University of Wyoming, Laramie

Chilled Water Utility Development Plan

Job Number: 0003.00

Report Date: 5/18/00

GLHN
ARCHITECTS & ENGINEERS

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I. Executive Summary

Buildings on the main campus of the University of Wyoming in Laramie have been heated and cooled from central utility production and distribution systems for over forty years. Major improvements were made to these systems in 1980, when a Central Energy Plant (CEP) heating and cooling plant with new distribution lines were constructed at the North of campus. The construction provided two new 500 Ton water-cooled water chillers and 14" mains to the heart of campus.

A number of operational problems, related to chilled water flow dynamics have developed over the ensuing years. Piping configuration and coil controls require flow rates substantially higher than the chillers and piping systems were originally designed for. Equipment design currently precludes use of the primary heat sink in the winter time, limiting the ability of the system to handle unseasonable weather or dissipate internal loads. Campus cooling loads are increasing as a function of both building expansion and more intense application of internal heat generating equipment, particularly computer and laboratory equipment. Although the plant and piping systems are in excellent condition, the plant chilling equipment is approaching the end of its useful life. One of the two original chillers was replaced in 1996 and the second, a CFC R-12 machine, is in near-term need of replacement.

In an effort to find solutions to the many related chilled water problems, and to plan for inevitable load and campus growth, the University commissioned the Architectural Engineering firm of GLHN Architects & Engineers, Inc. to evaluate the campus systems and prepare a development plan for the central chilled water utility. This report summarizes the analysis, and provides a set of corrective actions and implementation phasing plan.

The essential elements of the plan for the Central Energy Plant include replacement of the second of the original chillers, installation of a new cooling tower, optimized for lower condensing temperatures and capable of winter operation, and conversion of the plant pumping scheme to a direct primary, variable flow configuration. Much of this work should be done in the near to mid-term. Improvements to the distribution system include removal of existing pumps and decoupler bridges or "bridles" and replacement of existing three way valves with two-way valves. This work may be completed over a longer time frame provided it is begun on the buildings with the largest loads in the near term. High temperature differential coils with two way control valves should be specified for all future construction, and evaporative cooling techniques considered for high outside air laboratory building air handling systems.

Proximity to high quality coal reserves provides the University of Wyoming with a remarkably inexpensive source of input heat energy, compared to other campus facilities in the Rocky Mountain region. On a relative basis however, electric energy is also low, and the economic comparison of producing cooling with purchased electricity versus steam (as in an absorption chiller) heavily favors the electric alternative. Natural gas is currently priced at a level that precludes favorable comparison to either of the other fuel alternatives.

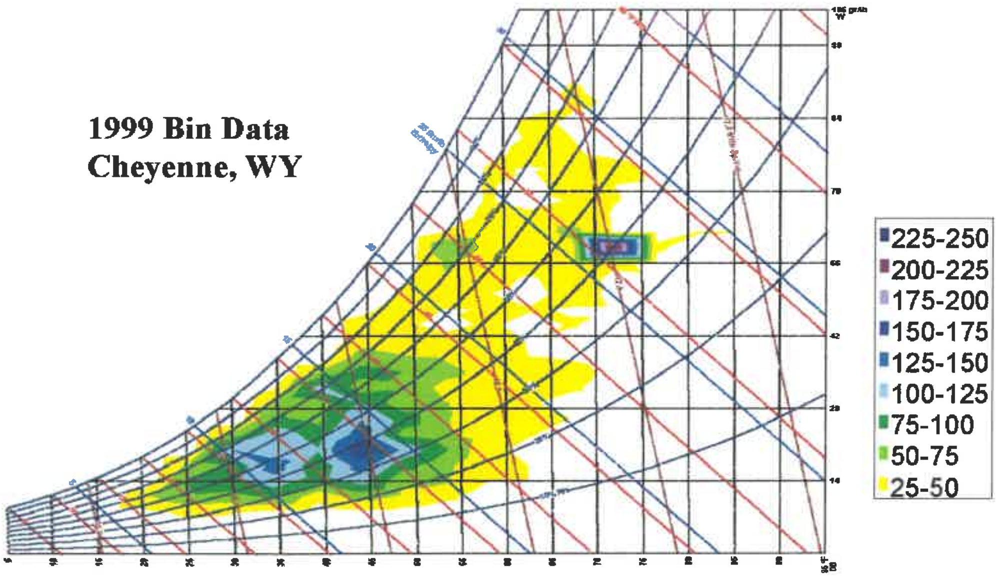
II. Description of Existing Conditions

A large portion of the campus of the University of Wyoming in Laramie is heated and cooled by the Central Energy Plant constructed in the early 1980's. In present operation, steam, for heating, is produced in coal fired boilers and distributed to campus buildings through a network of piping located in tunnels and buried directly. Cooling is accomplished by production of chilled water in electric driven centrifugal chillers. The chilled water supply, at 40°F, is pumped to buildings in a second distribution network of buried and tunnel piping. Pumps within the buildings draw chilled water supply from the distribution loop and pump through building air handler coils. Heat is extracted from the buildings by cooling the recirculation and ventilation air stream at the building air handlers to between 55 and 65°F, while warming the chilled water to between 45 and 50°F. The warmed water is drawn back to the Central Energy Plant by the distribution pumps and returns to the chillers. When the ambient dewpoint is low enough, the campus chilled water is routed through a Plate and Frame ("Flat Plate") type heat exchanger coupled to a set of cooling towers and campus heat is rejected to the atmosphere directly by means of evaporation. As the ambient moisture levels rises, the temperature at which evaporation occurs increases and electric driven vapor compression refrigeration must be employed to exchange heat from the circulating chilled water loop to a refrigerant circuit which is then condensed by the cooling tower water loop. Ultimately, in either mode, the campus heat is rejected out the Central Energy Plant cooling towers.

a) Weather and Loads

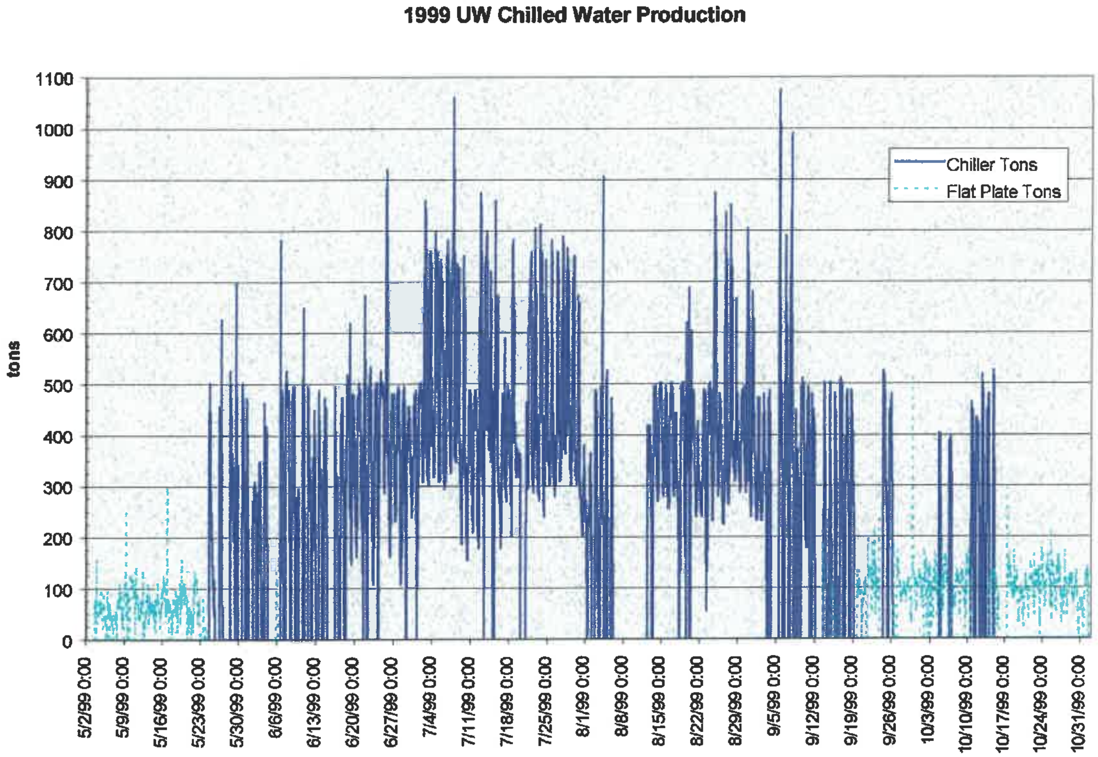
From a cooling perspective, ambient conditions in Laramie are mild. Weather data files are available in 15 minute increments from the NOAA observation site in Cheyenne, Wyoming. Although at a lower elevation and presumably somewhat warmer than Laramie, this data is helpful in understanding the qualitative nature of the cooling loads at the University of Wyoming.

Coincident ambient air wet bulb and dry bulb temperature bin data is plotted graphically in psychrometric charts (Appendix E). The annual chart shows the preponderance of temperatures lying below 40°F WB and 45°F DB.



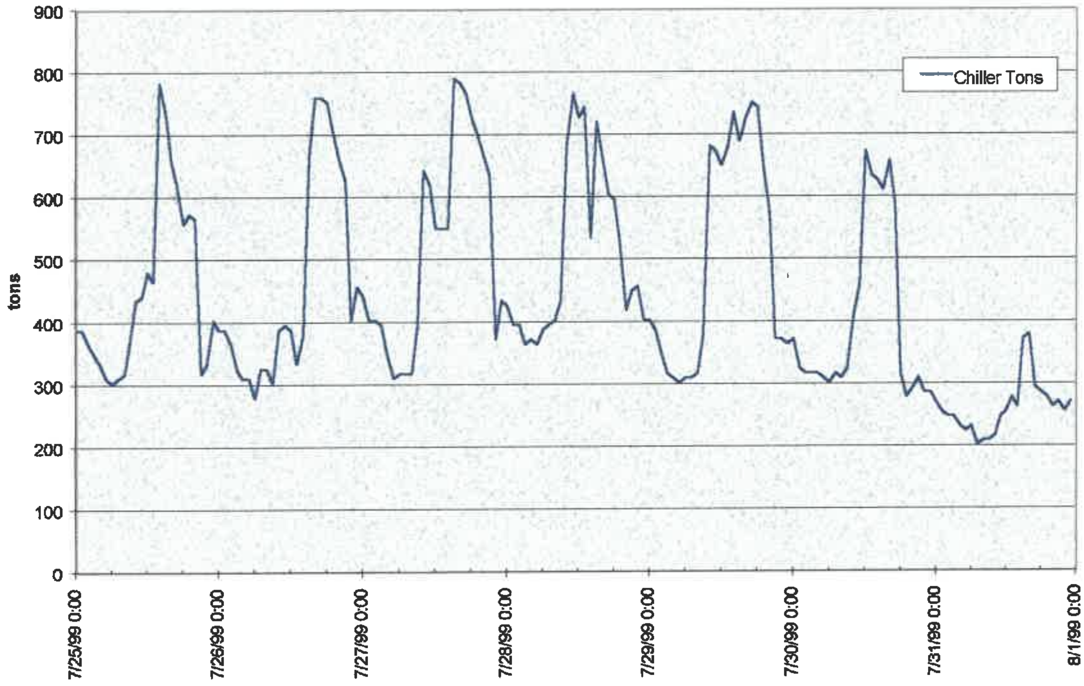
Charts for individual cooling months of May, June, July, August, September and October show outside air conditions translating up a line of constant relative humidity to reach extreme high temperature conditions of 95°F DB and 63°F WB by July and August, then sliding back down to dry bulb temperatures in the 50's by October.

Campus cooling load data, for 1999, is shown graphically below.



The cooling tower basins are filled with water from May to November and the system operated. Monthly Ton-hrs (TH) range from just over 50,000 TH in May to 330,000 in July. Typical daily cooling load data ranges from 200 tons to 1000 tons under peak conditions.

1999 UW Chilled Water Production



The long term projected peak connected load is 2370 Tons. No firm target dates have been established, although several hundred tons of additional load are anticipated in the next five years. Diversity in demand should be anticipated however, and a future connected load of 2370 probably corresponds to a future instantaneous plant peak load closer to 1800 Tons.

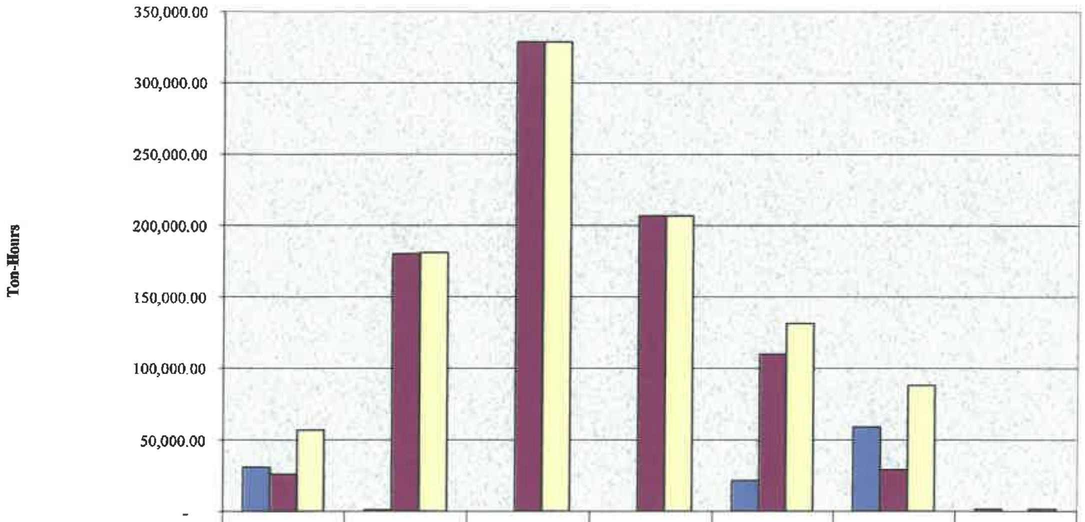
The three primary components of campus cooling at the University of Wyoming are outside air chilling loads, building envelope loads (solar radiation and conduction), and internal loads (lights, people and equipment). The ambient weather data demonstrates that outside air chilling, and building conduction loads are not significant prior to May and after November. The fact that daytime outside air temperatures reside below 55°F during this time suggests that ventilation and adequately-sized airside economizer cycles should be capable of compensating for much of the solar radiation and internal building load components.

