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CONSTRUCTION OF DISTRICT HEATING TO 300 RESIDENTIAL CUSTOMERS ST. PAUL, MINNESOTA

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INTRODUCTION

District Heating Development Company (DHDC) is the private, non-profit corporation providing hot water district heating service to the downtown and adjacent areas of St. Paul. The initial system was completed in 1984, a year ahead of schedule and $1.3 million under budget. In 1985 DHDC extended its distribution system to serve the residential public housing area of Mount Airy located immediately north east of DHDC's existing pipe.

The paper presents a summary of the planning, design and construction procedures that were used to install a hot water district heating system to heat the 298 unit residential Mount Airy community. The design and construction aspects of the project highlight some cost-effective ways to make the project feasible and within budget. The paper also discusses the importance of communication with all parties to maintain a smooth-running project.

BACKGROUND

Current Status Of DHDC System

DHDC's initial $45.8 million system was substantially complete as of November 1984. Piping installation, heating plant modifications, and other construction cost $30.6 million, or $1.3 million below the the amount of $31.9 million. Piping installation alone was just over $23 million.

A total of 102 customers were receiving DHDC service as of May 1986. Aggregate contract demand as of the May billing was 160 megawatts (MW).

Since its initial marketing effort in 1982, DHDC has continued to sign additional customers for hot water service, including both new developments and buildings being remodeled or rehabilitated. Customer contract demand commitments are significantly above the projections used in the feasibility study published prior to DHDC's system financing in 1982, as shown below:

Fiscal Year	Customers	Actual Demand	Previous Projection
1983-84	25	36.2 MW	35.0 MW
1984-85	89	127.2 MW	100.0 MW
1985-86	102	160.8 MW	135.0 MW

Operating, as well as construction costs, have been below previous estimates. Because of higher customer loads and lower costs, DHDC has been able to keep rate increases below 1% per year during the first three years of operation. As a result, the overall rate for a typical district heating customer is now $9.56 per MMBtu. Energy conservation benefits averaging over 20 percent from heating system conversion have added to the savings enjoyed by district heating customers, resulting in a high degree of customer satisfaction.

At the same time, competitive energy prices are also below earlier projections, so the pressure remains on DHDC to expand its customer base to achieve the most economical rates possible. Expansion is also consistent with the public financing of DHDC's initial system construction, which was provided for the explicit purpose of laying the groundwork for a system serving as much of the city of St. Paul as possible.

Mount Airy

The Mount Airy Public Housing community is situated immediately adjacent to the northeast side of the downtown St. Paul district heating system. Approximately 62 acres in size, it includes 298 single family low-rise housing units in buildings of one to six units each, a high-rise apartment building, a neighborhood center and school, and a community center building. The total district heating demand for the area is 5.8 MW.

DHDC investigated the possibility of including the Mount Airy area in its initial system construction but decided to omit it at that time in order to limit the size and cost of the project. As completion of the downtown system approached, however, analysis of Mount Airy was renewed. A DHDC study carried out in 1983 concluded that the economics of expanding to serve Mount Airy were favorable compared to other potential expansion areas.

In late 1983, the St. Paul Public Housing Authority (PHA), owner of the Mount Airy complex, obtained funding authorization of $652,000 from the U.S. Department of Housing and Urban Development (HUD) to replace the 25-year old gravity air furnaces in many of the low-rise units. DHDC proposed to PHA that this funding be used instead to convert the low-rise units to district heating. Conversion to district heating would reduce air infiltration, eliminate fire hazards, save on maintenance costs, and provide stable fuel prices. HUD was supportive of this recommendation and agreed to commit an additional $400,000 toward the cost of hot water distribution lines within the Mount Airy community.

Contract Between Public Housing Authority And DHDC

Under the terms of the Hot Water Delivery Agreement as negotiated between DHDC and the Public Housing Authority, certain exceptions were made to the standard customer contract terms.

