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PROCEEDINGS

Northwind Houston District Cooling
System Development

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ABSTRACT
The Northwind Houston limited partnership was formed in February 1997. Since that time, central plant and distribution piping system design and engineering have been completed for the first phase of the new district cooling system. The construction for the first central chilled water plant began June 1, 1998 and construction of the first underground piping began in July 1998.

The first central plant called the Union Station District Energy Center will have an ultimate capacity of 33,000 tons of cooling including 88,000 ton-hours of external melt ice-on-coil storage. The construction is nearing completion in the support of supplying chilled water to the new Astros baseball stadium for the year 2000 season.

Relative to the underground distribution piping system, approximately 5,000 trench feet of 24" diameter and larger piping has been installed connecting the plant to the new baseball stadium and other high-rise buildings in the Houston downtown business district.

The purpose of this paper is to provide cooling conference attendees with an overview of the plant design, the construction techniques involved, and the challenges faced by the Northwind team in getting the plant and the piping constructed in a fairly short time schedule. The majority of the presentation will be based upon slides of the physical construction activities as they progressed over the 14-month period of completion.

Kattner/FVB of Minneapolis has been involved with the Houston district cooling system development since the very beginning (November 1996) of the business analysis. They have continued to support the endeavor by preparing the conceptual system design and acting as the owner's engineering consultant.

KEYWORDS
Construction Status, Central Plant, Thermal Storage, Underground Piping

INTRODUCTION

Business Overview

The partnership between Reliant Energy (formerly Houston Industries, Inc.) and Unicom was officially established on February 7, 1997 resulting in the formation of Northwind Houston L.P. The affairs of the limited partnership are managed by its members Unicom Thermal Technologies (UTT) and Reliant Energy Thermal Systems (RETS) of which RETS is the controlling member. UTT and other Northwind affiliates have developed successful district cooling operations in Chicago, Boston, Las Vegas, Windsor and Toronto, Canada.

Northwind Houston L.P. was chartered to develop district energy services for the Houston central business district (CBD) along with other site-specific projects which may be developed in the future. The Houston CBD is a good candidate for development of a district cooling business because of the concentrated demand for air-conditioned office space during Houston's long, hot summers. In addition, the Houston CBD has many buildings with aging equipment and face near-term decisions regarding CFC phase out and chiller replacement.

The business model for the Houston CBD assumes an ultimate system load of approximately 80,000 tons of chilled water cooling provided by 3 production plants linked together by an underground piping distribution system. The underground supply and return piping system will deliver chilled water at a nominal day-time production temperature of 34°F to the 35-40 expected customers. The Houston CBD production and distribution plan is depicted in Figure 1. Northwind Houston secured a franchise agreement from the City of Houston on October 30, 1997.

General Construction and Customer Status

The design and installation of the underground piping distribution system was divided into discrete phases to facilitate permitting by the City and competitive bidding by qualified contractors. The phases were also customized to reflect customer commitments for service and business cash flow and budgeting constraints. Phases A, B and C of the underground piping system have been installed which totals approximately 5,000 trench feet of piping varying in size from 36" to 24" diameter. Future distribution pipe installation will be based upon customer chilled water contracts.

The first central chilled water production plant, called the Union Station District Energy Center (or P-1) is nearing construction completion on a full city block located on the eastern edge of downtown. The initial plant capacity of 4,000 tons, produced by centrifugal chillers, went operational on July 22, 1999 in order to meet the initial cooling load for the new Astros baseball stadium. The remainder of the plant, including the screw chillers, external melt ice-on-coil storage and evaporative condensers is scheduled to be substantially complete by October 31, 1999.

The contracted load for the new baseball stadium is 8,500 tons with delivery required by March 1, 2000. Other contracted or letter of intent customers total approximately 7,000 tons as of mid-August 1999.The initial plant capacity being installed is 17,000 tons with the total plant capacity at full build-out of 33,000 tons. This capacity includes chiller production and ice storage capacity as will be discussed in more detail later in this paper.

DISTRIBUTION PIPING SYSTEM DETAILS

Basic Design Information

The district cooling distribution system is the network of piping, pumps, heat exchangers and controls linking cooling sources with cooling customers. Northwind Houston, working with its consultants, identified the existing and future building loads in the Houston CBD. Proposed plant locations and capacities were identified along with proposed customer locations and loads. The system hydraulics were modeled resulting in pipe sizing in support of a totally built-out system. One basic philosophy included in this process was the ability to serve any load from any plant allowing maximum reliability and redundancy within the final interconnected system. Kattner/FVB performed the hydraulic modeling for the totally developed system along with incremental models for various in-process phases of system development.

The piping system design parameters include the following:

1. Supply and return pipes of the same diameter.

2. Parallel pipes may run side-by-side or stacked.

3. Both open-trench and trenchless technologies were used in construction.

4. The City required a minimum of 5 feet of cover over chilled water pipes.

5. The system design pressure is 150 psig.

6. Hydrostatic testing at 225 psig was required with no leakage over a four-hour period.

7. Peak day supply temperature of 34° and return temperature of 54° F are expected.

8. Welded carbon steel pipe was preferred but internally restrained ductile iron pipe was also allowed.

9. Piping 18" and smaller shall be insulated with a minimum of 2" polyurethane with a protective jacket.

10. 24" diameter supply pipe shall also be insulated unless it has more than 20 feet of cover or is encased in grouted tunnels.