The magnitude of internal load is increasing as a result of the proliferation of personal computers, heat producing laboratory and office equipment. To continue extracting internal heat the campus chilled water loop pumps continue to circulate even after the Central Energy Plant cooling towers have been deactivated for the winter. Heat picked up from building terminal loads (often environmental chamber compressors, or computer room fan coil units) is now dissipated from the piping system directly to the ground through conduction.

b) Central Energy Plant Operation

Operation of the primary equipment in the Central Energy Plant is shown graphically below.

1999 Cooling Monthly Ton-Hours



	May	June	July	August	September	October	November
Total Ton Hours Flat Plate=	30,581.91	728.49	-	-	21,456.03	58,945.82	1,525.88
Total Ton-Hours Chillers =	25,883.49	179,989.11	328,254.41	206,477.99	109,536.84	28,907.38	-
Total Ton-Hours =	56,465.39	180,717.60	328,254.41	206,477.99	130,992.87	87,853.21	1,525.88

The hydronic economizer (or Flat Plate) mode of operation can typically be employed in May, September, October and November. In this mode of operation, it is reasonable to expect a 3 to 4 degree approach between the ambient wet bulb and the flat plate chilled water supply temperature. In a properly designed and maintained system a 44°F wet bulb will yield 48°F chilled water; about the highest temperature sufficient to cool internal loads. Weather conditions prohibit operation of this mode in late spring when ambient wet bulb temperatures climb above 45°F.

Once the hydronic economizer is taken off line, one of two electric driven centrifugal chillers is staged on. Because of the design of the chillers, condensing loop, and the loop controls, there must be a time lag between these two events to allow the condensing water temperature to increase from the high 40's (plate and frame duty) to the low 70's (chiller duty). Steam heat is added to the sump to raise the temperature. Operationally, this lag limits the practicality of repeatedly toggling between the two modes for optimization. Once the plant is converted to chiller mode, it remains in chiller mode, regardless of the available dewpoint.

Both the flat plate heat exchanger and water chillers are hydraulically configured with primary-secondary flows. Single speed primary pumps circulate constant flow through the chillers. Leaving-water setpoint in both cases is controlled by valving on the heat exchanger, or by inlet vane positioning on the centrifugal compressors. The variable which changes with campus load is return (or entering) water temperature. Two distribution pumps may be staged on for secondary chilled water distribution to the campus. The pumps are sized such that the leaving water temperature from the plant should equal that leaving the chillers or heat exchanger. Although the system was designed for a net supply-to-return water temperature of 12 degrees, building interface conditions are such that 5 to 8 degrees are more often experienced. This low delta T means higher than anticipated flows per ton are experienced in the secondary distribution system, and it becomes difficult to fully load the constant flow chillers.

c) Fuel Costs

The University of Wyoming enjoys relatively inexpensive fuel rates compared to other areas of the country. Electricity in 1999 was purchased at $0.033/kWH (independent of time of year or peak demand), coal, to fuel the boilers was priced at an average of $2/MMBTU, and natural gas (for which there is currently little campus demand) at $5/MMBTU. A valid comparison of the relative price of coal versus natural gas for the purpose of steam production must account for the high electric demands associated with coal combustion in this plant. These include coal conveying systems (using compressed air), bag house filtration, recirculation and induced draft fans. The comparison is further complicated by the fact that much of the auxiliary electric load is insensitive to steam output, meaning the unit price of steam increases as production decreases. A detailed comparison between coal and natural gas in the Central Energy Plant is beyond the scope of this work.

Energy rates are expected to change in the near future. The University has been quoted a new electric rate from Pacific Power and Light. The new rate (Schedule 46) has the following components:

Service reduction of $0.30/kW for primary voltage over 11 KV
Demand Charge at $5.25/kW
Energy Charge at $0.02363/kWh
Reactive Power Charge of $0.60/Kvar

It is anticipated that this new rate structure will result in a 10-11% increase overall. Even so, electricity is a third to a half the cost experienced in other areas of the country.

The cost of steam using coal as the primary fuel may increase at some point in the future due to implementation of stricter air quality standards. The timing of this possibility is thought to be dependent on political conditions at the federal level. Local coal reserves are adequate.

d) Plant Chilled Water Production

Chilled water production at the Central Energy Plant is currently accomplished by a plate and frame type heat exchanger and one or two electric driven centrifugal chillers.

The plate and frame heat exchanger (see data attached) was originally designed to cool 1000 gpm of chilled water from 54 to 42°F with 1500 gpm of tower water at 40°F. This corresponds to 500 nominal tons of cooling. The original cooling tower design was based on water chiller duty however, with a much larger approach to the wet bulb. The best the existing cooling tower could be expected to achieve is about 150 Tons of heat rejection during plate and frame operation at ambient wetbulbs in the mid 40's. In operation, the unit can be run with tower water temperatures as high as 45 (meaning chilled water temperatures as high as 48°F) before deactivation. The general condition of the plate and frame heat exchanger is good.

Chiller #2 is a Carrier 19EB machine installed in the original construction in the early 1980's. This is a high pressure, open drive unit, charged with R-12. It was designed to produce 500 Tons with constant flow from 54°F to 42°F with condensing temperature of 80°F in, 90°F out. Condenser water flow was designed at 1500 gpm. Overall efficiency of units of this age and type is in the .80 to .90 kW/Ton range. Chiller capacity is regulated with inlet vanes by a proportional pneumatic controller. Seal leakage, particularly at the motor shaft is often a problem in these style units. The general condition of the Carrier chiller, which at 20+ years of age is nearing its design service life, is poor.

Chiller #1 is a McQuay PE-H machine installed, in 1995, as a replacement to the original chiller #1. This machine is high pressure, R-134 and direct drive. At design conditions, with 1800 gpm of condenser water from 70 to 80, this unit was rated to produce 1200 gpm of chilled water from 54/42 EWT/LWT, at a kW/Ton of 0.523. this corresponds to 600 Tons at peak conditions. Controls are electronic and direct digital and capacity control is by hydraulically operated inlet guide vanes. The general condition of the McQuay chiller appears to be excellent.

The cooling towers are concrete structures with ceramic block fill. The towers were originally configured to be dedicated to the chillers but modifications made to the piping during installation of the plate and frame allow various tower/chiller combinations. Variable frequency drives have been added to the tower fans for energy savings and capacity control. The condition of the cooling towers is good.

The original design duty of the towers (1500 GPM, 80/90, EWT/LWT at 60 WB) may not provide enough airflow or evaporating surface area to really meet the design duty of new chiller #2 (McQuay), which has a higher nominal capacity (600 Tons, 1800 GPM) at a lower design condensing temperature (70/80 EWT/LWT). It is doubtful that the towers could achieve an 8° approach at design conditions however. Actual operation at 75/85 appears more likely. This probably means that chiller #1 performance is derated to perhaps 500 Tons at a kW/Ton of more than 0.55. The more significant problem with these towers is the basin and inlet air geometry which promotes ice formation under cold outside conditions. This condition requires that the towers be shut down and drained in the winter. The central chilled water loop can then reject heat only through conduction to the ground and cannot respond to unseasonable warm snaps in late fall, winter and spring.

e) Distribution System

The piping is configured as a primary/secondary/tertiary network, with primary pumps of sufficient head to provide full flow at the chillers and heat exchanger, secondary pumps in the plant with head designed to overcome the distribution system losses, and tertiary pumps in the buildings with head designed to overcome coil and building piping losses.

The secondary pumps are vertical in-line style centrifugal type, rated to move 1800 GPM at 52 ft, with a shutoff head of 82 ft. The motors are 30 HP. There are two pumps, which can be operated in parallel. In practice, one pump is found to be capable of moving 1860 GPM at 51' while two units together move 2240 GPM at 46'. Distribution piping out of the plant to the center of campus is 14" diameter. With two pumps operating, 2260 gpm corresponds to a velocity of 4.5 fps and a friction pressure loss of 0.3 psi/100 ft. The general condition of the pumps and distribution piping appears to be good.

Load growth, combined with poor supply-to-return temperature differential, have increased the flow requirements in the existing piping. Velocities in main and branch lines are anticipated to increase, as new loads are brought on line, particularly at the west end of campus.

f) Building Air Conditioning and Process Cooling

Conditioning of buildings is primarily through cooling coils in central station air handlers and fan coil units. These units were typically installed with original building construction and connected to the chilled water distribution loop once the Central Energy Plant was completed. The coils are generally 4 row. Chilled water flow through the coils is controlled with a variety of three-way valving schemes. In general, balancing or flow control valves are employed to establish a constant flow rate to the unit. Pneumatic receiver-controllers in the leaving air stream send a signal to the valve actuator. Chilled water supply not needed to meet air handler demand is dumped or mixed back into the coil return water. Mixing of cold supply into the return water raises the net flow required per BTU of cooling and ultimately causes not only inefficiency but operational problems at the production plant. The general condition of the building air conditioning systems is fair, with pneumatic controls in reasonably good working order, and coils and filters reasonably maintained. Examination of the coil piping suggests high pressure drops were built in, in the form of multiple valves, balancing cocks, and flow control devices. It may well be possible to eliminate much of this parasitic loss without degradation of performance.

g) Building Interfaces

Building interface piping between the secondary distribution lines and the building chilled water lines are done (and show evidence of having been redone) in several ways. In two locations a plate and frame heat exchanger physically isolates the building water/glycol fluid from the campus chilled water loop. This is made necessary by building air handler design and outside air ventilation load. In general though, the intent has been to hydraulically decouple the building system from the distribution system by installing a bridge between the building supply and return lines before tying them to the main. In some cases check valves or balancing valves have been installed in the bridge, and in some cases multiple bridges have been installed. In all cases with decoupling bridges, mixing between cold supply and warm return water is allowed. This increase in entropy results in a lower temperature differential between supply and return at the plant, higher than necessary distribution flow rates, difficulty in fully loading chillers, and higher than necessary pumping energy. The general condition of the interfaces is poor, considering their energy inefficiency. The building pumps are largely original, with condition matching age of the building.

h) System Deficiencies

The following are noted as chilled water system deficiencies

Production

- Aging CFC R-12 open drive chiller in need of replacement
- Additional chiller plant capacity will be needed to meet near term load growth
- Original towers sized at 80/90 at 60 WB are not optimized for high efficient chiller duty
- Tower configuration requires steam and/or time to change over from economizer
- Tower configuration precludes winter operation
- Primary/Secondary constant flow pumping promotes mixing
- Summertime steam production at low load inefficient due to auxiliary demand distribution
- Mixing at building three-way coil control valves promotes 5 F dT
- Excessive pumping energy expended on parasitic pressure drops
- Multitude of interface configurations and tertiary pumps promote mixing to distribution

- No central control or monitoring of building flow or load
- Distribution pumps not capable of meeting anticipated flow or head requirements

III. Problem Statement

Survey and study of the central chilled water system at the University of Wyoming found a number of technical deficiencies as well as opportunities for operational and economic improvement. A development plan which corrects the immediate deficiencies while establishing the basis for long-term growth does not have to be implemented in one pass. The purpose of this study is to provide the groundwork for a long term plan; establishing long term goals and objectives as well as short term corrective actions.

In general terms, the plans goals and objectives are the following:

a. Technical Improvement
   1. Replace aging CFC chiller to eliminate operational and environmental problem
   2. Provide adequate plant cooling capacity to meet anticipated load growth
   3. Increase chilled water delta T to reduce flow/ton and extend capacity of existing buried pipe asset
   4. Transition to variable system and chiller flows for optimal load following and flow diversity
   5. Eliminate excess pumping to reduce maintenance and pumping hp/ton
   6. Improve chilled water production efficiency
   7. Improve chilled water reliability
   8. Improve winter heat rejection operation of system

b. Economic Improvement to help technical improvements
   1. Reduce energy and operating costs for pumping
   2. Improve chilled water production efficiency
   3. Allow for use of optimal fuel

c. Future Considerations
   1. Prepare for effects of deregulation
   2. Prepare for more stringent Air Quality Considerations
   3. Prepare for Campus and Load Growth

IV. Evaluation of Alternatives

a) Chilled Water Production

Three alternative chilled water production strategies, and one variation were evaluated. Comparison was made based on 1999 load data, with proposed electric rates.

Chiller Energy Cost Comparison

Electric Rate

$/kW=	5.25
$/kWh=	0.02363

Electric Centrifugal Chiller (McQuay)

Tons	kW/Ton	kW	hours	kWh	Cons. $
600	0.59	355.6	750	266700	$ 6,302
450	0.59	265.5	893	237091.5	$ 5,602
300	0.65	195.7	600	117420	$ 2,775
150	0.92	138.0	22	3036	$ 72
Total			2,265	624,248	$ 14,751

Cooling Tower	30 hp
CW Pump	33 hp
Total	63 hp
Total	47.0 kW

	Chiller	Auxiliaries	Total
Demand (5 months)	$ 9,335	$ 1,234	$ 15,985
Consumption	$ 14,751	$ 2,515	$ 11,850
Total	$ 24,085	$ 3,749	**$ 27,835**

VFD Electric Centrifugal Chiller (York)

Tons	kW/Ton	kW	hours	kWh	Cons. $
600	0.61	363	750	272250	$ 6,433
450	0.50	225	893	200925	$ 4,748
300	0.43	128	600	76800	$ 1,815
150	0.40	60.0	22	1320	$ 31
Total			2,265	551,295	$ 13,027

Cooling Tower=	30 hp
CW Pump=	33 hp
Total=	63 hp
Total=	47.0 kW

	Chiller	Auxiliaries	Total
Demand (5 months)=	$ 9,529	$ 1,234	$ 10,762
Consumption=	$ 13,027	$ 2,515	$ 15,543
Total=	$ 22,556	$ 3,749	**$ 26,305**

1. Electric driven vapor compression chilling provided the lowest operating cost in the current fuel market. A high efficiency unit with auxiliaries, and including peak demand charges for 5 months is estimated to cost approximately $28,000/year. A variation on this strategy is to install an vapor compression unit with a variable speed electric drive, capable of better part-load performance. Because of the limited number of hours of operation, however, projected annual cost reduction is minimal; on the order of $1,500 which may not be sufficient to warrant the additional capital cost of the unit (on the order of $10,000).