. The completion date of October 1, 1985, was treated as a target date, subject to subsequent agreement on the actual completion dates for the individual buildings to be converted to district heating. Initial demand was also dependent on the number of buildings which were hooked up at any given time.

DHDC agreed to bill individual tenants for demand and energy charges when units were occupied. PHA would pay demand and energy charges for all vacant units and would treat heating bill payments as rent for purposes of enforcing its dwelling lease; i.e., requiring tenants to keep current on utility bills as a condition of remaining in subsidized housing. Based on these conditions and past data on utility delinquencies, bad debt was not expected to be a major problem.

Financing

The total project cost (excluding individual heating system conversions but including any financing costs) was $1.8 million. Of this amount, HUD agreed to provide a $400,000 grant as part of its program to promote the use of district heating in public housing. The remaining $1.4 million had to be borrowed by DHDC.

Because of the complexity of its existing financing structure, issuance of additional floating rate bonds to finance the Mount Airy expansion would have required a substantial amount of time, numerous approvals, and heavy issuance costs in relation to the relatively small size of the project. In addition, the time available to complete the Mount Airy financing was short due to constraints related to availability of HUD money and DHDC and PHA construction timetables. Consequently, a more expedient approach was needed.

To provide the required financing, DHDC obtained a subordinated taxable loan from a major local bank. The loan had an eight-year term with a balloon payment scheduled for 1992. Later in the year, this loan was refinanced on a tax exempt basis as part of DHDC's Series B bond issue, which also provided fixed rate financing for one third of the original 1982 floating rate bonds.

Table A summarizes the sources and uses of funds for the Mount Airy district heating project.

TABLE A

DISTRICT HEATING DEVELOPMENT COMPANY

SERVICE TO MOUNT AIRY HOUSING COMPLEX

SOURCES AND USES OF FUNDS

JUNE 17, 1985

SOURCES OF FUNDS

New Financing (Bank Loan)*	$ 1,400,000
Distribution Line Contribution by HUD	400,000
Total Sources	1,800,000

USES OF FUNDS

Piping Construction	$ 777,000
Substation Construction	298,000
Engineering and Construction Services	240,000
Heat Meters and Installation	130,000
Contingency	130,000
Construction Subtotal	1,575,000
Capitalized Interest	73,000
Debt Service Reserve	140,000
Costs of Issuance	12,000
Total Uses	$ 1,800,000

*Later refinanced on tax exempt basis as part of Series B bond issue.

PROJECT DESIGN

The design of a district heating system to serve a residential area is critical. Because of the low heat density of the area, many feet of piping were required to serve many small heating loads in a large area. In order to obtain satisfactory payback on the project, it was essential to minimize the price of construction through use of a cost-effective design. It was important that all the costs for the total project were considered and minimized. This included DHDC's piping distribution system costs and PHA costs for conversion of the housing units. A combination of European district heating experience and recent lessons learned during the construction of the downtown St. Paul system was used to design the Mount Airy district heating system.

DHDC commissioned design studies to the joint-venture firm of Metcalf & Eddy/FVB, Inc., which designed and provided construction administration services for the initial downtown project. These studies, based on similar design principles used previously indicated a construction cost of approximately $1.58 million for connection of all 298 low-rise housing units. The high-rise apartment building, school, and community buildings were provided for in the design but are to be connected at a later date.

System Description

The Mount Airy Public Housing area lies northeast of the Minnesota State Capitol complex and the downtown area of St. Paul, Minnesota. It is bounded by Jackson, Arch, Pennsylvania, L'Orient, and Mount Airy streets and is approximately 62 acres in size, as shown in Figure 1. It includes 298 low-rise single-family townhouse units in buildings of one to six units each, a unit high-rise apartment building, a neighborhood center, a public school, and a community center building. The calculated total potential district heating demand for the area is 5.8 MW. This includes 3.7 MW for the low-rise housing units, 1.4 MW for the high-rise building, and 0.7 MW for the remaining buildings. The thermal demand includes both building heating and domestic hot water requirements.