11. All piping will be protected from corrosion with exterior coating/jacketing and cathodically protected with sacrificial anodes.

12. Chilled water velocities were kept in the 10 to 14 fps range.

Downtown Houston streets are very congested from both vehicular traffic and underground utilities. Pierce, Goodwin, Alexander and Linville (PGAL), a local civil engineering firm prepared the detailed plans and profile drawings based upon surveys of surface features and analysis of existing city street underground drawings. Design routes and alignments are further complicated by a network of existing pedestrian tunnels which link many downtown Houston buildings. Unfortunately, the existing pedestrian tunnels do not have enough space for adding the large distribution pipes. All plan and profile drawings must be submitted for city and major utility approval prior to receiving a construction permit from the city.

The schedule for installation of various phases of distribution piping are driven by several factors. The customer contracts and business cash flows have already been mentioned. Another driving force in the Houston CBD is the Metropolitan Transit Authority's (METRO) plan and schedule for resurfacing many downtown city streets. These projects are partially funded by federal funds in support of improving mass transit and will take place over 4 to 5 years. The cost and difficulty of installing chilled water pipes after street reconstruction will be significantly greater than doing the work before. Tellepsen Industrial Corporation was selected as the owner's field representative and oversaw the field construction activities performed by contractors.

Construction Implementation

Both ductile iron and welded carbon steel piping have been used in underground piping for the distribution of chilled water in district cooling systems. Northwind Houston's request for proposals (RFP) asked for unit pricing for welded carbon steel as the base bid and restrained ductile iron as the alternate bid. In response to the RFP, the low evaluated bid contained unit prices for restrained ductile iron piping being approximately $75 to$100 per trench foot less expensive than welded carbon steel. While properly installed welded carbon steel is generally more reliable than ductile iron, the additional premium for welded carbon steel was not justified for approximately 2,000 trench feet for Phase A of the distribution system. The decision was made to go forward with the restrained joint ductile iron system.

As a cost-savings measure, the selected contractor proposed a hybrid ductile iron/carbon steel approach. Because of the Houston street underground congestion, the McKinney Street design required deep tunnel crossings at street intersections and more shallow open cut installation between intersections. This design requires many changes in pipeline elevation requiring many additional fittings.

Ductile iron 45° and 90° fittings are very expensive in the 24" to 30" diameter and also require a long lead-time to supply from the manufacturer. The contractor suggested an approach where the pipeline would transition from ductile iron to carbon steel at the riser/downcomer sections of the pipeline. This would require a custom field weld for proper length and also necessitates the use of gasketed flange connections between each section of ductile iron and carbon steel pipe. This proposal was reviewed and accepted as a method of construction that would expedite the work and reduce costs. The contractor did not identify any concerns or reservations at the time of their proposed technique.

The contractor proceeded with the installation of vertical shafts and tunnels at each major street intersection along Phase A's route in parallel to procuring material and valves. Approximately one-half of the piping required pre-insulation which had to be considered in the project scheduling due to pre-insulation lead-time.

The contractor utilized local boring and tunneling subcontractors to install the shafts and the tunnels. Shafts were either round liner plate or rectangular beam and lagging designs depending on size and depth required. Figure 2 shows a typical shaft plan view. The tunnels between shafts were hand excavated wood-box tunnels utilizing 3-inch thick oak timbers to hold the tunnels open for installation of chilled water pipes. Most of the tunnels allowed for pipes to be stacked one over the other although some situations required tunnels to be side by side.

Figure 3 shows a typical cross section of the wood box tunnel for the stacked configuration. The stiff clays in the local soil make the installation of the wood box tunnels practical in Houston. Tunnel progress varied from 12 to 15 feet per day with removed soil being transferred by small carts to the shafts for removal via dump truck at the surface.

The use of flanged connections between the ductile pipe and carbon steel pipe at the risers and downcomers proved to be troublesome. The contractor experienced leaks at each flange connection requiring re-work in order to pass the hydrotest requirement of minimal leakage at 225 psig for four hours. On Phase B of the underground piping system, flanges were avoided at all places except for valves. Hydrotesting was also delayed on that phase due to a leaking ductile iron 45° fitting that proved difficult to find due to deep burial. Phase C of the system was all welded carbon steel, which did not experience any difficulty in passing the required hydrotest.

Lessons Learned

The following "lessons learned" were gained from the street piping installed to date:

1. Underground flange connections should be avoided when possible.

2. Flange connections must be properly fit-up to minimize leakage.

3. Full-face neoprene gaskets can be used with B7 studs. Neoprene ring gaskets can be used with A307 grade B bolts.

4. Care should be exercised in bolt-up procedures to avoid cracking grey-iron valve flanges when using B7 studs.

5. Frequent transitions from ductile to steel requiring numerous flanges should be avoided.

The installed cost of the piping system including material has ranged from approximately $900 to $1500 per trench foot depending on the construction techniques used, i.e., mostly open cut to mostly tunneled.

CHILLED WATER PRODUCTION PLANT DETAILS

Basic Design Information

Twenty-six (26) different plant configurations were investigated on a life cycle cost basis in order to establish the present plant configuration as schematically shown in Figure 4.