   Sizing of the new machine requires some consideration. A look a the 1999 demand data and the load growth projections suggests that the replacement machine be somewhat larger to create growth freeboard. The new chiller duty could be matched to a new cooling tower proposed below, leaving the existing towers to serve the existing McQuay machine at a lower condensing temperature, and higher efficiency. Reliability and redundancy of the plant is another consideration. Although campus loads are not generally critical enough to require full size, dedicated standby capacity (as is the case in the steam generation system), there is a desire to allow for as much reliability as possible. Installation of a dual circuit, dual compressor water chiller in place of the Carrier might provide this sort of reliability. Floor-to-structure height in the existing chiller bay will create an upper limit on machine size however. At this level of evaluation, we would recommend a dual compressor 800 nominal Ton unit, specified to operate at high efficiency (<0.55 kW/Ton) with cold condenser water (70/80) and the ability to operate with variable flow from 50 – 100%.

Chiller Energy Cost Comparison

Electric Rate		Steam Rate	
$/kW=	5.25	$/MMbtu=	$ 2.00
$/kWh=	0.02363	Boiler Eff=	74%
Gas Rate		Btu/lb=	947
$/MMbtu=	$ 5.00	$/lb=	$ 0.0026

Single Effect Absorption Chiller- Steam

Tons	lb/hr	hours	lb	$
600	10599	750	7949475	$ 20,346
450	5314	893	4745448	$ 12,146
300	2218	600	1330673	$ 3,406
150	749	22	16475	$ 42
Total		2,265		$ 35,940

Cooling Tower	50	hp
CW Pump	55	hp
Total	105	hp
Total	78.3	kW

Demand (5 months)	$	2,056
Consumption	$	4,192
Total	$	6,249

Chiller	$	35,940
Auxiliaries	$	6,249
Total Annual Energy	**$**	**42,189**

Double Effect Absorption Chiller- Direct Fired

Tons	Gas MBH	hours	MMBtu	$
600	7102	750	5326.5	$ 26,633
450	4914	893	4387.8	$ 21,939
300	3062	600	1837.3	$ 9,186
150	1776	22	39.1	$ 195
Total		2,265	11,591	$ 57,953

Cooling Tower	50	hp
CW Pump	55	hp
Total	105	hp
Total	78.3	kW

Demand (5 months)	$	2,056
Consumption	$	4,192
Total	$	6,249

Chiller	$	57,953
Auxiliaries	$	6,249
Total Annual Energy	**$**	**64,202**

2. Steam driven chilling through the use of single stage absorption chilling was evaluated using $2.00/MMBTU as the marginal cost of steam for chilling. This is undoubtedly a low estimate for the actual price of steam as it does not include the parasitic cost of conveying or filtration, but, for the purposes of chilled water analysis, these costs are already committed to existing campus steam production. Nevertheless, the poor efficiency of single stage absorption, coupled with higher heat rejection demands yield an annual cost estimate on the order of $42,000/yr; substantially higher than electric driven vapor compression. This is primarily due to the thermodynamic Coefficient of Performance (COP) of single stage absorption chilling (2.0) versus vapor compression (6.5).

3. Plant steam pressure is not currently sufficient to drive double effect absorption chilling (requiring a minimum of 150psi), but natural gas direct fired double effect machines are commercially available. Analysis of a unit of this type, using $5.00/MMBTU as the price of gas yielded annual cost estimates of over $60,000.

b) Heat Rejection: Tower Sizing

The existing concrete counterflow cooling towers were each sized to cool 1500 gpm from 90°F entering, to 80°F leaving at a 62°F wet bulb. This was consistent with the original chiller specification both in temperatures and flows, and corresponds to the equivalent of 500 Tons. Two speed, 15 Hp fan motors were originally specified as were 1500 GPM at 70' constant speed condenser pumps. The towers have since been applied to the hydronic economizer loop where the cold side (tower water) of the Plate and Frame heat exchanger was originally designed for 1500 GPM from 48 to 40°F. Performance simulation runs for the new McQuay chiller indicate it is designed to produce 600 Tons while heating 1800 GPM of condenser water from 70 to 80.

The fact that the original tower selection does not match the performance criteria of McQuay chiller does not mean the equipment will not operate satisfactorily, merely that the chiller is unlikely to meet full performance criteria under periods of high (above 60°F) wetbulb. The two cells together provide for a nominal 1000 Tons at an 18°F approach (80°F LWT, 62°F ambient WB). Current chiller design allows substantially better efficiency (in kW/Ton) with colder condensing conditions. Performance simulation of similar towers indicates that the two tower cells are jointly capable of providing a nominal 600 Tons at a 70°F LWT (8 degree approach). To accomplish this, flow rates would be reduced, and would be the most critical factor in re-rating the cells. Minimum flow rates, to keep the fill properly flushed would need to be confirmed with the original manufacturer. Modifications to the distribution nozzles might have to be made to properly spread out the water pattern.

Equipment age and near term load growth is driving installation of a new chiller of 600 to 800 tons. A component of the chilled water development plan must therefore improve the tower capacity to meet mid term campus demand on the order of 1200 to 1500 tons. This could be done a number of ways. One solution would be to refit the condenser water pumps with new impellers designed at 1000 GPM (consistent with 300 tons/cell) and nominal and allow them to pump to a header common with a new tower rated at, say, 800 tons (2400 gpm 80/70/62). This would allow some flexibility in operation. Another thought would be to pipe the two existing cells together and install a single new pump, at

2000 GPM matched in head to a second 2400 GPM pump and headered in common with a new 800 Ton tower.

c) Winter Operation

Configuration of the inlet air section of the existing towers severely limits their use under cold conditions, as ice build up becomes a significant problem. The cooling towers are currently shut down and drained from early November to late April. The towers are therefore off line during unseasonably warm conditions in late fall and early spring. Furthermore, internal campus loads (computer rooms, environmental chambers, etc.) continue to require heat extraction and rejection to the ambient. While this can theoretically be done by outside air ventilation, it often requires substantial modification to the building air handling systems to accomplish. Low internal relative humidity, due to introduction of tempered wintertime outside air may be a problem in computer room situations.

In present operation, the chilled water distribution pumps operate throughout the winter, and heat extracted from building loads is dissipated by conduction into the adjacent soil. The overall capacity of this form of heat rejection is thought to be less than 100 Tons making it suitable only for limited process and computer room cooling. The development plan must include modifications to allow heat rejection from the chilled water loop to ambient air. This will provide a reliable heat sink for internal laboratory and computer type loads and allow comfort cooling during unseasonably warm conditions.

Again, there are a number of ways to accomplish the objective. A dry cooler, in which a freeze protected chilled water/glycol mixture flows through a coil over which outside air is drawn could be piped in series with the existing plate and frame to fit the wintertime criteria, but it would require relatively higher fan energy and would have severely limited application during summer or when the drybulb temperature exceeded 45. A variation on this theme, considered as a part of this study, was to employ the existing glycol/chilled water heat exchangers at Biological Sciences and BioChem, along with new glycol "preheat" coils in the outside air stream (necessary for fume hood make up). This loop would function as a "free" dry cooler for the chilled water loop while heating raw make up air. Although feasible, and requiring few additional components, the concept adds parasitic pressure drop to the building air handling system, and its performance greatly diminishes as the outside air temperature rises above 20°F.

A winterized tower, capable of operation under subzero ambient conditions could serve both winter plate and frame and summertime chiller duties. One design approach would be to use a blow-through style tower, with modulating discharge dampers in a weatherproof cowling. If the tower basin were actually an insulated remote tank (perhaps located inside the plant itself) the water could be protected from freezing. Two speed fans, or pony motors could be provided for further capacity control under cold condition. Sizing of the winter tower could be consistent with the requirements of the new chiller, discussed above, at a nominal 800 Tons (2400gpm, 80/70/62). Improving the tower performance under chiller heat rejection conditions would be expected to improve the net approach of the hydronic economizer; extending the number of useful hours of the plate and frame. Installation of automatic changeover valving at this time would allow for much more rapid transition from plate and frame mode to chiller mode, which could now be done on a daily basis; further extending plate and frame operating hours and reducing electric chiller consumption. One common way to effect rapid changeover is to modulate a chiller condenser water discharge valve based on head pressure. Chillers can now be specified to be capable of start up with cold condenser water inlet and low flow.

d) Chilled Water Distribution

A number of deficiencies were observed in the chilled water distribution system which combine to result in a low net differential between supply and return temperature. The fundamental problem with a low dT is that it results in high flow rates per ton of heat rejection. With a specific heat of 1 BTU/lb/F, water is a rather poor energy transport medium (compared to say steam, which is capable of carrying 1000 BTU/Lb). It takes energy to move heat from the campus buildings to the plant cooling towers. The higher the chilled water dT, the more heat can be carried from campus to the plant per pound, and the lower the cost per BTU. Because pumping energy in a fixed distribution system is proportional to the flow raised to the third power, pump annual energy costs are very sensitive to flowrate, in turn proportional to the dT. At some point (typically considered 12- 14 fps) pipe velocities and frictional pressure drop simply become too high to allow additional flow. In a situation like the University of Wyoming, where extensive distribution mains of fixed size are in place, capital costs of increasing carrying capacity would be very high. There are therefore both operational and economic benefits to improving the poor dT. This fact has not been lost on plant operators at many university and college campuses, and the published literature on operation and efficiency improvement through temperature differential increase is vast.

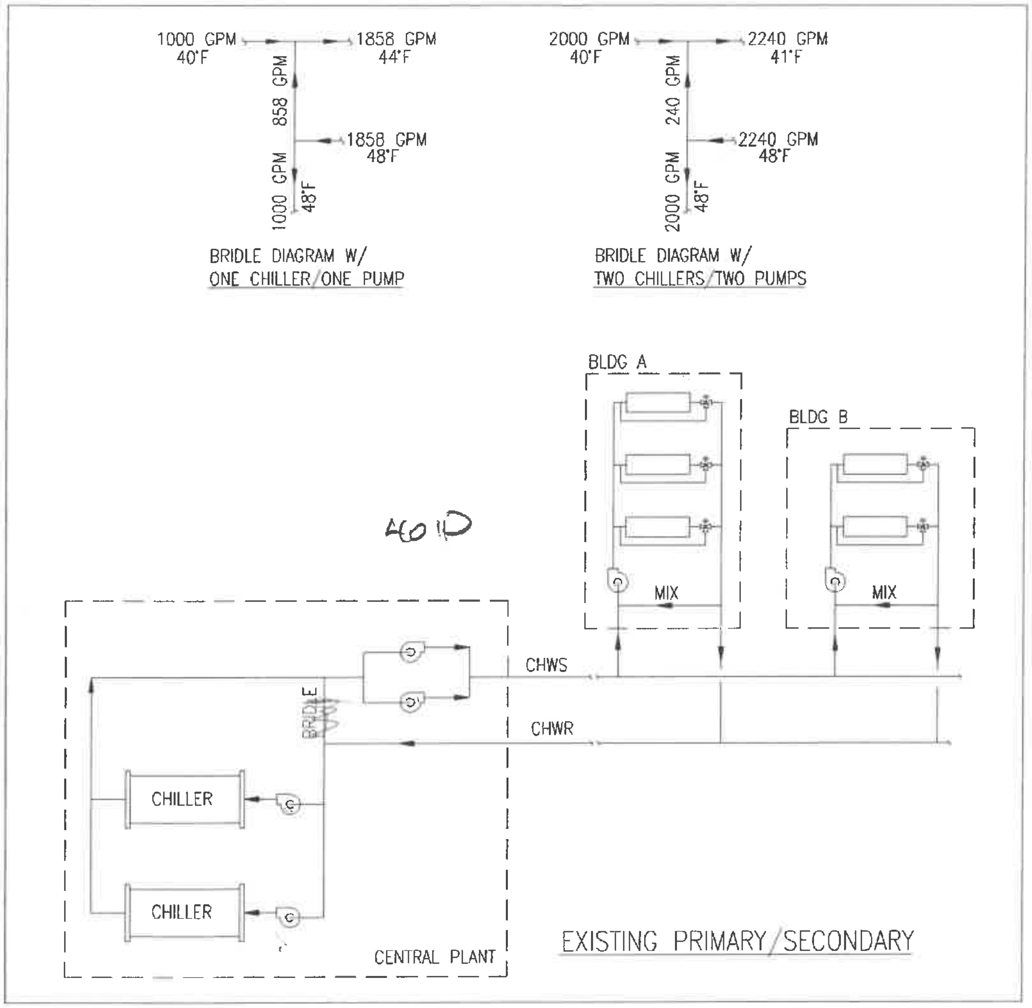
The normal summer time temperature differential in the University of Wyoming system is between 5 and 8 degrees. Water pumped out of the plant at 40°F returns at 45 to 48°F. The primary problem with low dT has to do with control of the chilled water at the air handler coil. Temperature sensors in the discharge air stream send a pneumatic signal to the actuator of the chilled water control valve with regulates the quantity of cold water flow through the coil. Because of a desire to maintain a constant water flow through the chilled water loop, three-way control valves were installed to either divert chilled water around the coil or to mix supply water with coil return. At 50% load for example, a three way valve will allow 50% of the chilled water supply (at 40°F) to bypass the coil and mix with the remaining 50% of the water that traversed the coil, extracting building heat while exiting at 52. The full flow at mixed temperature is now 46°F and on its way back to the chiller. Thermodynamic potential of the chilled water supply is lost; cooling effect produced by the chiller is unused by being mixed back into the water headed back to the plant. In this example, twice the water we needed was being circulated. The reasons for using three way valves to control chilled water coils largely disappeared with the advent and industry acceptance of variable frequency drives applied to chilled water pumps. Variable flow in the piping loop no longer represents a pressure or deadhead problem, as the pump speed can modulate to maintain sufficient differential pressure. Two-way valves that meter chilled water supply only through the coil are now specified. With elimination of mixing, the net water temperature leaving the coil will be warmer and excess bypass flow will disappear.

The first step to increasing the dT at the University of Wyoming is to systematically replace three-way coil control valves with two way coil control valves.