From its present termination point at the St. Paul-Ramsey Medical Center, the existing DHDC primary piping distribution system was extended to a new substation located on the perimeter of the housing area. The primary system is designed for operation at 250°F and 250 psig. The operating temperature of the system is variable with a low of 190°F in summer and a maximum of 250°F in winter. The operating pressure presently is 175 psig.

The small (20' x 20' x 8') concrete substation is the interface between the primary DHDC system and a secondary piping system serving the housing units. The substation contains heat exchangers, secondary system pumps, expansion tanks, and heat-metering equipment. The substation operates unattended with remote monitoring from the DHDC Third Street Plant. The heat exchangers within the substation transfer the hot water energy from the primary piping system to the secondary piping system.

The closed-loop secondary piping system has a maximum design rating of 200°F and 150 psig. The prefabricated piping was direct buried mainly under the sidewalks and grass areas. The pipe distribution system was also routed through the building basements with individual services installed for each housing unit. The secondary system delivers heat to fan-coil units which were installed in place of the furnaces in each individual building unit.

The secondary piping was designed to serve all buildings in the area except the high-rise. Because of the higher heating requirements and conversion costs, the high-rise apartment building will be served more cost-effectively by a primary piping system similar to that used by the customers on the existing district heating system. The substation piping design incorporated provisions for future primary service to the high-rise building. The system's final design layout is shown in Figure 1.

Major Design Decisions

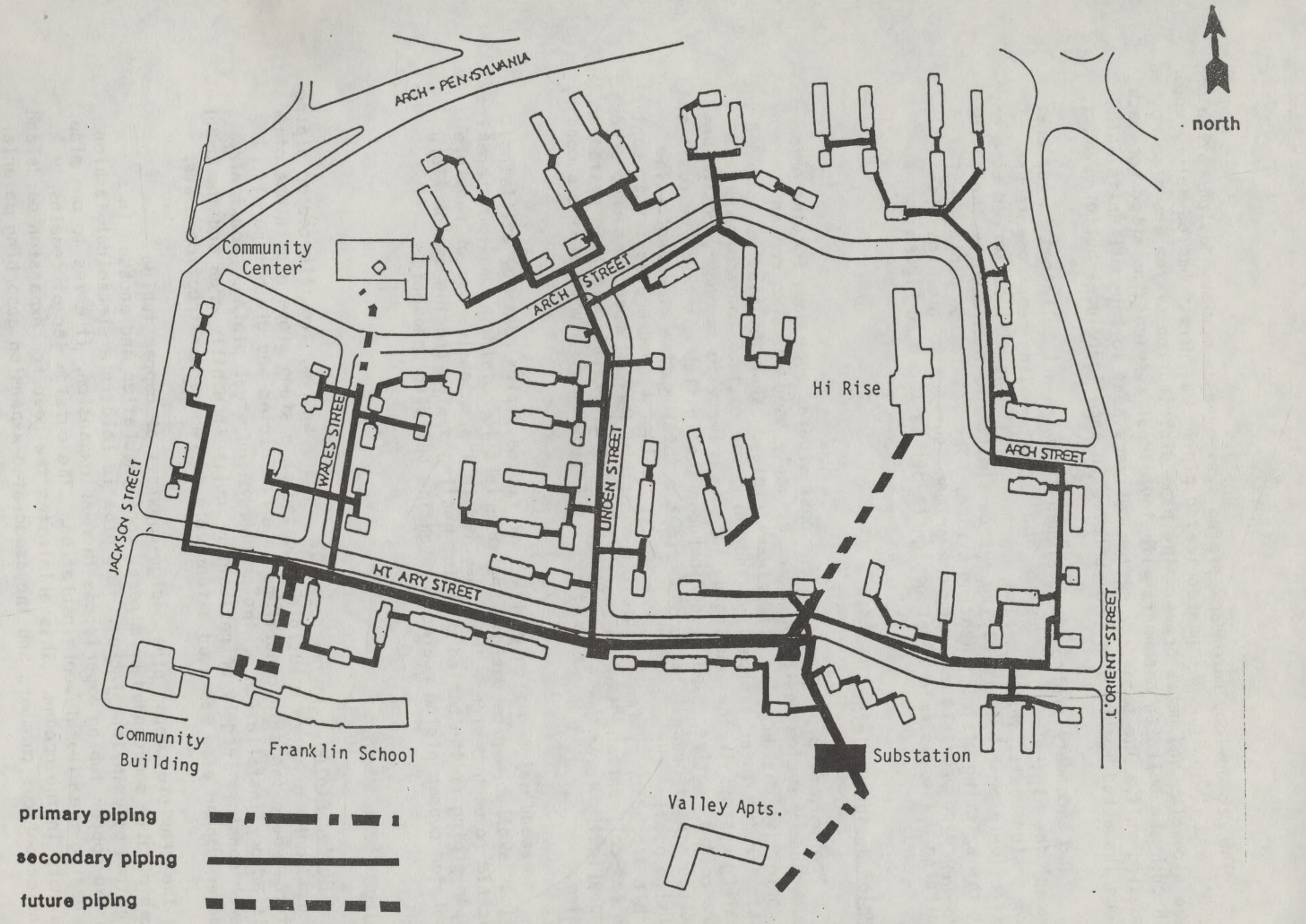
Preliminary piping layouts and cost studies were made for the primary to secondary system design that was actually used and also for an alternataive design using all primary piping. When the studies included the costs for the total system i.e. including the cost of conversion of the heating systems in the housing units, the primary to secondary design was more cost effective. The study included the initial construction costs and the subsequent operational costs from a a total system viewpoint. The housing heating systems are less costly to install and are easier to control with a secondary system to obtain a necessary large temperature drop across the fan-coil units. Heat losses through the distribution piping system are also slightly lower due to the lower operating temperatures of the secondary system.