The first central cooling plant consists of screw and centrifugal compressor/chillers, an 88,000 ton-hour thermal ice storage system, cooling towers, heat exchangers, primary and secondary pumping systems, and all necessary auxiliary equipment. The peak instantaneous cooling capacity will be 33,000 Tons. Ultimately, there will be several plants interconnected through the distribution system with the design intent that any plant may serve any customer for added reliability and redundancy.

The Union Station Plant capacity can be divided into three basic categories each providing approximately 11,000 tons (peak hour) of chilled water capacity:

1. Centrifugal chillers
2. Rotary screw chillers
3. External melt ice-on-coil thermal storage

More details as to how the central plant systems operate are provided in the following discussion and depicted in the flow diagram shown in Figure 4.

1. Water Chilling System:

   Water is designed to be returned from the distribution system through the water chilling system or directly into the storage discharge system. The water chilling system will be hydraulically decoupled from the distribution system.

The water chilling system includes ten primary pumps that serve either a rotary screw compressor/chiller package or a centrifugal compressor/chiller package. The centrifugal chillers are rated at 2,000 tons each and utilize R-134a as the refrigerant.

Design Parameters:

- Chilled Water Entering Temperature 54°
- Chilled Water Leaving Temperature 40.3°

2. Glycol Chilling/Ice Build Systems:

Ice will be built on coils that are arranged in a large tank, open to atmosphere, and filled with water. An aqueous solution with 25 percent glycol by weight, is circulated within the coils to allow for ice to be built on the outer surface of the coils.

Five pumps are connected to a common header and will circulate the glycol solution through five heat exchanger packages. The heat exchanger packages are a part of the rotary screw compressor/chiller packages discussed in the Refrigeration System section. The supply line serving each thermal storage coil stack includes a remotely operated isolation valve allowing for selective ice building.

3. Storage Discharge Systems:

Water from the distribution system may be diverted to the thermal storage tank by control system action that opens the selected tank feed control valves. This will normally occur when 34°F distribution system supply water is required.

The temperature of the water entering the thermal system storage tank is controlled by operation of the water chilling system. During periods of combined water chilling system and storage discharge system operation, the tank effluent temperature is controlled via adaptive algorithms. The distribution system supply water temperature can be re-set through the control system.

There are multiple ice melt sections within the thermal storage tank; each served by a feed control valve. Water in each section will be drawn through a tank effluent pipe and connected to the tank bypass line in the distribution system ahead of the distribution system pumps. During storage discharge system operation, the temperature of the water supplied to the distribution system is controlled by mixing tank effluent with tank bypass flows.

4. Refrigeration Systems:

The rotary screw compressor/chiller manufacturer provided the compressor, motor, evaporator surface, refrigerant vessels, oil cooling and circulation equipment, interconnecting piping, safety relief, and specific refrigeration system control components. Those components are factory packaged to minimize field refrigeration piping. HCFC-22 refrigerant is used in the screw chiller system. The screw chillers were rated at 2,500 tons each for chilled water production or 2,000 tons each for ice production.

Evaporative condensers were selected for maximum heat rejection requirements at 80°F ambient wet bulb. Condensers are located on the roof of the building to serve the rotary screw compressor/chiller packages by way of a large common liquid refrigerant receiver tank.

5. Condensing Water System:

   Condenser water is distributed to the heat exchangers that are part of the centrifugal chiller packages via five horizontal split case pumps arranged on a common supply and return header. Cooling towers are located on the roof of the building to serve the centrifugal compressor/chiller packages.

6. Plant Control System:

   The control system design provides the following:

   - Minimize the number of operating personnel needed for operation of the system by providing automated plant, distribution system pumping, and customer controls from a central location. This includes automated control of the distribution system supply pressure and plant loading based on current and forecasted weather conditions.

   - Provides information from each plant and customer to a central location for business level analysis such as determining system performance and providing input for customer billing.

7. Control System Architecture:

   The district cooling system utilizes industrial microprocessor based control system and field devices. The control system incorporates distributed controllers to achieve the above stated goals. The hardware and software was selected to support control functions for up to six (6) district cooling plants incorporating thermal energy storage and for up to sixty (60) customers located throughout the downtown Houston area.

   The control system provides for the ability to monitor and control each plant and customer Energy Transfer Station (ETS) from a central location at the Union Station Plant. The control system employs a fiber optic data highway communication network to interface the cooling control system with each ETS and cooling plant. Operator interface to the control system is provided by personal computer based workstations. The number of workstations is dependent upon the complexity of the cooling system as well as the number of ETSs and remote cooling plants in operation; however, in no case shall the loss of one workstation affect the operation of the cooling control system. The system is capable of trending and performing historical data storage in a retrievable format. The control system hardware was selected to allow for isolated control system inputs and outputs and redundant controllers and power supplies in critical areas to maximize control system availability.

The district cooling system employs a flow and supply water temperature strategy that will vary both parameters based on outside temperature and load demand. The central plants incorporate thermal ice storage to lower the supply temperature and further optimize the district cooling distribution system. Usually, each customer is connected to the distribution system indirectly through an Energy Transfer Station (ETS). A modulating control valve located on the distribution system side (Northwind side) of the customer connection controls the actual load delivered to each customer by way of the plate and frame heat exchanger. After energy transfer, the higher temperature chilled water is returned to the central plants via return piping for re-cooling and re-distribution.