The second step is a bit more subtle. The campus chilled water piping is currently configured as a hydraulically decoupled Primary/Secondary/Tertiary system. One set of constant speed pumps circulates water through the chillers , a second set circulates water through the buried distribution system to building basements, and a third set circulates it through the buildings. In some cases, a fourth level of pumping circulates water through the coils themselves. The pumps are not stacked in series, where the discharge of one unit directly feeds the inlet of a second and must necessarily operate at identical flow, but are cascaded. The primary pumps establish a flow in the primary loop. Secondary pumps draw from and return to an adjacent set of tees (known as a "decoupler bridge" or "bridle") on the primary loop. These pumps establish secondary loop flow that is totally pressure and flow independent of the primary. If the secondary pumps are moving less water than the primary pumps, primary flow moves through the bridge and mixes with secondary return. The water temperature in the primary return is now the flow weighted average of the secondary return and primary supply. If the secondary pumps are moving more water than the primary pumps, secondary loop water moves the other direction, mixing secondary return into primary supply. Now the secondary supply water temperature is raised by secondary return temperature in proportion to the flow imbalance between supply and return. In either case, hydraulic decoupling allows mixing between the return water temperature of one loop with the supply of the other. The only time mixing does not occur is when the two pump flows are synchronized, in which case bridle flow is zero. Before the advent of variable frequency drives applied to pumps, and microprocessor capacity control applied to chillers there was a real need to decouple the distribution loop from the production loop. Because earlier generation chiller controls were proportional and slow responding, overshoot was flow sensitive, and there was a real risk of freezing tubes by rapidly changing flow. Chiller manufacturers often required constant evaporator flow. Without VFDs, secondary distribution systems were designed with three way valves and constant speed pumps to provide constant flow, independent of load. System design temperature differentials were met only in the case where all the coils were calling for full cooling (no bypass) and all of the secondary pump flows match the primary flow. Under any other condition, this system design provides lower than design dT and full pump energy regardless of load.

The pumping system in the Central Energy Plant is currently configured as Primary/Secondary. Individual chiller pumps are scheduled to move 1000 gpm at 40 feet of head (sufficient to overcome chiller pressure drop, primary piping and valve losses. Secondary pumps are scheduled to move 1800 gpm at 54 feet (intended to be sufficient to overcome pressure drop in the distribution piping to the farthest building and back). Building pumps are sized to overcome building pipe losses as well as coil and coil control valve losses. There are two sets of bridles then; one at the plant between the chiller loop and the distribution loop, and one at each of the buildings to separate distribution pumping from building pumping

Interestingly, this is not the pumping arrangement shown in the original (1980) CEP design drawing. Originally the chiller pumps were designed at 137 feet and established constant flow through both the chillers and the distribution piping. The primary loop encompassed both the chillers and the buried mains. Modifications to the original design added a tier of decoupling (converting the campus from Primary/Secondary to Primary/Secondary/Tertiary) and lowered the net available head to drive the system from 137 feet to 94 feet (54+40). The current campus hydraulic system is shown graphically below.

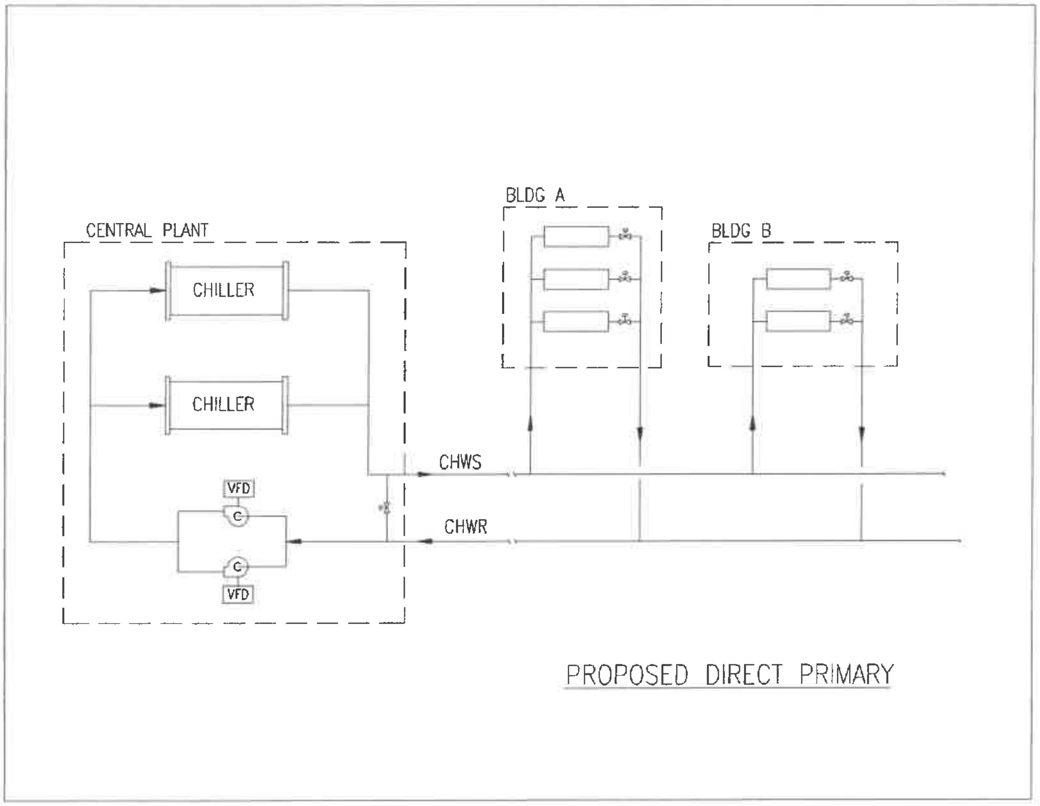


40 ID

Mixing across the bridles at the buildings and at the plant is inevitable and further erodes the poor dT provided by the coil three-way valves. Temperature differentials as low as 5 F means very high flows are required. Under these conditions, the relatively low head distribution pumps cannot provide sufficient pressure differential to support buildings at the end of the loop. Temperature in the building piping loop rises as warmed building return is mixed right back into the weak supply.

Our recommendation is to eliminate the decoupling bridges or bridles in the plant and buildings, remove all of the pumps (including the building pumps and install a single set of variable speed pumps capable of overcoming chiller, distribution and building losses as shown below.

– Leads @ VFD's / 2-way @ Bldg loops.



Flow through the chillers will now be variable. Variation from 100% to 50% should be acceptable to the microprocessor-controlled McQuay unit and certainly to the new unit scheduled to replace the original Carrier. A small (4") diameter bypass line would be installed across the plant to sustain minimum chiller flow under light load (less than 50% or 400 Tons). Not all of this work needs to happen at once. Reconfiguration of the plant and installation of the new pumps could occur along with chiller installation, followed by a transitional period in which building control valves would be replaced and building interface piping and pumps removed.

For reference, drawings are included in the appendix that show the proposed building interfaces for a direct primary system, booster pump detail, and 2-waycooling coil detail.

Currently, there are a number of expansion tanks on the chilled water system in the individual buildings. There are potential pressure problems with this arrangement because the tanks are on the discharge side of the pumps. The problem may be compounded if there is more than one makeup water point. It is recommended that one, large expansion tank be installed in the plant at the makeup water point and pressure relief vales in each of the buildings. The expansion tank would be on the order of 500 gallons, and would handle the expansion needs for the entire campus chilled water distribution system. The pressure relief valves protect the piping in the individual buildings if the buildings are isolated from the campus loop.

A hydraulic model of the campus chilled water distribution system was created in Excel utilizing the William and Hazen equation. The purpose of the hydraulic model was to verify the existing pipes and pumps were sized correctly, and to provide a tool to verify the effects of future cooling loads on the existing distribution system.

Williams and Hazen Equation

$F = 0.2083 \times (100 / C)\ 1.85 \times Q\ 1.85 / D\ 4.8655$

F = pressure drop, ft of $H2O$ / 100 ft
C = surface roughness constant
Q = flow, GPM
D = inside pipe diameter

The input into the hydraulic model utilizes maximum building cooling loads, pipe sizes, and lengths. The chilled water temperature split is assumed to be uniform throughout the distribution system. The output from the model is pipe flows, velocities, and pressure drops. The pressure drops were added up from the plant to each individual buildings to determine the available differential pressure at that building and the overall system pressure drop.

There were several scenarios tested with the hydraulic model. A summary table is provided below. The complete Excel spreadsheet for each iteration is included in Appendix A.

Summary Table

Iteration Tag	Cooling Load (tons)	Flow (gpm)	Delta T (°F)	Distribution Pump Head (ftwg)
Existing 1858 gpm Flow	1010	1858	13	41
Existing 2240 gpm Flow	1010	2240	11	58
Existing 8°F Split	1010	3030	8	101
Future Load w/ Existing Pipe	2370	3555	16	153

The results demonstrate that the pressure drop of a piping system is proportional to the flow squared. The existing pipe system can handle the 2240 gpm flow with a reasonable overall pressure drop and pipe velocities (<5.3 FPS). In this condition, the existing distribution pumps are adequately sized. As the flow climbs to 3030 gpm which corresponds to a lower temperature split, the pressure head almost doubles. With these higher flow and pressure head, the existing distribution pumps are grossly undersized.

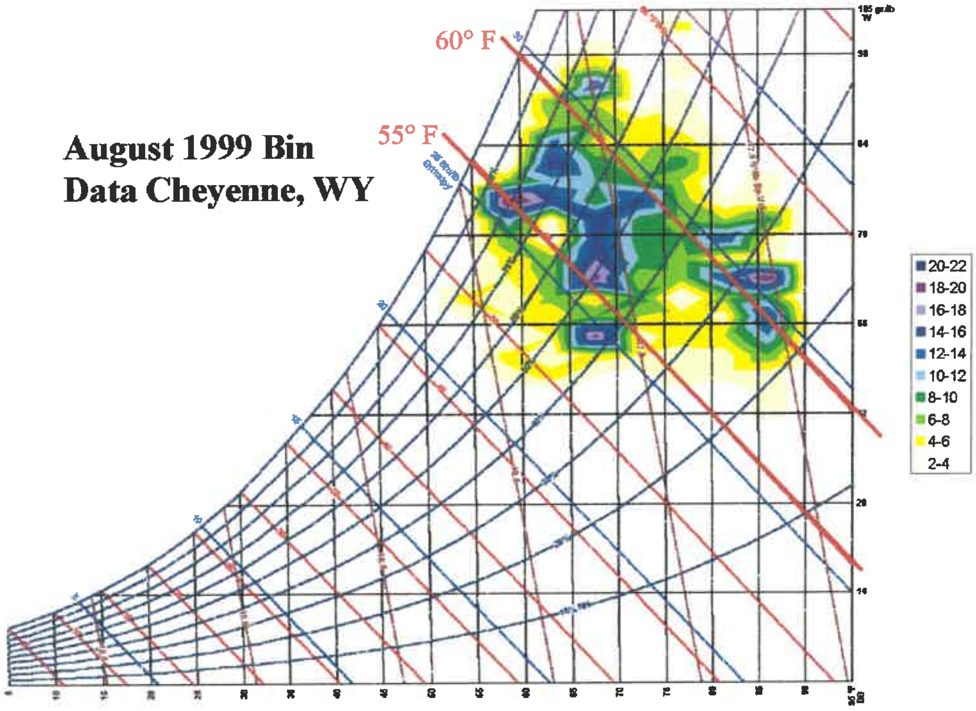
In the future, the central chilled water system is predicted to climb to 2370 tons. The hydraulic model shows that the existing distribution system can handle the extra load. However, the only way to get the extra cooling capacity from the central plant to the buildings through the existing piping is to increase the temperature split. With a 16oF split, the hydraulic model calculates the cooling load of 2370 tons will require 3555 gpm and a pumps head of 153 ft. The penalty for the higher flow is the higher pressure drop. The chilled water velocity is still within practical design limits (<8.5 fps).

e) Evaporative Cooling

Climatic conditions in Laramie justify careful evaluation of evaporative cooling schemes; particularly in buildings with high ventilation rates, and in new construction where air distribution systems can be designed specifically for this cooling mechanism.

Operation

Direct evaporative cooling involves spraying or washing a porous media with water while drawing air through it. Dry bulb temperature of the air stream is reduced by the process of evaporating water. Effectiveness of modern evaporative cooling media (often referred to by trade name "celdek") allows dry bulb air temperature leaving the cooler to approach within a few degrees of the ambient wet bulb. An ambient wet bulb temperature of 60 (close to the summertime design wetbulb in Laramie) will yield 65 degree discharge air in a properly designed system. This is 10 to 15 degrees higher than air temperature leaving a chilled water coil; meaning more air must be provided to satisfy the same internal load. The air distribution system must therefore be able to move greater air quantities, meaning ducts and fan must be larger. Review of several existing buildings at University of Wyoming suggests that retrofit of evaporative cooling to existing systems would be very difficult and expensive due to limited duct capacity. An analysis was done (using Cheyenne weather data) of the practicality of applying direct evaporative cooling to an existing air handling system. The percentage of hours at which the wetbulb is too high to meet a 55°F discharge air setpoint is too high to warrant consideration.



August 1999 Bin Data Cheyenne, WY

New construction, and particularly new construction with systems already requiring high ventilation rates (such as laboratories) are good candidates for evaporative cooling. In these cases, higher air temperatures can be anticipated in design. Air distribution quantities, fan sizes and duct runs are primarily ventilation driven to provide make up air for fume hoods, or once-through laboratory airchange requirements, and sufficient interstitial space to route large distribution ducting can be programmed in to the architecture.

A second evaporative cooling mechanism is indirect cooling, where a dedicated cooling tower is piped to a preconditioning coil, and does sensible cooling. Approach here can reasonably be expected to be 8 degrees (4 at the tower, 4 across the coil). On a peak day in Laramie, with 62 WB, indirect cooling would provide 70 degree air. Indirect cooling is often used in series with direct cooling (two stage evaporative cooling) to provide lower composite air temperatures. In the arid southwest, two stage evaporative cooling is often applied to laboratory buildings to provide summer discharge air temperatures in the low 60's. A large number of components and controls are required in this scheme however, limiting its economic practicality to large, consolidated air handling systems, laboratories and new construction.