A second major design goal was to reduce piping costs by utilizing various available pipe designs and materials to obtain the maximum benefits specific to each design. This resulted in the extensive use of flexible copper piping in the buried district heating system and the use of field insulated copper piping routed through the building basements.

Piping

Buried Piping. In the downtown primary system, flexible copper piping was used only to serve a building located on a steep slope and in one other instance where the site conditions were restricted and did not permit satisfactory installation of the prefabricated steel piping. Mount Airy however consists largely of residential units in a hilly area and the small diameter copper pipe was used extensively to reduce construction costs.

The flexible copper pipe design consists of copper tubing concentrically surrounded by mineral wool insulation and encased in a corrugated polyethylene jacket. The pipe is laid in a sinusoidal fashion. When the copper tubing experiences thermal expansion, it moves to one side, compressing the mineral wool insulation. The outside jacket remains stationary in the ground. This eliminates the need for expansion bends and expansion bellows chambers and the associated expansion absorbing material



Distribution Piping Network (Mt. Airy

FIGURE 1

Housing Heating System Conversion

As with the downtown buildings, each building connecting to the district heating system needed to be converted to accept the hot water service. The satisfactory coordination of the design of the district heating system by DHDC consultants and the design of the housing heating system conversion by PHA's consultants was very important to ensure that the total system operated efficiently and was mutually cost effective and reliable for both parties.

The supply temperatures, pressures and the required pressure and temperature drop parameters had to be compatible for both the distribution system and the building heating system as neither system can operate efficiently or safely without regard to the other. The pressure and temperature parameters affect not only the costs of equipment purchase and installation but also the long term operating efficiency of both systems.

The selection of a large design temperature drop of 50°F across the building coil is very important for the district heating system to minimize piping diameters. The use of lower design pressures and the use of a simple control valve was important for the building heating system. Meetings were held with PHA staff and consultants to agree on the final criteria to be used in the heating conversion and district heating system design.