Construction Implementation

As previously mentioned, Kattner/FVB prepared a conceptual design description issued as the Owners Requirements Document (ORD). This document was issued with the owner's request for proposal to a list of several pre-qualified local architect/engineering firms. After evaluation of proposals the detailed engineering contract was split as follows:

1. Carter-Burgess, Inc.
   - Architectural
   - Plumbing
   - Fire protection
   - Civil
   - Structural
   - Landscaping
   - Construction administration

2. Shah, Smith & Assoc.
   - Mechanical
   - Electrical
   - HVAC
   - Controls (via Intellex)

Detailed engineering and design progressed through the typical phases of studies, schematic design, design development and construction documents.

The selection of a construction team was held up pending the final selection of a chilled water supplier to the new Astros baseball stadium. Upon the selection of Northwind Houston as the provider, the construction team had to be quickly selected since the ballpark required service within 16 months. This short duration required a fast track approach.

Northwind Houston negotiated a guaranteed maximum (GMAX) contract with Tellepsen Corporation to serve as the general contractor. Other primary sub-contractors were also selected based upon previous work experience with Reliant Energy. Since engineering was still in the schematic design phase, the GMAX target was not finalized until later in the design effort. A budget estimate was established and refined at each engineering package issue, i.e. schematic design, design development, etc. The construction team and the engineering team participated in value engineering jointly as the design proceeded.

The site selected for this first chilled water production plant was a full Houston city block measuring 250' by 250' to the property lines. The original plant arrangement was revised to utilize most (80%) of the site footprint allowing the plant overall height to be reduced. Demolition of the existing surface parking lot began approximately June 15, 1998. Previous historical record searches and soil sampling had indicated the presence of low-level soil contamination from previous site businesses such as a filling station and an auto repair garage. Most of the existing soil removed from the site was trucked to a low-level landfill as a precautionary measure. In addition, four unregistered hydrocarbon storage tanks were located requiring special removal. Approximately twelve underground brick cistern type storage tanks were also discovered with the largest being approximately 20' deep. These had to be removed and flowable fill installed for proper soil bearing. The unknown site conditions delayed the early construction by four to six weeks.

The engineering and construction team had selected a reinforced concrete building structure with each load-bearing column supported by spread footings. The foundation below the ice storage tank was designed as a 4' thick concrete mat, which extends beyond the tank walls. The walls themselves are 3' thick concrete extending up approximately 38' above tank bottom. The tank was constructed with a divider wall dividing the tank in half with each side holding approximately one million gallons of water. The tank weight was a concern due to settlement as the tank was constructed and filled. Both sides of the tank will be filled with water at the same time to prevent tank tilt. The inside walls of the tank were insulated with spray-on urethane foam (nominal 2" thick) with a 60 mil thick spray-on waterproofing.

Intermediate floors and the building roof were poured concrete using pan deck construction techniques. The plant grade slab was thickened to 21" in the load bearing areas under the centrifugal and screw chiller skids. The majority of the building concrete had to be poured before mechanical and electrical installation could start since the floor and roof decks had to be supported from scaffolding off the plant grade slab. Based upon this critical path and the actual construction progress, the first pipe was not hung in the plant until February 19, 1999.

In an effort to save time and to parallel activities, Northwind Houston elected to pre-purchase the following major equipment:

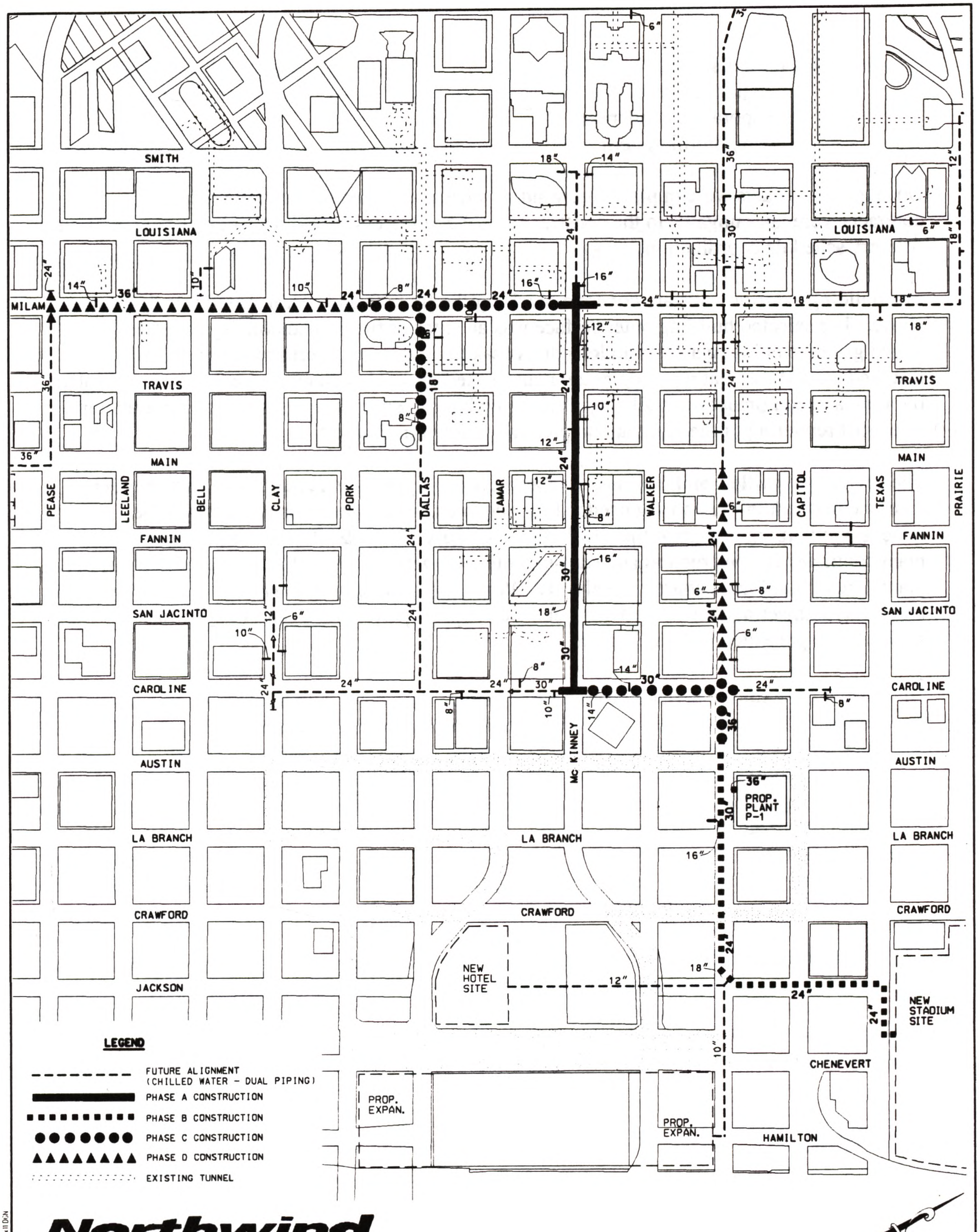
- Centrifugal chillers
- Rotary screw chillers

- Ice coils
- Cooling towers
- Evaporative condensers
- Plant control system

Once these contracts were in place, the vendors were authorized to start fabrication. The contracts were later novated to the construction subcontractors including progress payments and delivery schedule coordination.

The building exterior walls are concrete block for the first 20' and double thickness dry wall above. The selected building outer surface was an exterior finish insulating system (EFIS), which gave the building a uniform look at a cost-effective price. Perforated screen walls were installed around the heat rejection equipment located on steel grillage above the roof. The plant building and equipment meet all City of Houston building permit and inspection requirements. The artist rendering of the plant at completion is shown in Figure 5.

The centrifugal chillers and their required auxiliary equipment were started up first in order to meet the ballpark initial cooling needs. Forty degree chilled water was pumped via the underground piping system to the new ballpark on July 22, 1999. The ice storage part of the plant continued in construction and start-up until October 31, 1999. The budgeted cost for the plant at total buildout is approximately $1250/ton. At the time of this writing, the plant was well on its way to meeting that goal. More details as to plant performance and final actual cost will hopefully be presented in future papers.