Maintenance

Although electric energy demand and consumption associated with evaporative cooling are substantially less than mechanical refrigeration, the analysis needs to include additional operation and maintenance costs. Prevention of scale formation, particularly in areas with hard water, requires continuous or timed bleed and flush of the recirculating water in the celdek and tower. Automatic control system are often more complex, and sensors more critical particularly with two stage cooling, and require frequent calibration. Chemical treatment for biological and scale in the cooling tower is standard, but must be done very carefully in the wet section, because of direct contact with the airstream. High duct humidity provides environment for certain molds, and odors from biological activity in the cooling media is inevitable. In our experience, occupant complaints of odors, perception of high space humidity, and concern over duct air quality are common.

From the standpoint of the chilled water system however, installation or retrofit of evaporative cooling will lower peak demand and consumption. Installation of building evaporative cooling reduces chiller demand and extends the capacity of the distribution piping. This cooling mechanism should be aggressively evaluated for new laboratory facilities and/or major building renovations.

V. Strategy Selection

a) Capital Cost Estimate Table

(Complete Cost Estimates in Appendix D)

Production		
Replace Chiller (800 T)	$540,000	✓
Install New Tower (800 T; winterizable)	$179,000	✓
Reconfigure Plant Pumping	$199,000	
Refrigeration Room Code Upgrade	$44,000	
Distribution		
Replace Three Way Valves	$100,000	
Remove Building Pumps and Bridges	$35,400	
Central Expansion Tank	$24,000	

b) Energy Savings Estimate Table

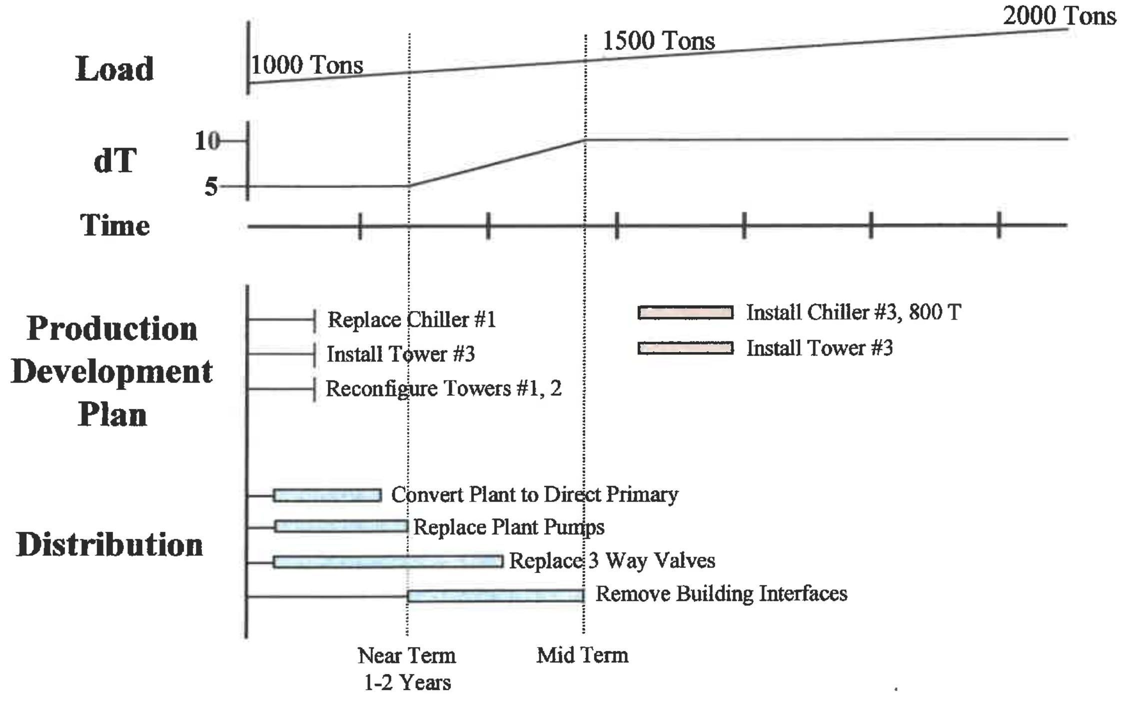
(Complete Estimates in Appendix C)

Pumping

Existing Constant Speed Pumping	239,968 kWh,	$16, 798
Proposed Variable Speed Pumping	27,131 kWh,	$1, 899
Savings	212,837 kWh,	$14, 899

VI. Implementation Plan

Chilled Water UDP



a) Production Strategy Phasing

Deregulation of electric markets in the western united states will have an impact on the cost to produce chilled water at the University of Wyoming. As regional electric rates become more homogenized, UW is likely to see increases in energy and consumption rates, conceivably even time-of-day rates. The first order comparison between electric driven chilling and coal fired steam driven chilling so heavily favors the more efficient electric process that it is recommended not withstanding. Even though integrated campus load (Ton-Hrs) and the overall significance of water chilling on the annual utility bill is relatively low, a hedge against rising electric power costs is higher operating efficiency.

Chiller #2, the R-12 Carrier machine is in near term need of replacement from reliability, maintenance, and refrigerant perspectives. Because of plant footprint space constraints and imminent load growth, the replacement machine should be as large as can practically fit in the existing envelope; perhaps 800 Tons. The unit would ideally be dual compressor, to allow excellent part load performance while providing a better plant reliability index. Coincident with installation of this machine would be installation of a winterizable cooling tower with remote sump. Ideally, plant piping and pumping modifications to convert to direct primary would occur at the same time. Conversion of the existing towers to provide closer approach (and higher efficiency) for the existing McQuay chiller could occur after completion of this work.

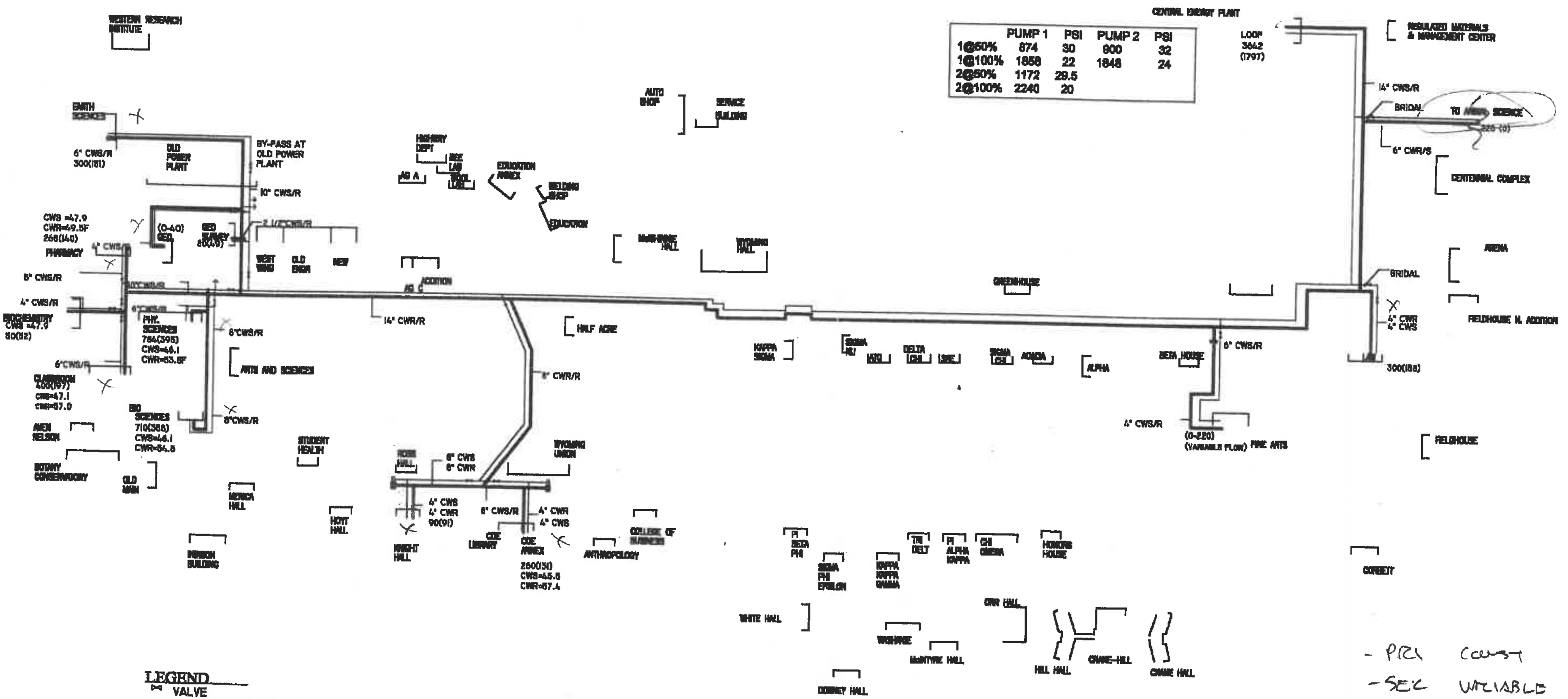
This project would bring plant capacity to 1400 Tons. A third tower and chiller will be needed in the mid-to-long term (5 to 10 years?) to handle projected load growth. Planning the general arrangement of the additional tower and chiller #3 prior to installation of chiller #2 might be prudent.

b) Distribution Strategy Phasing

Improvement of the distribution system temperature differential is essential to long term growth and efficiency of the campus chilled water system. Although it might make sense to accomplish all of the valve and building interface conversions at one time from a construction project standpoint, it could be stretched out over a number of years and could be done after conversion of the plant. If it is to be phased, initial attention should be focused on the highest load buildings and those with the poorest return dT. Overall system temperature differential is the flow weighted average of all the building. Conversion of the 3 largest buildings would be expected to yield a substantial effect on the system as a whole.

VII. Appendix

a) Chilled Water Model



	PUMP 1	PSI	PUMP 2	PSI
1@50%	874	30	900	32
1@100%	1858	22	1848	24
2@50%	1172	29.5		
2@100%	2240	20		

LEGEND
⋈ VALVE
━ CHILLED WATER SUPPLY
─ CHILLED WATER RETURN
XX GPM BUILDING DESIGN
(XX) GPM SET
◁ REDUCER
↑ AIR VENT
BRIDAL BRIDAL LOOP LOCATION

CHILLED WATER PIPING SCHEMATIC

DATE: 12.02.99
SCALE: 1"=300' (rough)

0' 150' 300'

- PRI CONST
- SEC VARIABLE
- ΔP @ Last loop for VFD's @ LOOP.

Chilled Water Distribution Calculations

Iteration Tag: Existing 1858 gpm Flow

Start Node	End Node	Bldg Attached	Pipe Size (in)	Inside Dia. (in)	Pipe Length (ft)	Attached Cooling (tons)	Total Cooling (tons)	Diversity Cooling (tons)	Calc Flow (gpm)	Vel (fps)	Friction Head (ftwg/100ft)	Press. Drop (ftwg)	Supply Press. (ftwg)	Return Press. (ftwg)	Different. Press. (ftwg)
	S00												40.7	0.0	40.7
S00	S10		14	13.125	1000	0	1010	1010	1858	4.4	0.453	4.5	36.2	4.5	31.7
S10	S20		14	13.125	800	0	1010	1010	1858	4.4	0.453	3.6	32.6	8.2	24.4
S20	S30		14	13.125	320	0	931	931	1713	4.1	0.390	1.2	31.3	9.4	21.9
S30	S40		14	13.125	2180	0	821	821	1510	3.6	0.309	6.7	24.6	16.1	8.5
S40	S50		14	13.125	850	0	711	711	1308	3.1	0.237	2.0	22.6	18.1	4.5
S50	S60		10	10.02	20	0	591	591	1087	4.4	0.625	0.1	22.5	18.3	4.2
S60	S70		10	10.02	280	0	195	195	359	1.5	0.080	0.2	22.2	18.5	3.8
S70	S80		6	6.065	40	0	125	125	230	2.6	0.406	0.2	22.1	18.7	3.4
S10	B80	Animal Science	6	6.065	50	0	0	0	0	0.0	0.000	0.0	36.2	4.5	31.7
S20	B77	Law	4	4.026	200	79	79	79	145	3.7	1.276	2.6	30.0	10.7	19.3
S30	B78	Fine Arts	6	6.065	250	110	110	110	202	2.3	0.320	0.8	30.5	10.2	20.3
S40	S42		8	7.981	650	0	110	110	202	1.3	0.084	0.5	24.1	16.7	7.4
S42	S44		8	7.981	200	0	65	65	120	0.8	0.032	0.1	24.0	16.7	7.3
S44	B26	Coe Library	4	4.026	50	65	65	65	120	3.0	0.889	0.4	23.5	17.2	6.4
S42	S46		8	7.981	200	0	45	45	83	0.5	0.016	0.0	24.0	16.7	7.3
S46	B44	Knight Hall	4	4.026	50	45	45	45	83	2.1	0.450	0.2	23.8	16.9	6.9
S50	S52		10	10.02	200	0	120	120	221	0.9	0.033	0.1	22.5	18.2	4.3
S52	B87	Geo Survey	2.5	2.469	50	25	25	25	46	3.1	1.639	0.8	21.7	19.0	2.7
S52	S54		10	10.02	230	0	95	95	175	0.7	0.021	0.0	22.5	18.3	4.2
S54	B18	Geology	4	4.026	100	20	20	20	37	0.9	0.100	0.1	22.4	18.4	4.0
S54	S56		10	10.02	100	0	75	75	138	0.6	0.014	0.0	22.5	18.3	4.2
S56	BES	Earth Science	6	6.065	150	75	75	75	138	1.5	0.158	0.2	22.2	18.5	3.7
S60	S62		8	7.981	150	0	396	396	728	4.7	0.901	1.4	21.1	19.6	1.5
S62	B33	Phy Sciences	6	6.065	50	198	198	198	364	4.1	0.951	0.5	20.6	20.1	0.5
S62	B09	Bio Sciences	8	7.981	300	198	198	198	364	2.3	0.250	0.8	20.4	20.4	0.0
S70	B32	Pharmacy	5	5.047	120	70	70	70	129	2.1	0.340	0.4	21.8	18.9	2.9