The air gravity gas-fired furnaces in each housing unit were removed and new fan-coil cabinet units were installed by PHA contractors. Floor mounted cabinet installations were used to reduce possible vibration problems (see Figure 2). In each housing unit, the secondary piping is connected to a fan-coil unit installation where heat is extracted from the water to heat air which in turn is distributed throughout the building by the existing ducting system. A simple on-off thermostatically controlled control valve regulates both the flow of district heating water to the heat exchanger and the fan operation in the fan coil unit. After the heat is extracted in the fan-coil installation, the water is returned to the secondary system piping and subsequently to the substation for reheating and reuse.

For billing purposes, a battery powered heat meter was installed in each housing unit to measure the amount of heat used. The heat meter can be read at the meter installation site in each basement and at a remote readout installed on an exterior building wall.

CONSTRUCTION EXPERIENCE

DHDC's previous construction experience was based on the installation of a large district heating system in downtown St. Paul, Minnesota. The downtown piping system cost just over $23 million and provides service to over 100 large, commercial customers. A major portion of the construction consisted of large diameter piping which was installed underneath traffic and utility congested streets.

and anchors.

The smaller diameter pipes can also be supplied with both the supply and return pipes in a common polyethylene jacket instead of separate jackets for each pipe. The use of duplex pipe design for service connections reduces to half the number of required exterior wall penetrations and number of pipe jacket joints. Trenching widths can also be reduced slightly as only one pipe assembly is installed in the trench.

The flexibility of this pipe allows for easy installation and avoidance of existing utilities. The Mount Airy area is extremely hilly, with numerous large abrupt elevation changes within the area itself. An elevation change of 150 feet occurs from the highest to the lowest points of the area. In areas where steep slopes are unavoidable, the flexible pipe follows the contour of the ground surface without additional fittings or special miter joints. The total piping and trench length is also decreased by the elimination of 90° bends. This also decreases the number of joints which, in turn increases the reliability of the system.

Both flexible copper pipe and rigid steel composite pipe were used in the distribution system. The combination of the less expensive steel pipe for the larger pipe diameters (greater than 3 inches) and the easily installed flexible copper pipe for smaller diameters resulted in a reduction of 5 percent in construction costs. Cost reductions on future projects should be even greater when this product becomes known to designers and contractors.

Interior Piping. In a few cases during the downtown St. Paul project, piping was installed in building basements instead of the sidewalk or street. This experience indicated that routing pipe through buildings, instead of the burying it below the ground outside, lowers the cost of construction significantly. This concept was used extensively in the Mount Airy public housing service area and the construction bid prices reflected a 40 percent savings using the interior piping routed through basements as compared to direct buried piping.

The secondary system was designed for a lower maximum working water pressure and a temperature of 150 psi and 200°F respectively, which permitted the use of copper pipe with field applied insulation for the indoor hot-water piping. Copper pipe could not have been used if the primary system maximum working pressures and temperatures of 250 psi and 248° respectively had been extended to serve the individual housing units.

Design Criteria

Based on a review of the design issues, the following design criteria were used for the system design.

Primary Piping. The same design factors used in the original St. Paul district heating system were used for the primary piping connection to the substation.

1. Use of factory prefabricated direct buried steel pipe, polyurethane insulation and high density polyetheylene outside conduit.

2. A maximum supply water temperature of 250°F with a design pressure of 250 psi.

3. A design temperature drop between supply and return water of 90°F.

4. Pipe sizing with head losses below 7 feet per 1,000 feet.

5. Use of piping bends and loops to compensate for piping thermal expansion.

6. All fittings (U, Z, L bends) spaced to keep pipe stresses within conservative limits.

Secondary Piping. For the lower temperature and pressure secondary piping, design criteria were as follows:

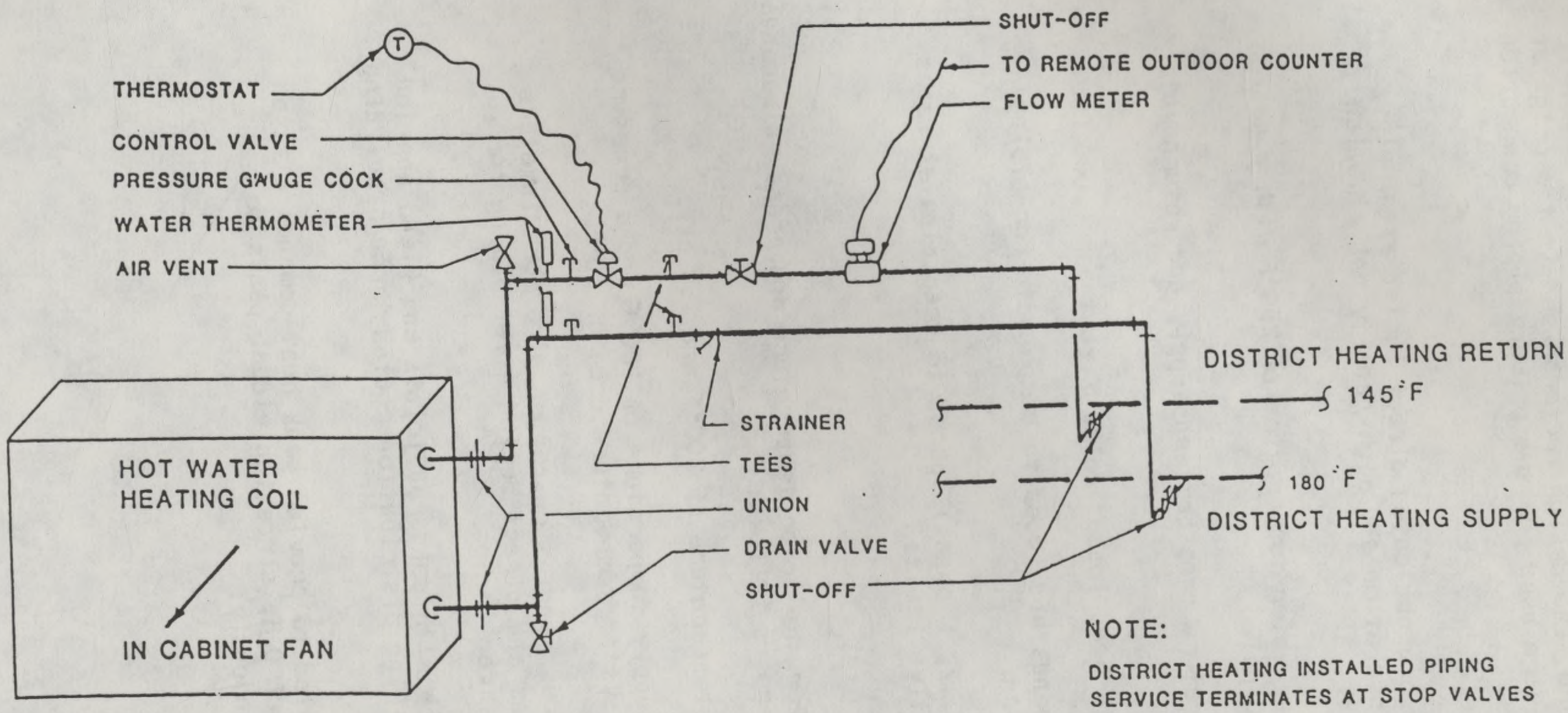
1. A system design temperature of 200°F and 150 psi.

2. An operational supply temperature of 180°F and a pressure of 75 psi and a system temperature drop of 50°F.

3. Flexible continuous lengths of copper pipe for diameters under three inches and direct buried steel piping for diameters above three inches.

4. Use of copper pipe with soldered joints and field applied insulation for piping distribution routed through building basements.

5. Pipe size calculated to provide peak heat demands with a diversity factor of 0.8, since individual peaks do not occur simultaneously.