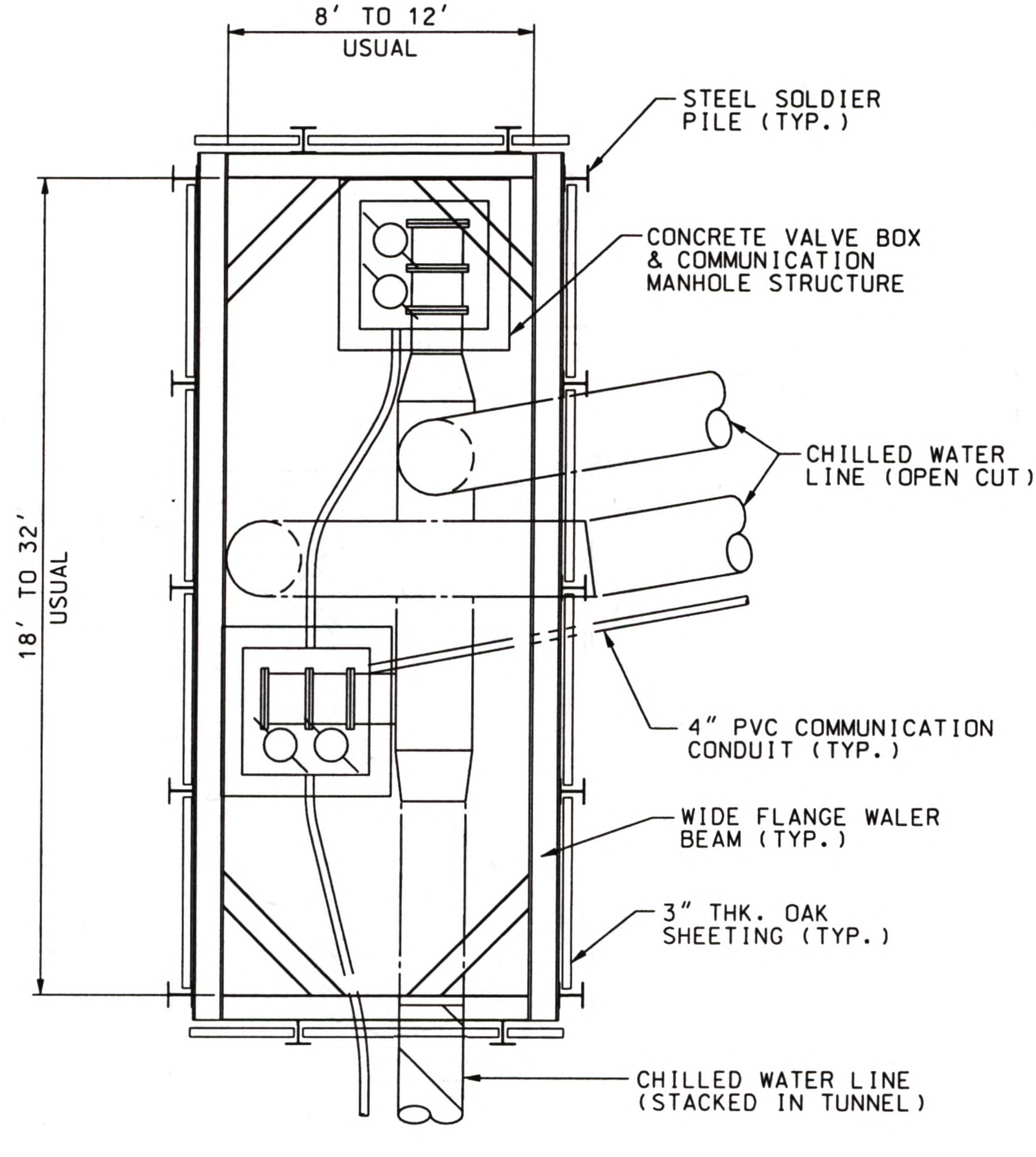
LEGEND

FUTURE ALIGNMENT (CHILLED WATER - DUAL PIPING)
PHASE A CONSTRUCTION
PHASE B CONSTRUCTION
PHASE C CONSTRUCTION
PHASE D CONSTRUCTION
EXISTING TUNNEL