Iteration Tag: Existing 1858 gpm Flow

Start Node	End Node	Bldg Attached	Pipe Size (in)	Inside Dia. (in)	Pipe Length (ft)	Attached Cooling (tons)	Total Cooling (tons)	Diversity Cooling (tons)	Calc Flow (gpm)	Vel (fps)	Friction Head (ftwg/100ft)	Press. Drop (ftwg)	Supply Press. (ftwg)	Return Press. (ftwg)	Different. Press. (ftwg)
S80	B11	Biochemistry	4	4.026	100	26	26	26	48	1.2	0.163	0.2	21.9	18.8	3.1
S80	B12	Classroom	6	6.065	140	99	99	99	182	2.0	0.264	0.4	21.7	19.0	2.7
						1010									

Variables

DELTA T= 13.05 °F
C= 140
Diversity= 100%
B09 Delta Press= 0.0 ftwg
Plant Delta Press= 0.0 ftwg

Required Distribution Pump

Flow= 1,858 gpm
Head= 41 ftwg
Eff.= 80%
HP= 23.9

Pipe Lookup Table

Pipe Size (in)	Inside Dia. (in)
2	2.067
2.5	2.469
3	3.068
4	4.026
5	5.047
6	6.065
8	7.981
10	10.020
12	11.938
14	13.125
16	15.000
18	16.874
20	18.814

Chilled Water Distribution Calculations

Iteration Tag: Existing 2240 gpm Flow

Start Node	End Node	Bldg Attached	Pipe Size (in)	Inside Dia. (in)	Pipe Length (ft)	Attached Cooling (tons)	Total Cooling (tons)	Diversity Cooling (tons)	Calc Flow (gpm)	Vel (fps)	Friction Head (ftwg/100ft)	Press. Drop (ftwg)	Supply Press. (ftwg)	Return Press. (ftwg)	Different. Press. (ftwg)
	S00												57.6	0.0	57.6
S00	S10		14	13.125	1000	0	1010	1010	2240	5.3	0.640	6.4	51.2	6.4	44.8
S10	S20		14	13.125	800	0	1010	1010	2240	5.3	0.640	5.1	46.0	11.5	34.5
S20	S30		14	13.125	320	0	931	931	2065	4.9	0.551	1.8	44.3	13.3	31.0
S30	S40		14	13.125	2180	0	821	821	1821	4.3	0.436	9.5	34.8	22.8	12.0
S40	S50		14	13.125	850	0	711	711	1577	3.7	0.334	2.8	31.9	25.6	6.3
S50	S60		10	10.02	20	0	591	591	1311	5.3	0.883	0.2	31.8	25.8	5.9
S60	S70		10	10.02	280	0	195	195	432	1.8	0.114	0.3	31.4	26.1	5.3
S70	S80		6	6.065	40	0	125	125	277	3.1	0.574	0.2	31.2	26.4	4.8
S10	B80	Animal Science	6	6.065	50	0	0	0	0	0.0	0.000	0.0	51.2	6.4	44.8
S20	B77	Law	4	4.026	200	79	79	79	175	4.4	1.803	3.6	42.4	15.1	27.3
S30	B78	Fine Arts	6	6.065	250	110	110	110	244	2.7	0.453	1.1	43.1	14.4	28.7
S40	S42		8	7.981	650	0	110	110	244	1.6	0.119	0.8	34.0	23.6	10.4
S42	S44		8	7.981	200	0	65	65	144	0.9	0.045	0.1	33.9	23.7	10.2
S44	B26	Coe Library	4	4.026	50	65	65	65	144	3.6	1.257	0.6	33.3	24.3	9.0
S42	S46		8	7.981	200	0	45	45	100	0.6	0.023	0.0	34.0	23.6	10.3
S46	B44	Knight Hall	4	4.026	50	45	45	45	100	2.5	0.636	0.3	33.6	23.9	9.7
S50	S52		10	10.02	200	0	120	120	266	1.1	0.046	0.1	31.8	25.7	6.1
S52	B87	Geo Survey	2.5	2.469	50	25	25	25	55	3.7	2.316	1.2	30.7	26.9	3.8
S52	S54		10	10.02	230	0	95	95	211	0.9	0.030	0.1	31.8	25.8	6.0
S54	B18	Geology	4	4.026	100	20	20	20	44	1.1	0.142	0.1	31.6	25.9	5.7
S54	S56		10	10.02	100	0	75	75	166	0.7	0.019	0.0	31.7	25.8	5.9
S56	BES	Earth Science	6	6.065	150	75	75	75	166	1.9	0.223	0.3	31.4	26.1	5.3
S60	S62		8	7.981	150	0	396	396	878	5.6	1.274	1.9	29.8	27.7	2.1
S62	B33	Phy Sciences	6	6.065	50	198	198	198	439	4.9	1.344	0.7	29.2	28.4	0.8
S62	B09	Bio Sciences	8	7.981	300	198	198	198	439	2.8	0.353	1.1	28.8	28.8	0.0
S70	B32	Pharmacy	5	5.047	120	70	70	70	155	2.5	0.480	0.6	30.9	26.7	4.2

Chilled Water Distribution Calculations

Iteration Tag: Existing 2240 gpm Flow

Start Node	End Node	Bldg Attached	Pipe Size (in)	Inside Dia. (in)	Pipe Length (ft)	Attached Cooling (tons)	Total Cooling (tons)	Diversity Cooling (tons)	Calc Flow (gpm)	Vel (fps)	Friction Head (ftwg/100ft)	Press. Drop (ftwg)	Supply Press. (ftwg)	Return Press. (ftwg)	Different. Press. (ftwg)
S80	B11	Biochemistry	4	4.026	100	26	26	26	58	1.5	0.231	0.2	31.0	26.6	4.4
S80	B12	Classroom	6	6.065	140	99	99	99	220	2.4	0.373	0.5	30.7	26.9	3.8
						1010									

Variables

DELTA T= 10.82 °F
C= 140
Diversity= 100%
B09 Delta Press= 0.0 ftwg
Plant Delta Press= 0.0 ftwg

Required Distribution Pump

Flow= 2,240 gpm
Head= 58 ftwg
Eff.= 80%
HP= 40.7

Pipe Lookup Table

Pipe Size (in)	Inside Dia. (in)
2	2.067
2.5	2.469
3	3.068
4	4.026
5	5.047
6	6.065
8	7.981
10	10.020
12	11.938
14	13.125
16	15.000
18	16.874
20	18.814

Chilled Water Distribution Calculations

Iteration Tag: Existing 8 °F Split

Start Node	End Node	Bldg Attached	Pipe Size (in)	Inside Dia. (in)	Pipe Length (ft)	Attached Cooling (tons)	Total Cooling (tons)	Diversity Cooling (tons)	Calc Flow (gpm)	Vel (fps)	Friction Head (ftwg/100ft)	Press. Drop (ftwg)	Supply Press. (ftwg)	Return Press. (ftwg)	Different. Press. (ftwg)
	S00												100.7	0.0	100.7
S00	S10		14	13.125	1000	0	1010	1010	3030	7.2	1.119	11.2	89.5	11.2	78.3
S10	S20		14	13.125	800	0	1010	1010	3030	7.2	1.119	9.0	80.5	20.1	60.4
S20	S30		14	13.125	320	0	931	931	2793	6.6	0.963	3.1	77.4	23.2	54.2
S30	S40		14	13.125	2180	0	821	821	2463	5.9	0.763	16.6	60.8	39.9	20.9
S40	S50		14	13.125	850	0	711	711	2133	5.1	0.585	5.0	55.8	44.8	11.0
S50	S60		10	10.02	20	0	591	591	1773	7.2	1.544	0.3	55.5	45.1	10.4
S60	S70		10	10.02	280	0	195	195	585	2.4	0.199	0.6	55.0	45.7	9.3
S70	S80		6	6.065	40	0	125	125	375	4.2	1.003	0.4	54.6	46.1	8.5
S10	B80	Animal Science	6	6.065	50	0	0	0	0	0.0	0.000	0.0	89.5	11.2	78.3
S20	B77	Law	4	4.026	200	79	79	79	237	6.0	3.152	6.3	74.2	26.5	47.8
S30	B78	Fine Arts	6	6.065	250	110	110	110	330	3.7	0.792	2.0	75.5	25.2	50.2
S40	S42		8	7.981	650	0	110	110	330	2.1	0.208	1.4	59.4	41.2	18.2
S42	S44		8	7.981	200	0	65	65	195	1.3	0.079	0.2	59.3	41.4	17.9
S44	B26	Coe Library	4	4.026	50	65	65	65	195	4.9	2.197	1.1	58.2	42.5	15.7
S42	S46		8	7.981	200	0	45	45	135	0.9	0.040	0.1	59.4	41.3	18.1
S46	B44	Knight Hall	4	4.026	50	45	45	45	135	3.4	1.113	0.6	58.8	41.8	17.0
S50	S52		10	10.02	200	0	120	120	360	1.5	0.081	0.2	55.7	45.0	10.7
S52	B87	Geo Survey	2.5	2.469	50	25	25	25	75	5.0	4.050	2.0	53.6	47.0	6.6
S52	S54		10	10.02	230	0	95	95	285	1.2	0.052	0.1	55.6	45.1	10.4
S54	B18	Geology	4	4.026	100	20	20	20	60	1.5	0.248	0.2	55.3	45.4	9.9
S54	S56		10	10.02	100	0	75	75	225	0.9	0.034	0.0	55.5	45.1	10.4
S56	BES	Earth Science	6	6.065	150	75	75	75	225	2.5	0.390	0.6	54.9	45.7	9.2
S60	S62		8	7.981	150	0	396	396	1188	7.6	2.227	3.3	52.2	48.5	3.7
S62	B33	Phy Sciences	6	6.065	50	198	198	198	594	6.6	2.350	1.2	51.0	49.7	1.4
S62	B09	Bio Sciences	8	7.981	300	198	198	198	594	3.8	0.618	1.9	50.3	50.3	0.0
S70	B32	Pharmacy	5	5.047	120	70	70	70	210	3.4	0.839	1.0	54.0	46.7	7.3

Chilled Water Distribution Calculations

Iteration Tag: Existing 8 °F Split

Start Node	End Node	Bldg Attached	Pipe Size (in)	Inside Dia. (in)	Pipe Length (ft)	Attached Cooling (tons)	Total Cooling (tons)	Diversity Cooling (tons)	Calc Flow (gpm)	Vel (fps)	Friction Head (ftwg/100ft)	Press. Drop (ftwg)	Supply Press. (ftwg)	Return Press. (ftwg)	Different. Press. (ftwg)
S80	B11	Biochemistry	4	4.026	100	26	26	26	78	2.0	0.403	0.4	54.2	46.5	7.7
S80	B12	Classroom	6	6.065	140	99	99	99	297	3.3	0.652	0.9	53.7	47.0	6.7
						1010									

Variables

DELTA T= 8 °F
C= 140
Diversity= 100%
B09 Delta Press= 0.0 ftwg
Plant Delta Press= 0.0 ftwg

Required Distribution Pump

Flow= 3,030 gpm
Head= 101 ftwg
Eff.= 80%
HP= 96.3

Pipe Lookup Table

Pipe Size (in)	Inside Dia. (in)
2	2.067
2.5	2.469
3	3.068
4	4.026
5	5.047
6	6.065
8	7.981
10	10.020
12	11.938
14	13.125
16	15.000
18	16.874
20	18.814

Chilled Water Distribution Calculations

Iteration Tag: Future Load w/ Existing Pipe and 16°F Split

Start Node	End Node	Bldg Attached	Pipe Size (in)	Inside Dia. (in)	Pipe Length (ft)	Attached Cooling (tons)	Total Cooling (tons)	Diversity Cooling (tons)	Calc Flow (gpm)	Vel (fps)	Friction Head (ftwg/100ft)	Press. Drop (ftwg)	Supply Press. (ftwg)	Return Press. (ftwg)	Different. Press. (ftwg)
	S00												152.8	0.0	152.8
S00	S10		14	13.125	1000	0	2370	2370	3555	8.5	1.504	15.0	137.7	15.0	122.7
S10	S20		14	13.125	800	0	2370	2370	3555	8.5	1.504	12.0	125.7	27.1	98.6
S20	S30		14	13.125	320	0	2291	2291	3437	8.2	1.413	4.5	121.2	31.6	89.6
S30	S40		14	13.125	2180	0	2181	2181	3272	7.8	1.290	28.1	93.1	59.7	33.3
S40	S50		14	13.125	850	0	1671	1671	2507	6.0	0.788	6.7	86.4	66.4	20.0
S50	S60		10	10.02	20	0	1531	1531	2297	9.4	2.492	0.5	85.9	66.9	19.0
S60	S70		10	10.02	280	0	1115	1115	1673	6.8	1.386	3.9	82.0	70.8	11.2
S70	S80		6	6.065	40	0	145	145	218	2.4	0.366	0.1	81.8	70.9	10.9
S10	B80	Animal Science	6	6.065	50	0	0	0	0	0.0	0.000	0.0	137.7	15.0	122.7
S20	B77	Law	4	4.026	200	79	79	79	119	3.0	0.874	1.7	124.0	28.8	95.1
S30	B78	Fine Arts	6	6.065	250	110	110	110	165	1.8	0.220	0.5	120.6	32.1	88.5
S40	S42		8	7.981	650	0	510	510	765	4.9	0.987	6.4	86.6	66.1	20.5
S42	S44		8	7.981	200	0	365	365	548	3.5	0.531	1.1	85.6	67.2	18.4
S44	B26	Coe Library	4	4.026	50	115	115	115	173	4.4	1.751	0.9	84.7	68.1	16.6
S42	S46		8	7.981	200	0	145	145	218	1.4	0.096	0.2	86.5	66.3	20.1
S46	B44	Knight Hall	4	4.026	50	145	145	145	218	5.5	2.689	1.3	85.1	67.7	17.4
S44	S48		8	7.981	50	0	250	250	375	2.4	0.264	0.1	85.5	67.3	18.1
S48	BWU	(N)Wyoming Uni	5	5.047	50	150	150	150	225	3.6	0.953	0.5	85.0	67.8	17.2
S48	BCB	(N)College of B	4	4.026	300	100	100	100	150	3.8	1.352	4.1	81.4	71.4	10.0
S50	S52		10	10.02	200	0	140	140	210	0.9	0.030	0.1	86.3	66.5	19.8
S52	B87	Geo Survey	2.5	2.469	50	25	25	25	38	2.5	1.123	0.6	85.7	67.0	18.7
S52	S54		10	10.02	230	0	115	115	173	0.7	0.021	0.0	86.3	66.5	19.7
S54	B18	Geology	4	4.026	100	40	40	40	60	1.5	0.248	0.2	86.0	66.8	19.2
S54	S56		10	10.02	100	0	75	75	113	0.5	0.009	0.0	86.2	66.5	19.7
S56	BES	Earth Science	6	6.065	150	75	75	75	113	1.3	0.108	0.2	86.1	66.7	19.4
S60	S62		8	7.981	150	0	416	416	624	4.0	0.677	1.0	86.9	67.9	19.0
S62	B33	Phy Sciences	6	6.065	50	198	198	198	297	3.3	0.652	0.3	86.6	68.3	18.3
S62	S64		8	7.981	250	0	218	218	327	2.1	0.205	0.5	86.0	68.4	17.6

