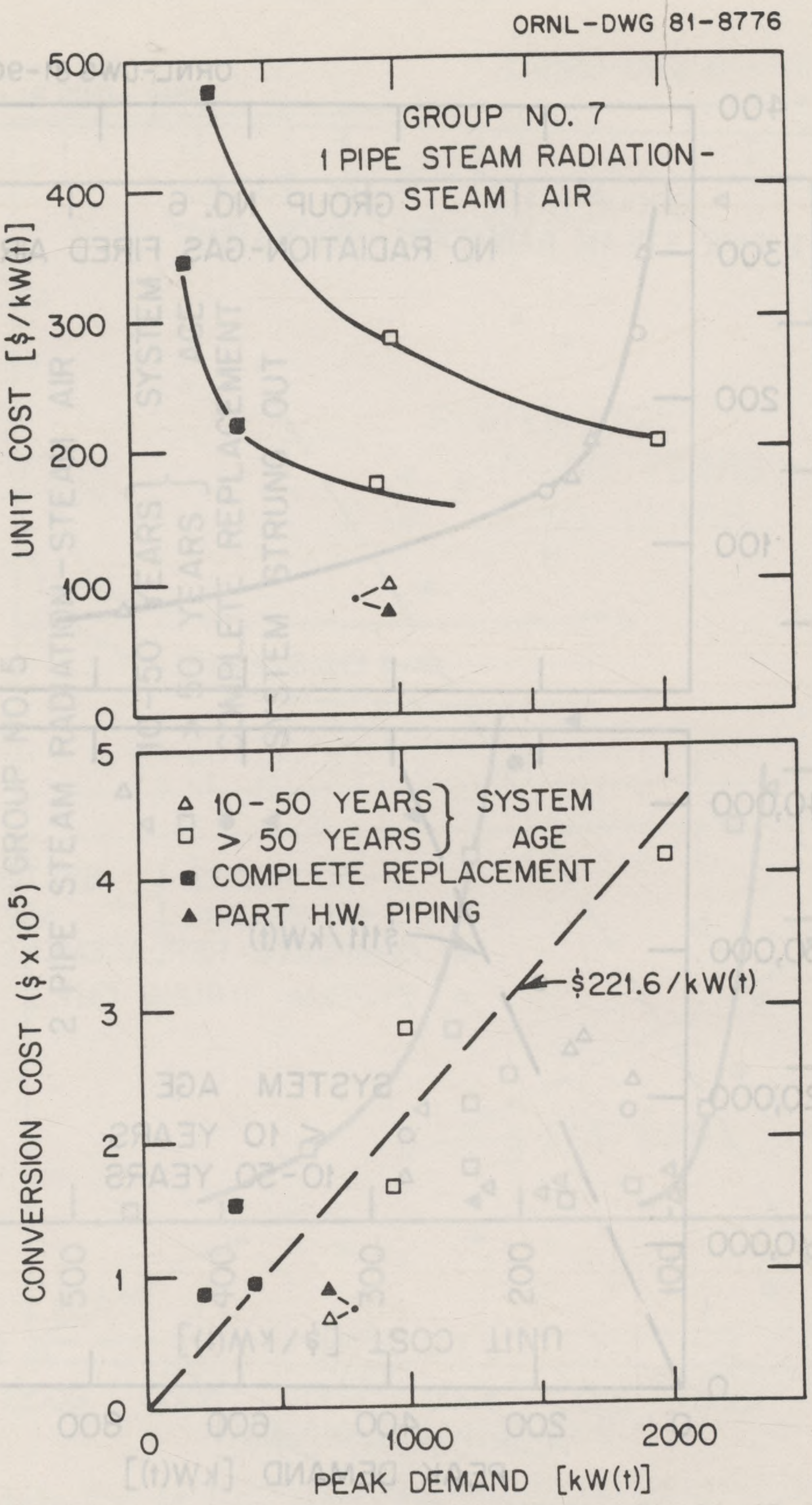

Fig. 9. Conversion cost and unit conversion (1980 $) for group No. 7 buildings served by 250°F hot water system.