TYPICAL CABINET FAN INSTALLATION

MOUNT AIRY HOMES

DHDC

Figure 2

The scope of the downtown project justified DHDC's use of a qualified construction management team to support the work. The team consisted of a construction manager, an experienced field engineer, a draftsman, clerical staff, and quality control personnel, all of whom were located in a field office. These services were provided by Metcalf & Eddy/FVB, Inc., the system's design engineer. DHDC also provided a full time quality control person.

Traffic and utility congestion were not a concern when DHDC planned construction in the Mount Airy homes residential area adjacent to downtown St. Paul. Although the piping cost of the Mount Airy project was much less than the downtown project ($1.8 million versus $23 million), the project used almost 50 percent of the length of the piping used downtown. On the average, the piping was much smaller in diameter and was installed under sidewalks and in grassy areas.

Other major factors that differed from the downtown experience were the higher number of services to be installed (298 versus 100) and the higher percentage of distribution piping that was actually to be installed inside the buildings. DHDC was concerned about the residents' privacy and safety, and it was important to gain the respect of the residents and the community. The residents' co-operation was needed for DHDC to meet project costs and schedules. A communication program (described in a later section) was established by DHDC to deal with these issues.

To keep the Mount Airy construction management costs proportionate to the cost of the project, the staffing needed to be at a minimum. Metcalf & Eddy/FVB assigned an experienced field engineer to inspect and to manage the project. Technical support was provided only on an as needed basis. DHDC's management team had a full time role in communication and coordination with the residents, the PHA, the contractor and the city of St. Paul.

The Contract

The Mount Airy contract contained complete design drawings and specifications and was competitively bid by three local contractors. NewMech Companies, Inc. of St. Paul was awarded to contract.

The project was bid in May, 1985, and the contract was awarded in June. To meet the heating needs of the Mount Airy residents, the contract required that the district heating system be operational by October 1, 1985. In addition, the contractor was to schedule and complete the piping work inside the building units prior to arrival of the PHA's building heating system conversion contractor.

The contract required the contractor to provide labor and other services to install the piping. The piping, valves, and fittings were supplied by DHDC. The contract's format used unit-prices for the payment of and then broken down into subcategories such as excavation, pipe installation, insulation, backfilling, and restoration. This breakdown allowed for changes at a known price because of unknowns associated with underground piping installation.

The substation, which is above ground, represented a low risk to the contractor, and therefore was bid as a lump sum. The bidding format shared the risks of the unknowns between DHDC and the contractor, and it ultimately resulted in a lower project cost.

Pipe Trench Excavation

The Mount Airy site is extremely hilly, with sandy soil conditions covered by thin top soil to support the grass. These conditions were both good and bad for excavation. The sandy soil was very easy to excavate and was suitable for reuse as backfill. Initially the trench-side stability was not a problem because of the shallow trench depth required by the 24-30 inches of pipe cover. The hilly terrain combined with heavy summer rains, however, eroded the trench walls and required significant re-excavation. The contractor also contributed to the re-excavation problem by opening more trench than was necessary to efficiently install the piping. The digging was easy, and, initially, the consequences of having extra open trench were not apparent.

The time required to install and test the piping was underestimated by the contractor and many open trenches were exposed for up to eight weeks to the elements and the playful children of the area. A significant number of manhours were required to dig out the piping and clean it up for welding and insulation at the joints. Fences and warnings could not keep the children in the area from using the trenches as elongated sandboxes. This also required significant trench re-excavation and removal of rocks from the piping.

The excavation contractor's experience with installation of underground utilities for water and sewer piping was not completely transferable to district heating pipe. Water and sewer pipe is laid, joined, and backfilled for each day's installation. District heating pipe requires welding, testing, joint insulation, and assembly before backfilling.

The pipe must therefore remain accessible for a longer period of time than the water and sewer pipe and the excavation schedule must be adjusted accordingly. It is important, however, to excavate "ahead" in areas of known or suspected utility interferences. Early identification of interferences or other problems permit timely corrective actions.

The contractor used a small backhoe for excavation, which was especially efficient near the housing and in the back yard areas. Manual excavation was used on very steep hills and in a few areas where obstacles made use of the backhoe impractical.