Chilled Water Distribution Calculations

Iteration Tag: Future Load w/ Existing Pipe and 16°F Split

Start Node	End Node	Bldg Attached	Pipe Size (in)	Inside Dia. (in)	Pipe Length (ft)	Attached Cooling (tons)	Total Cooling (tons)	Diversity Cooling (tons)	Calc Flow (gpm)	Vel (fps)	Friction Head (ftwg/100ft)	Press. Drop (ftwg)	Supply Press. (ftwg)	Return Press. (ftwg)	Different. Press. (ftwg)
S64	B09	Bio Sciences	8	7.981	50	198	198	198	297	1.9	0.171	0.1	86.0	68.5	17.4
S64	BOM	(N)Old Main	3	3.068	300	20	20	20	30	1.3	0.258	0.8	85.2	69.2	16.0
S70	B32	Pharmacy	5	5.047	120	70	70	70	105	1.7	0.233	0.3	81.7	71.1	10.6
S70	BNB	(N)New Loads	10	10.02	600	900	900	900	1350	5.5	0.933	5.6	76.4	76.4	0.0
S80	B11	Biochemistry	4	4.026	100	26	26	26	39	1.0	0.112	0.1	81.7	71.0	10.7
S80	S82		6	6.065	100	0	119	119	179	2.0	0.254	0.3	81.6	71.2	10.4
S82	B12	Classroom	6	6.065	40	99	99	99	149	1.7	0.181	0.1	81.5	71.3	10.2
S82	B12	(N)Aven Nelson	3	3.068	300	20	20	20	30	1.3	0.258	0.8	80.8	72.0	8.8
						2370									

Variables

DELTA T= 16 °F
C= 140
Diversity= 100%
BNB Delta Press= 0.0 ftwg
Plant Delta Press= 0.0 ftwg

Required Distribution Pump

Flow= 3,555 gpm
Head= 153 ftwg
Eff.= 80%
HP= 171.4

Total Attached Tons= 2370
Total Diversity Tons= 2370

Pipe Lookup Table

Pipe Size (in)	Inside Dia. (in)
2	2.067
2.5	2.469
3	3.068
4	4.026
5	5.047
6	6.065
8	7.981
10	10.020
12	11.938
14	13.125
16	15.000
18	16.874
20	18.814

VII. Appendix

b) Evaporative Cooling Effectiveness

Effectiveness of Evaporative Cooling in Cheyenne, Wyoming
Results based on 1999 NOAA Weather Data

POSSIBLE HOURS (24 hrs/day)

	80% Sat. Efficiency		60% Sat. Efficiency	
Month	Hours [1]	% Time	Hours [1]	% Time
JAN	743	100%	743	100%
FEB	672	100%	672	100%
MAR	736	100%	736	100%
APR	720	100%	718	100%
MAY	671	90%	625	84%
JUN	460	64%	386	54%
JUL	132	18%	97	13%
AUG	172	23%	129	17%
SEP	581	81%	520	72%
OCT	701	94%	637	86%
NOV	716	100%	683	95%
DEC	742	100%	742	100%

OFFICE HOURS- 7:00 to 17:00

	80% Sat. Efficiency		60% Sat. Efficiency	
Month	Hours [1]	% Time	Hours [1]	% Time
JAN	340	100%	340	100%
FEB	307	100%	307	100%
MAR	337	100%	337	100%
APR	329	100%	327	99%
MAY	276	81%	237	70%
JUN	128	39%	86	26%
JUL	12	4%	9	3%
AUG	19	6%	16	5%
SEP	213	65%	167	51%
OCT	297	88%	234	69%
NOV	325	100%	292	90%
DEC	339	100%	339	100%

1. Hours represent the supply air temperature from an evaporative cooler with the stated saturation efficiency is less then 55 °F.

VII. Appendix

c) Pump Energy Calculations

Proposed Direct Primary Chilled Water System
Calculation of Pump Energy Consumption
Variable Speed Pumping

Ton Range	Used Tons	Bin Hours	Pump HP	Pump kW	kWh
0-49	25	102	7.5	5.6	570.7
50-99	75	542	7.5	5.6	3032.5
100-149	125	474	7.5	5.6	2652.0
150-199	175	102	7.5	5.6	570.7
200-249	225	240	7.5	5.6	1342.8
250-299	275	318	7.5	5.6	1779.2
300-349	325	393	7.5	5.6	2198.8
350-399	375	249	7.5	5.6	1393.2
400-449	425	253	7.7	5.7	1448.9
450-499	475	351	10.7	8.0	2806.3
500-549	525	88	14.5	10.8	949.9
550-559	575	35	19.0	14.2	496.4
600-649	625	61	24.4	18.2	1111.0
650-699	675	73	30.8	22.9	1674.8
700-749	725	73	38.1	28.4	2075.3
750-799	775	49	46.5	34.7	1701.5
800-849	825	11	56.2	41.9	460.8
850-899	875	8	67.0	50.0	399.8
900-950	925	4	79.1	59.0	236.2
950-999	975	1	92.7	69.1	69.1
>1000	1025	2	107.7	80.3	160.7
Total		3,429			27,131

Pump Hp= 100
@ Ton= 1000
Min HP= 7.5
kWh= 27,131
$/kWh= 0.07
Cost= $ 1,899

Summary

	kWh	Cost
Existing Constant Speed Pumping =	239,968	$16,798
Proposed Variable Speed Pumping =	27,131	$ 1,899
Savings =	212,837	$ 14,899

Existing Primary-Secondary-Tertiary Chilled Water System
Calculation of Pump Energy Consumption
Constant Speed Pumping

Building	Flow (gpm)	Head (ft)	Pump Eff.	Horse Power	Notes
Biochemistry	50	50	70%	0.90	
Bio Sciences	710	25	70%	6.40	2
Classroom	400	43	70%	6.20	
Coe Library	130	55	70%	2.58	
Earth Science	300	50	70%	5.41	1
Fine Arts	220	50	70%	3.97	1
Geo Survey	80	50	70%	1.44	1
Geology	135	48	70%	2.34	
Knight Hall	90	43	70%	1.40	
Law	82	70	70%	2.07	
Pharmacy	265	50	70%	4.78	
Physical Sciences	784	50	70%	14.14	1,2
Distribution Pumps	1800	52	80%	29.55	
Chiller Pumps	1000	40	80%	12.63	3
Totals				93.81	

Total Hp=	93.81
kW=	70.0
Hours=	3429
kWh=	239,968
$/kWh=	0.07
Cost=	**$ 16,798**

Notes:
1. Pump information estimated.
2. P&F in Building
3. Only one chiller pump included in energy calculations.

VII. Appendix

d) Cost Estimates

GLHN
ARCHITECTS & ENGINEERS, INC.

OPINION OF PROBABLE CONSTRUCTION COST

BASIS FOR ESTIMATE

☒ CODE A (No design completed)
☐ CODE B (Preliminary design)
☐ CODE C (Finished design)
☐ OTHER

COMPUTED BY: WOW	**University of Wyoming**	**PROJECT NO.**	**0003.00**
CHECKED BY: HWJ	**Chilled Water Study**	**DEPT.**	MECHANICAL
DATE 04/13/00	**Refrigeration Room Code Upgrade**	**SHEET NO.**	

SUMMARY	QUANTITY		MATERIAL		LABOR		EQUIP	TOTAL COST
MECHANICAL	**No. UNITS**	**UNIT MEAS.**	**PER UNIT**	**TOTAL**	**PER UNIT**	**TOTAL**	**PER UNIT**	
Equipment								
Exhaust Fan, 5hp utility set	1	ea	$4,200	$4,200	$298	$298		$ 4,498
Self Contained Breathing Apparat	2	ea			$300	$600		$ 600
								$ -
Sub-Total								$ 5,098
PIPING								
4" Sch 40 Welded Steel Pipe	100	lf	$6.80	$680	$12.95	$1,295		$ 1,975
Ductwork								
30" Dia Steel Galv Duct	100	lf	$9.55	$955	$16.20	$1,620		$ 2,575
Return Air Grille	4	ea	$90.50	$362	$18.60	$74		$ 436
Sub-Total								$ 3,011
CONTROLS								
Automatic Plant Controls	1	ls	$1,000	$1,000	$3,000	$3,000		$ 4,000
Refrigerant Monitor	1	ls	$4,000	$4,000	$2,000.00	$2,000		$ 6,000
Sub-Total								$ 10,000
ELECTRICAL								
Electrical	1	ls	$400	$400	$600	$600		$ 1,000
ARCHITECTURAL/ STRUCTURAL								
Window Wall	2500	sf	$1.00	$2,500	$1.33	$3,325		$ 5,825
Roof Penetrations	3	ea	$50	$150	$150	$450		$ 600
Sub-Total								$ 6,425

Total of Subtotals = $ 27,509
Overhead and Profit = 5,777
Total Construction Cost = $ 33,286
Design and Project Mngt = 9,986
Total Project Cost = $ 43,272
Total Project Cost = $ 44,000

*** SUMMARY OF MARKUPS**

Overhead = 10%
Profit = 10%
Design and Project Mngt = 30%

GLHN
ARCHITECTS & ENGINEERS, INC.

OPINION OF PROBABLE CONSTRUCTION COST

BASIS FOR ESTIMATE

☒ CODE A (No design completed)
☐ CODE B (Preliminary design)
☐ CODE C (Finished design)
☐ OTHER

COMPUTED BY: WOW	**University of Wyoming**	PROJECT NO.	0003.00
CHECKED BY: HWJ	**Chilled Water Study**	DEPT.	MECHANICAL
DATE 04/13/00	**New Cooling Tower**	SHEET NO.	

SUMMARY	QUANTITY		MATERIAL		LABOR		EQUIP	TOTAL COST
MECHANICAL	No. UNITS	UNIT MEAS.	PER UNIT	TOTAL	PER UNIT	TOTAL	PER UNIT	
EQUIPMENT								
Cooling Tower, 800 T	1	ea	$36,400	$36,400	$4,000	$4,000		$ 40,400
Fiberglass Sump, 4800 gpm	1	ea	$3,800	$3,800	$400	$400		$ 4,200
Equipment Rigging	1	ls			$3,000	$3,000		$ 3,000
Centrifugal Pump, 40 hp	2	ea	$3,100	$6,200	$530.00	$1,060		$ 7,260
Sub-Total								$ 54,860
PIPING								
12" Sch 40 Welded Steel Pipe	200	lf	$52.00	$10,400	$42.00	$8,400		$ 18,800
Butterfly Valves	8	ea	$370	$2,960	$165	$1,320		$ 4,280
Check Valve	2	ea	$920	$1,840	$298	$596		$ 2,436
Expansion Joints	4	ea	$269	$1,076	$90	$360		$ 1,436
Sub-Total								$ 26,952
CONTROLS								
Automatic Plant Controls	1	ls	$4,000	$4,000	$6,000	$6,000		$ 10,000
ELECTRICAL								
Electrical	1	ls	$2,000	$2,000	$3,000	$3,000		$ 5,000
ARCHITECTURAL/ STRUCTURAL								
Support Steel	1	ls	$8,000	$8,000	$11,000	$11,000		$ 19,000
Concrete	10	cy	$100	$1,000	$100	$1,000		$ 2,000
Access Demolition	1	ls	$1,000	$1,000	$3,000	$3,000		$ 4,000
Sub-Total								$ 25,000

Total of Subtotals = $ 113,660
Overhead and Profit = 23,869
Total Construction Cost= $ 137,529
Design and Project Mngt = 41,259
Total Project Cost= $ 178,787
Total Project Cost= $ 179,000

*** SUMMARY OF MARKUPS**

Overhead = 10%
Profit = 10%
Design and Project Mngt= 30%

GLHN
ARCHITECTS & ENGINEERS, INC.

OPINION OF PROBABLE CONSTRUCTION COST

BASIS FOR ESTIMATE

☒ **CODE A (No design completed)**
☐ **CODE B (Preliminary design)**
☐ **CODE C (Finished design)**
☐ **OTHER**

COMPUTED BY: WOW	**University of Wyoming**	**PROJECT NO.**	**0003.00**
CHECKED BY: HWJ	**Chilled Water Study**	**DEPT.**	MECHANICAL
DATE 04/13/00	**Distribution Pump Modifications**	**SHEET NO.**	

SUMMARY	QUANTITY		MATERIAL		LABOR		EQUIP	TOTAL COST
MECHANICAL	No. UNITS	UNIT MEAS.	PER UNIT	TOTAL	PER UNIT	TOTAL	PER UNIT	
EQUIPMENT								
Centrifugal Pumps- 100 hp	3	ea	$12,200	$36,600	$1,050	$3,150		$ 39,750
Variable Vrequency Drives- 100 hp	3	ea	$13,800	$41,400	$1,576	$4,728		$ 46,128
Air Separator w/ Strainer- 8"	3	ea	$2,875	$8,625	$250	$750		$ 9,375
Expansion Tank- 500 gal	2	ea	$7,550	$15,100	$201	$402		$ 15,502
Sub-Total								$ 110,755
PIPING								
12" Sch 40 Welded Steel Pipe	100	lf	$51.50	$5,150	$41.50	$4,150		$ 9,300
8" Sch 40 Welded Steel Pipe	60	lf	$22	$1,320	$27	$1,620		$ 2,940
Insulation- Fiberglass	140	lf	$7.30	$1,022	$5.95	$833		$ 1,855
Butterfly Valves	6	ea	$370	$2,220	$165	$990		$ 3,210
Check Valve	3	ea	$920	$2,760	$298	$894		$ 3,654
Expansion Joints	6	ea	$269	$1,614	$90	$540		$ 2,154
Small Piping	1	ls	$500	$500	$1,500	$1,500		$ 2,000
Sub-Total								$ 23,113
CONTROLS								
Automatic Plant Controls	1	ls	$3,000	$3,000	$5,000	$5,000		$ 8,000
ELECTRICAL								
Electrical	1	ls	$2,000	$2,000	$3,000	$3,000		$ 5,000
ARCHITECTURAL/ STRUCTURAL								
Pump Equipment Pads	3	ea	$25	$75	$75	$225		$ 300
								$ -
Sub-Total								$ 300

Total of Subtotals = $ 126,209
Overhead and Profit = 26,504
Total Construction Cost= $ 152,713
Design and Project Mngt = 45,814
Total Project Cost= $ 198,527
Total Project Cost= $ 199,000

*** SUMMARY OF MARKUPS**

Overhead = 10%
Profit = 10%
Design and Project Mngt= 30%

GLHN
ARCHITECTS & ENGINEERS, INC.