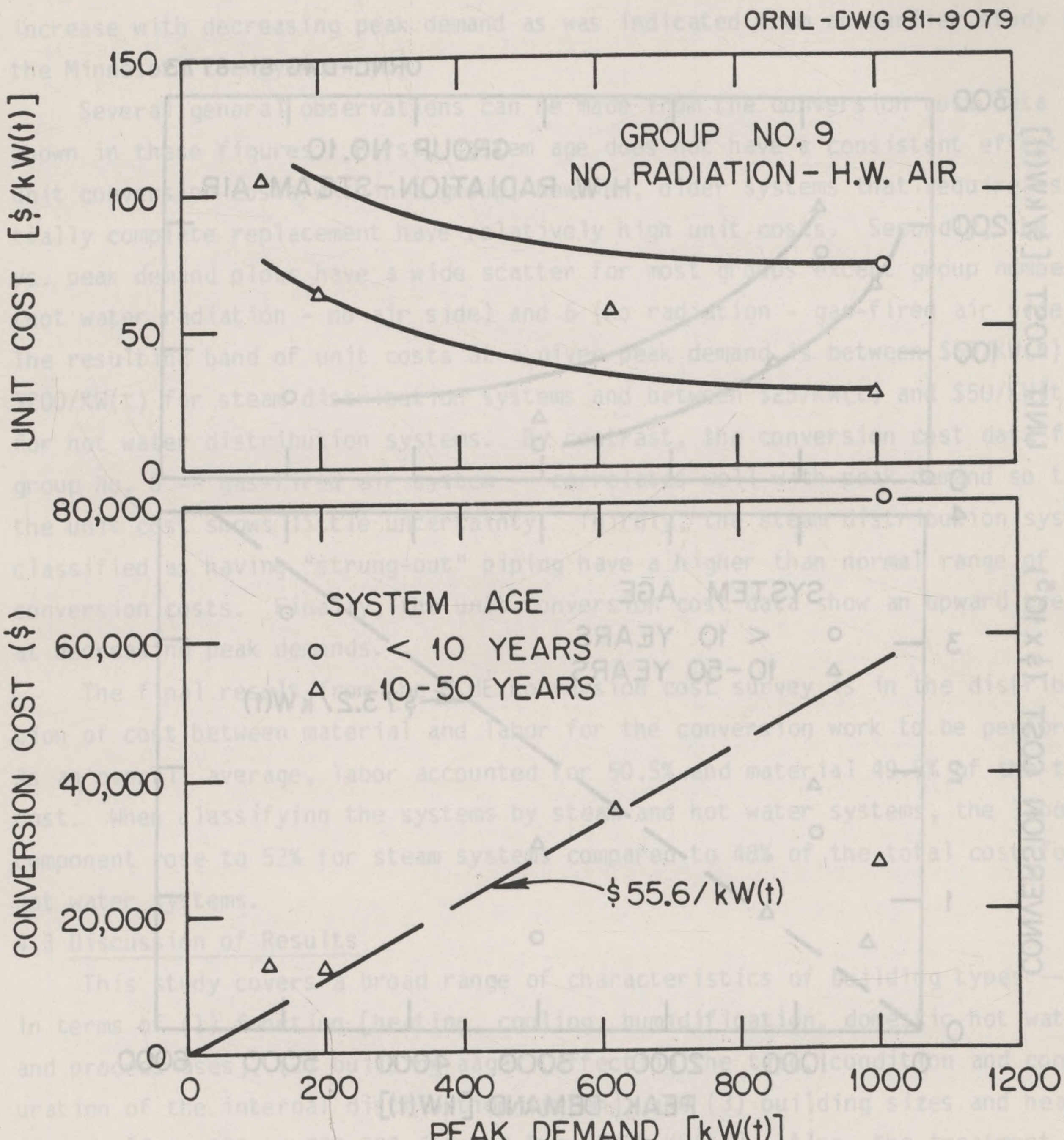

Fig. 10. Conversion cost and unit conversion cost (1980 $) for group No. 9 buildings served by 250°F hot water system.