Northwind HOUSTON

DOWNTOWN DISTRICT COOLING DISTRIBUTION PLAN

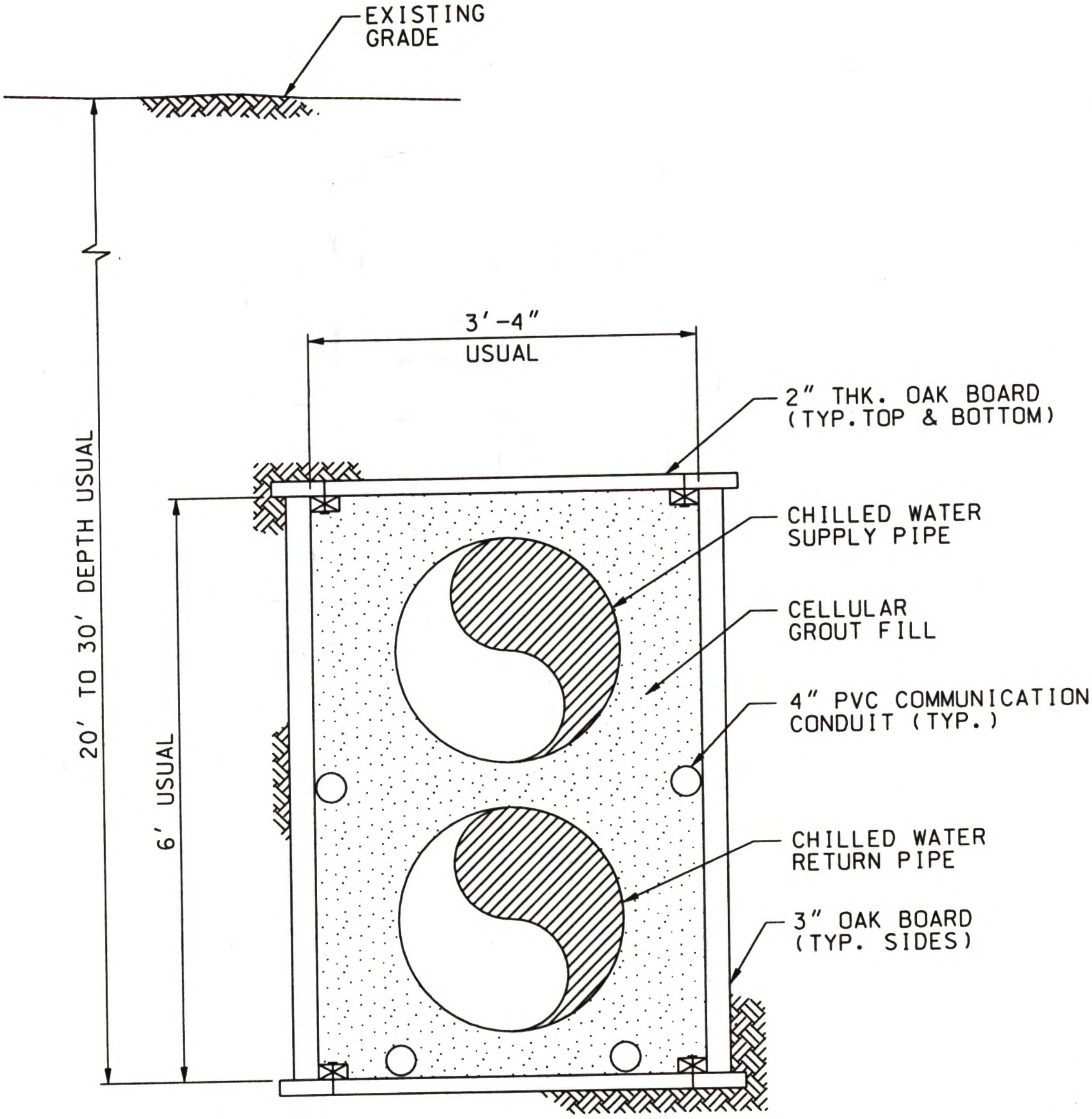
FIGURE 1



PLAN

TYPICAL RECTANGULAR ACCESS SHAFT FOR TUNNEL

FIGURE 2



SECTION

TYPICAL WOOD BOX TUNNEL

FIGURE 3

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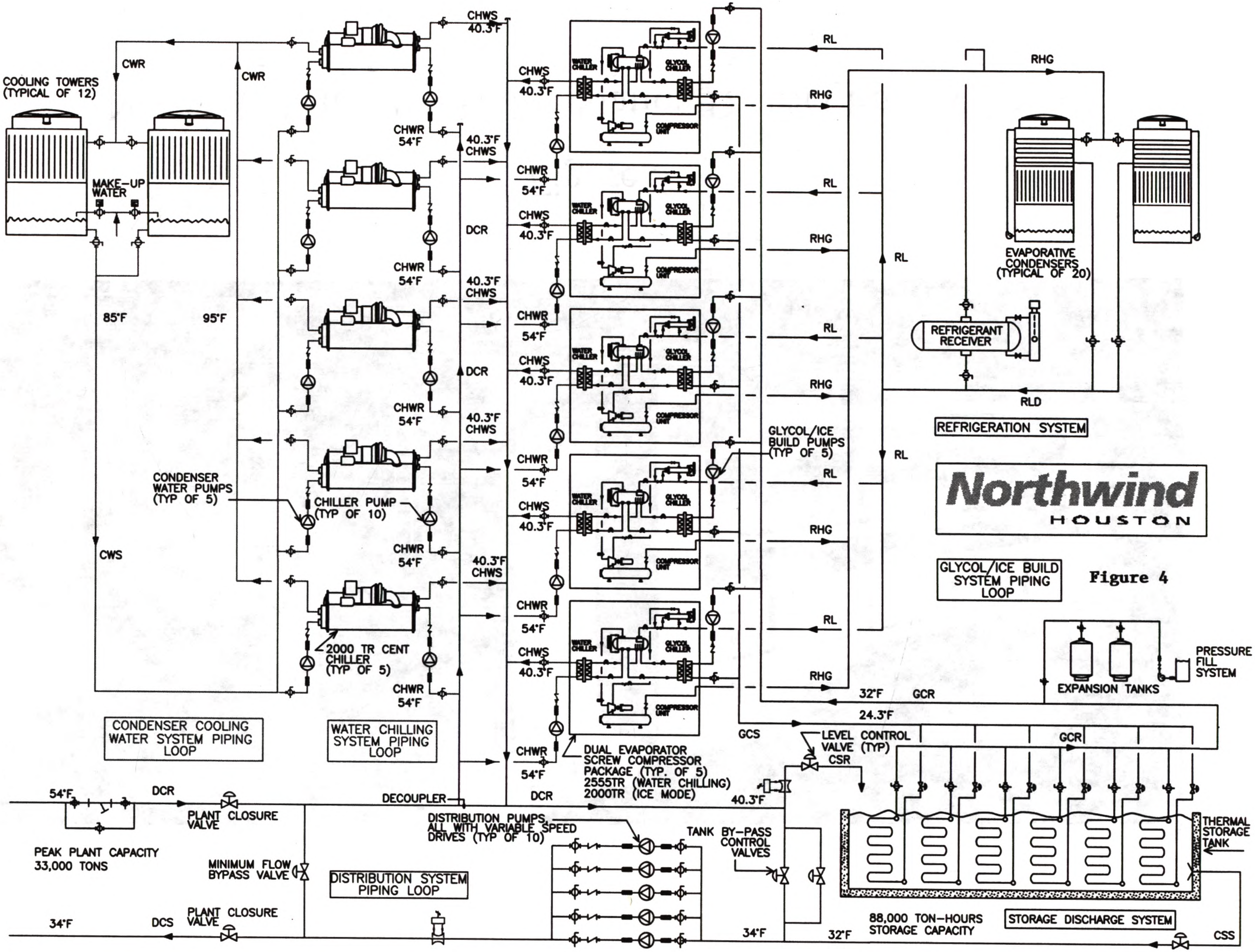
COOLING TOWERS (TYPICAL OF 12)
CWR
CWR
MAKE-UP WATER
85°F
95°F
CWS
CONDENSER WATER PUMPS (TYP OF 5)
CHILLER PUMP (TYP OF 10)
2000 TR CENT CHILLER (TYP OF 5)
CHWS 40.3°F
CHWR 54°F
40.3°F CHWS
DCR
CONDENSER COOLING WATER SYSTEM PIPING LOOP
WATER CHILLING SYSTEM PIPING LOOP
WATER CHILLER
GLYCOL CHILLER
COMPRESSOR UNIT
DUAL EVAPORATOR SCREW COMPRESSOR PACKAGE (TYP. OF 5) 2555TR (WATER CHILLING) 2000TR (ICE MODE)
GLYCOL/ICE BUILD PUMPS (TYP OF 5)
RL
RHG
RLD
REFRIGERANT RECEIVER
EVAPORATIVE CONDENSERS (TYPICAL OF 20)
REFRIGERATION SYSTEM
Northwind
HOUSTON
GLYCOL/ICE BUILD SYSTEM PIPING LOOP
EXPANSION TANKS
PRESSURE FILL SYSTEM
32°F
GCR
24.3°F
GCS
LEVEL CONTROL VALVE (TYP)
CSR
54°F
DCR
PLANT CLOSURE VALVE
DECOUPLER
DISTRIBUTION PUMPS, ALL WITH VARIABLE SPEED DRIVES (TYP OF 10)
TANK BY-PASS CONTROL VALVES
40.3°F
THERMAL STORAGE TANK
PEAK PLANT CAPACITY 33,000 TONS
MINIMUM FLOW BYPASS VALVE
DISTRIBUTION SYSTEM PIPING LOOP
34°F
DCS
PLANT CLOSURE VALVE
34°F
32°F
88,000 TON-HOURS STORAGE CAPACITY
STORAGE DISCHARGE SYSTEM
CSS