Work Inside Housing Units

The design required that the copper distribution-system piping be installed through each of the multi-housing unit buildings. The piping entered the basement at one end of the building, and the pipe was then installed through the separate walled basements of each unit and out the far end of the building. Only two outside building wall penetrations were required to service up to six housing units. Individual service lines were valved off in each unit.

To install the pipe and services, the contractor required numerous entries to each housing unit basement. The work was performed as efficiently, safely, and neatly as possible. The contractor was required to clean up construction debris on a daily basis. DHDC and the contractor made special efforts to ensure the cooperation and respect of the tenants. The contractor hired a resident to communicate with the residents and resolve construction problems if they arose.

Project Communications

DHDC set up and carried out the traditional project communications programs that consisted of weekly in-house team meetings and periodic meetings with contractors, city inspectors, PHA staff, and utility personnel. DHDC's on-site personnel were in daily contact with the contractor's personnel.

DHDC also extended its communications program to the residents of Mount Airy. DHDC had made a commitment to respect the rights of its customers, and every effort was made to lessen the construction impact on them.

Initially, DHDC sent letters explaining the project to all the residents. As the project proceeded, DHDC sent project reports to the residents. To make sure that a home would be accessible to the contractor, DHDC sent a letter to the tenant well in advance of the expected entry. DHDC held large group meetings with the residents to explain the project and to answer their questions. Eighty percent of the residents are southeast Asian; therefore English and Hmong were used in both oral and written communications. Language and cultural differences had to be dealt with to enable the project to progress smoothly.

As a part of DHDC's comprehensive communications program the contractor's workers were given numbered badges to identify them as part of the district heating project. The badges provided easy identification for entry purposes, and if there was a problem, the resident could easily identify the individual(s) by their badge number. This program worked successfully. The residents cooperated fully, the contractor was not delayed, and there were no major problems.

Construction Schedule

The time frame for the project, from award of contract operational service to the Mount Airy residents on October 1 was four months. Visible piping progress was slow in the initial construction stages mainly because of the time required to establish working procedures with unfamiliar piping. Three individual piping manufacturers conducted training sessions with the contractor's personnel to ensure that installations were accomplished correctly. Follow up help was also available later during construction. The heavy spring rains caused some delay due to lost work days and trench re-excavation.

Material shortages caused some delay in specific areas of construction. The contractor in most instances was able to move ahead and come back when the material was available. The long lead time in transporting fittings from overseas was a major delay factor. Initially, all shipments were by sea and an order took from six to eight weeks for delivery. Later shipments of small items such as fittings were by air freight which required about a week to ten days. Clearing customs sometimes took longer than the actual overseas transportation time. Europeans traditionally take a holiday for the whole month of July, and during this period the pipe supplier is essentially shut down. Material must be shipped prior to holiday or there is a four week delay in shipping time.

PHA's heating-systems contractor was also on-site to connect the housing heating system after the district heating service was installed in each building. Good coordination by both contractors kept the work flowing smoothly. The district heating service was operational by October 1 and available to those housing units that required service. The complete district heating system was operational in November while the final building units were converted and connected in February of 1986.

CONCLUSION

The success of this project can be credited to the constant effort to make the most beneficial choices for building owners, tenants, and DHDC given the factors presented by the Mt. Airy project. Situational factors such as initial construction and future operating costs, available piping and materials and the terrain of the Mt. Airy area itself all effected the creation of the project's design.

The construction experience was influenced by the learning process which both the contractor and DHDC underwent. The contractor was introduced to the important differences in installation of sewer piping as compared to district heating piping. DHDC experienced the process of doing their own purchasing so the right materials were available at the right time; a valuable experience for future projects. Construction efforts were also affected by the DHDC's committment to respecting the rights of the residents of Mt. Airy and maintaining effective communication with all personnel involved in the project.

A successful project itself, the construction of a district heating system to the Mt. Airy community provided DHDC with valuable experience for future district heating systems for the residential areas of St. Paul.