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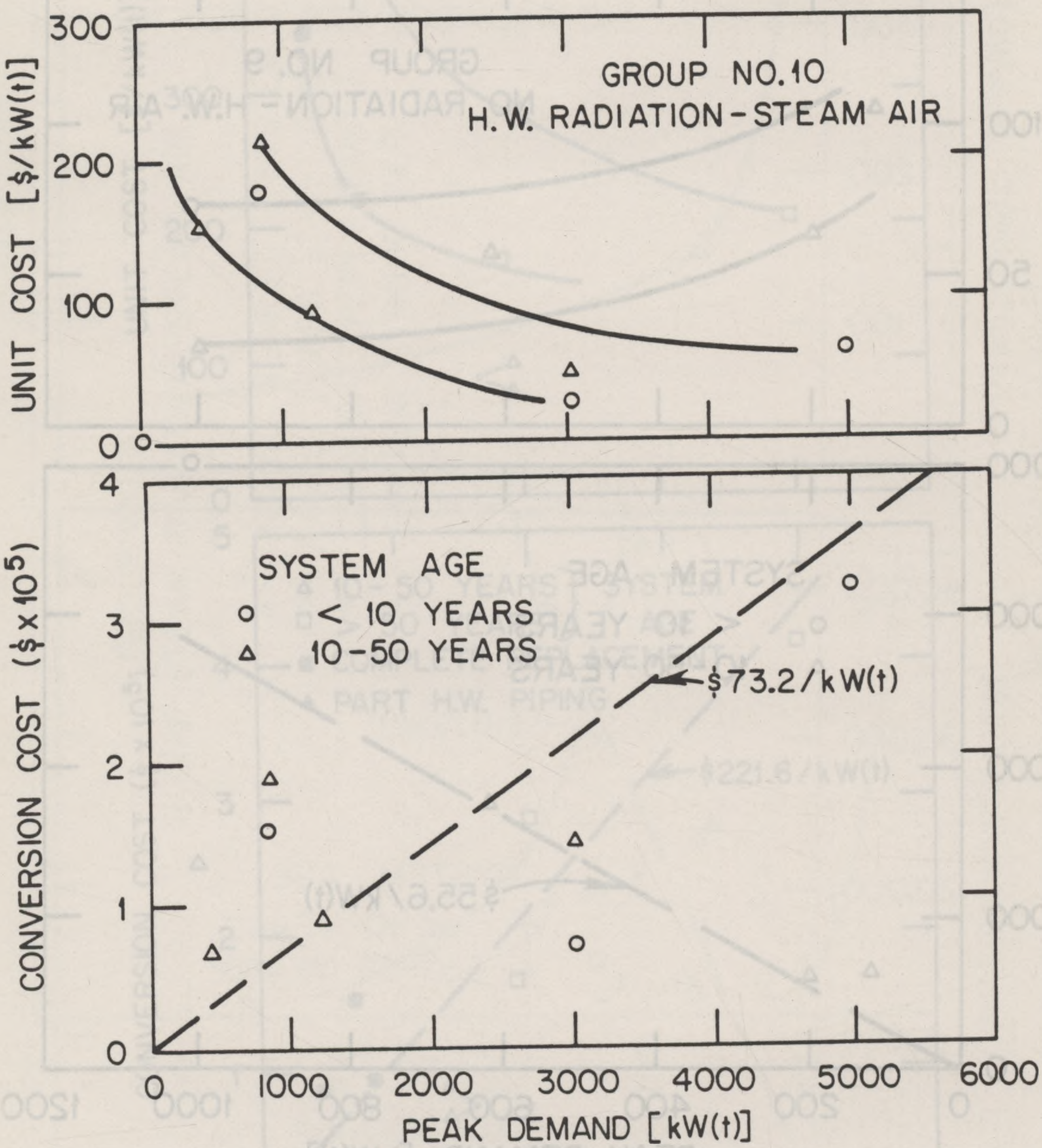

Fig. 11. Conversion cost and unit conversion cost (1980 $) for group No. 10 buildings served by 250°F hot water system.

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) function [heating, cooling, humidification, domestic hot water and process uses], (2) building aages [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. This 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 system 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 system - 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 data of this type to the author's 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 cause 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.

SUMMARY AND CONCLUSIONS

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.

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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.

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