Figure 4

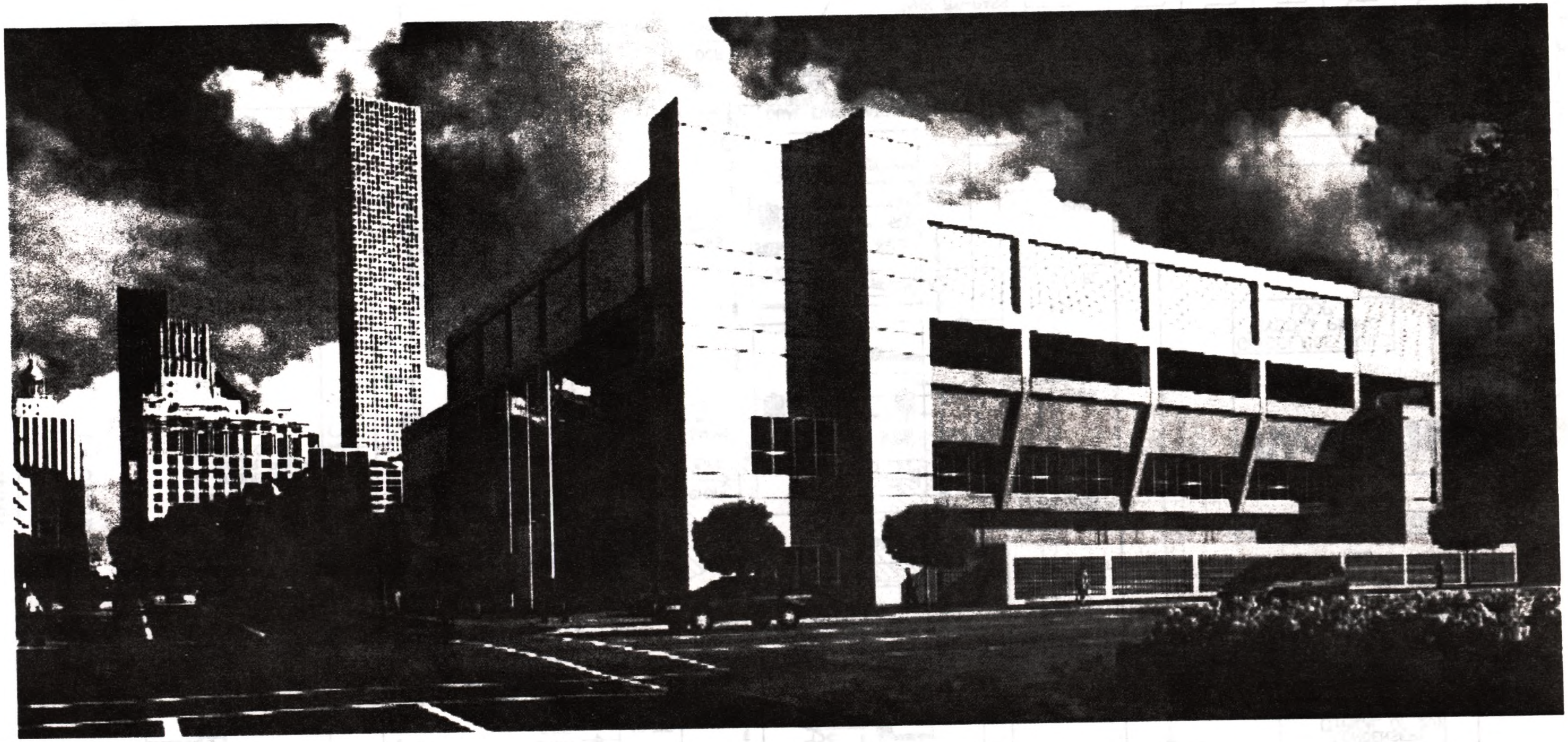

Figure 5

Northwind Houston Union Station District Energy Center