OPINION OF PROBABLE CONSTRUCTION COST

BASIS FOR ESTIMATE

☒ **CODE A (No design completed)**
☐ **CODE B (Preliminary design)**
☐ **CODE C (Finished design)**
☐ **OTHER**

COMPUTED BY: WOW
CHECKED BY: HWJ
DATE 04/13/00

University of Wyoming
Chilled Water Study
Electric Chiller Replacement

PROJECT NO. **0003.00**
DEPT. MECHANICAL
SHEET NO.

SUMMARY MECHANICAL	QUANTITY No. UNITS	UNIT MEAS.	MATERIAL PER UNIT	MATERIAL TOTAL	LABOR PER UNIT	LABOR TOTAL	EQUIP PER UNIT	TOTAL COST
EQUIPMENT								
800T Electric Centrifugal Chiller	1	ea	$182,000	$182,000	$14,700	$14,700		$ 196,700
Sub-Total								$ 196,700
PIPING								
Chilled Water and Condensate Pi	1	ls	$45,000	$45,000	$38,700	$38,700		$ 83,700
CONTROLS								
Automatic Plant Controls	1	ls	$16,000	$16,000	$21,000	$21,000		$ 37,000
ELECTRICAL								
Electrical	1	ls	$27,000	$27,000	$40,000	$40,000		$ 67,000
ARCHITECTURAL/ STRUCTURAL								
Access Demolition	1	ls			$3,000	$3,000		$ 3,000
Sub-Total								$ 3,000

*** SUMMARY OF MARKUPS**

Overhead =	10%
Profit =	10%
Design and Project Mngt=	15%

Total of Subtotals =	$	387,400
Overhead and Profit =		81,354
Total Construction Cost=	$	468,754
Design and Project Mngt =		70,313
Total Project Cost=	$	539,067
Total Project Cost=	**$**	**540,000**

GLHN
ARCHITECTS & ENGINEERS, INC.

OPINION OF PROBABLE CONSTRUCTION COST

BASIS FOR ESTIMATE
☒ **CODE A (No design completed)**
☐ **CODE B (Preliminary design)**
☐ **CODE C (Finished design)**
☐ **OTHER**

COMPUTED BY: WOW
CHECKED BY: HWJ
DATE 05/18/00

University of Wyoming
Chilled Water Study
Central Expansion Tank

PROJECT NO. 0003.00
DEPT. MECHANICAL
SHEET NO.

SUMMARY	QUANTITY		MATERIAL		LABOR		EQUIP	TOTAL COST
MECHANICAL	No. UNITS	UNIT MEAS.	PER UNIT	TOTAL	PER UNIT	TOTAL	PER UNIT	
Central Plant								
500 gal Bladder Expansion Tank	1	ea	$7,550	$7,550	$201	$201		$ 7,751
Hot Tap	1	ea			$100	$100		$ 100
1-1/2" Type L Copper	30	lf	$2.93	$87.90	$5.10	$153.00		$ 241
1-1/2" 90 Copper Elbows	6	ea	$2.16	$12.96	$20.50	$123.00		$ 136
2"x2"x1-1/2" Copper Tee	1	ea	$4.45	$4.45	$33.50	$33.50		$ 38
								$ -
Sub-Total								$ 8,266
Individual Buildings								
Contractor Set Up	1	ls			$300	$300		$ 300
Drain Chilled Water	1	ls			$100	$100		$ 100
Demo Expansion Tank	1	ls			$100	$100		$ 100
Pressure Relief Valve	1	ea	$63.00	$63	$10	$10		$ 73
1/2" Type L Copper	30	lf	$1.14	$34.20	$3.28	$98.40		$ 133
								$ -
Sub-Total/ Building				$97.20		$608.40		$ 706
Sub-Total	12	ea	$97	$1,166	$608.40	$7,301		$ 8,467

Total of Subtotals =	$ 16,733
Overhead and Profit =	3,514
Total Construction Cost=	$ 20,247
Design and Project Mngt =	3,037
Total Project Cost=	$ 23,284
Total Project Cost=	**$ 24,000**

*** SUMMARY OF MARKUPS**

Overhead =	10%
Profit =	10%
Design and Project Mngt=	15%

GLHN
ARCHITECTS & ENGINEERS, INC.

OPINION OF PROBABLE CONSTRUCTION COST

BASIS FOR ESTIMATE

☒ **CODE A (No design completed)**
☐ **CODE B (Preliminary design)**
☐ **CODE C (Finished design)**
☐ **OTHER**

COMPUTED BY: WOW	**University of Wyoming**	**PROJECT NO.**	**0003.00**
CHECKED BY: HWJ	**Chilled Water Study**	**DEPT.**	MECHANICAL
DATE 04/13/00	**Bldg CHW Interface Modfications**	**SHEET NO.**	

SUMMARY	**QUANTITY**		**MATERIAL**		**LABOR**		**EQUIP**	**TOTAL COST**
MECHANICAL	**No. UNITS**	**UNIT MEAS.**	**PER UNIT**	**TOTAL**	**PER UNIT**	**TOTAL**	**PER UNIT**	

4" Chilled Water Connection

DEMOLITION								$ -
Contractor Set Up	1	ls			$300	$300		$ 300
Drain Chilled Water	1	ls			$100	$100		$ 100
Remove Pumps	1	ls			$200	$200		$ 200
Demo Pipe/ Insulation	1	ls			$150	$150		$ 150
Remove Control Valve	1	ls			$50	$50		$ 50
								$ -
NEW CONSTRUCTION								$ -
4" Sch. 40 Piping, Welded	30	lf	$6.80	$204	$13.27	$398		$ 602
4" x1.5" Fiberglass Insulation	30	lf	$3.71	$111	$3.19	$96		$ 207
4" Cap	1	ea	$9	$9	$44	$44		$ 53
Fill/ Start Up	1	ls			$50	$50		$ 50
								$ -
								$ -

Subtotals = $ 1,712
Markups* = 670
Total = $ 2,382
Total Project Cost = $ 2,400

*** SUMMARY OF MARKUPS**

Overhead = 10%
Profit = 10%
Design and Project Mngt = 15%

6" Chilled Water Connection

DEMOLITION								$ -
Contractor Set Up	1	ls			$300	$300		$ 300
Drain Chilled Water	1	ls			$100	$100		$ 100
Remove Pump	1	ls			$200	$200		$ 200
Demo Pipe/ Insulation	1	ls			$175	$175		$ 175
Remove Control Valve	1	ls			$75	$75		$ 75
								$ -
NEW CONSTRUCTION								$ -
6" Sch. 40 Piping, Welded	30	lf	$16.60	$498	$21.85	$656		$ 1,154
6" x1.5" Fiberglass Insulation	30	lf	$4.26	$128	$4.07	$122		$ 250
6" Cap	1	ea	$17	$17	$79.37	$79		$ 96
Fill/ Start Up	1	ls			$100	$100		$ 100
								$ -
								$ -

Subtotals = $ 2,450
Markups* = 959
Total = $ 3,409
Total Project Cost = $ 3,500

*** SUMMARY OF MARKUPS**

Overhead = 10%
Profit = 10%
Design and Project Mngt = 15%

GLHN
ARCHITECTS & ENGINEERS, INC.

OPINION OF PROBABLE CONSTRUCTION COST

BASIS FOR ESTIMATE

☒ **CODE A (No design completed)**
☐ **CODE B (Preliminary design)**
☐ **CODE C (Finished design)**
☐ **OTHER**

COMPUTED BY: WOW	**University of Wyoming**	**PROJECT NO.**	**0003.00**
CHECKED BY: HWJ	**Chilled Water Study**	**DEPT.**	MECHANICAL
DATE 04/13/00	**Bldg CHW Interface Modfications**	**SHEET NO.**	

SUMMARY	**QUANTITY**		**MATERIAL**		**LABOR**		**EQUIP**	**TOTAL COST**
MECHANICAL	**No. UNITS**	**UNIT MEAS.**	**PER UNIT**	**TOTAL**	**PER UNIT**	**TOTAL**	**PER UNIT**	

8" Chilled Water Connection

DEMOLITION								$ -
Contractor Set Up	1	ls			$300	$300		$ 300
Drain Chilled Water	1	ls			$100	$100		$ 100
Remove Pump	1	ls			$200	$200		$ 200
Demo Pipe/ Insulation	1	ls			$175	$175		$ 175
Remove Control Valve	1	ls			$75	$75		$ 75
								$ -
NEW CONSTRUCTION								$ -
8" Sch. 40 Piping, Welded	30	lf	$22.00	$660	$27.18	$815		$ 1,475
8" x1.5" Fiberglass Insulation	30	lf	$5.35	$161	$4.97	$149		$ 310
8" Cap	1	ea	$26	$26	$99	$99		$ 125
Fill/ Start Up	1	ls			$100	$100		$ 100
								$ -
								$ -

Subtotals =	$ 2,860
Markups* =	1,120
Total =	$ 3,980
Total Project Cost =	**$ 4,000**

*** SUMMARY OF MARKUPS**

Overhead =	10%
Profit =	10%
Design and Project Mngt =	15%

GLHN
ARCHITECTS & ENGINEERS, INC.

OPINION OF PROBABLE CONSTRUCTION COST

BASIS FOR ESTIMATE

☒ **CODE A (No design completed)**
☐ **CODE B (Preliminary design)**
☐ **CODE C (Finished design)**
☐ **OTHER**

COMPUTED BY: WOW	**University of Wyoming**	**PROJECT NO.**	**0003.00**
CHECKED BY: HWJ	**Chilled Water Study**	**DEPT.**	MECHANICAL
DATE 04/13/00	**2-Way Valve Conversion**	**SHEET NO.**	

2" Valve Conversion

SUMMARY MECHANICAL	QUANTITY No. UNITS	QUANTITY UNIT MEAS.	MATERIAL PER UNIT	MATERIAL TOTAL	LABOR PER UNIT	LABOR TOTAL	EQUIP PER UNIT	TOTAL COST
DEMOLITION								$ -
Contractor Set Up	1	ls			$300	$300		$ 300
Drain Chilled Water	1	ls			$50	$50		$ 50
Remove 3-way Valve	1	ea			$50	$50		$ 50
Demo Pipe/ Insulation	1	ls			$100	$100		$ 100
								$ -
NEW CONSTRUCTION								$ -
2" 2-way Control Valve	1	ea	$480	$480	$30	$30		$ 510
Temperature Sensor	1	ea	$100	$100	$25	$25		$ 125
Temperature Well	1	ea	$38.50	$39	$19	$19		$ 58
Pete Plugs	2	ea	$5	$10	$25	$50		$ 60
2" Sch. 40 Piping, Welded	5	lf	$3.20	$16	$8.65	$43		$ 59
2" x1.5" Fiberglass Insulation	5	lf	$2.87	$14	$2.35	$12		$ 26
2" Cap	1	ea	$7.05	$7	$24.22	$24		$ 31
								$ -
Valve Adjustment	1	ls			$50	$50		$ 50
Fill/ Start Up	1	ls			$50	$50		$ 50

*** SUMMARY OF MARKUPS**

Overhead = 10%
Profit = 10%
Design and Project Mngt = 15%

Subtotals = $ 1,469
Markups* = 575
Total = $ 2,044
Total Project Cost = $ 2,100

3" Valve Conversion

SUMMARY MECHANICAL	QUANTITY No. UNITS	QUANTITY UNIT MEAS.	MATERIAL PER UNIT	MATERIAL TOTAL	LABOR PER UNIT	LABOR TOTAL	EQUIP PER UNIT	TOTAL COST
DEMOLITION								$ -
Contractor Set Up	1	ls			$300	$300		$ 300
Drain Chilled Water	1	ls			$50	$50		$ 50
Remove 3-way Valve	1	ea			$50	$50		$ 50
Demo Pipe/ Insulation	1	ls			$100	$100		$ 100
								$ -
NEW CONSTRUCTION								$ -
3" 2-way Control Valve	1	ea	$675	$675	$106	$106		$ 781
Temperature Sensor	1	ea	$100	$100	$25	$25		$ 125
Temperature Well	1	ea	$38.50	$39	$19	$19		$ 58
Pete Plugs	2	ea	$5	$10	$25	$50		$ 60
3" Sch. 40 Piping, Welded	5	lf	$5.05	$25	$12.28	$61		$ 87
3" x1.5" Fiberglass Insulation	5	lf	$3.24	$16	$2.63	$13		$ 29
3" Flange	1	ea	$21.50	$22	$37	$37		$ 59
3" Cap	1	ea	$7.05	$7	$24.22	$24		$ 31
								$ -
Valve Adjustment	1	ls			$50	$50		$ 50
Fill/ Start Up	1	ls			$50	$50		$ 50

*** SUMMARY OF MARKUPS**

Overhead = 10%
Profit = 10%
Design and Project Mngt = 15%

Subtotals = $ 1,830
Markups* = 716
Total = $ 2,546
Total Project Cost = $ 2,600

GLHN
ARCHITECTS & ENGINEERS, INC.

OPINION OF PROBABLE CONSTRUCTION COST

BASIS FOR ESTIMATE

☒ **CODE A (No design completed)**
☐ **CODE B (Preliminary design)**
☐ **CODE C (Finished design)**
☐ **OTHER**

COMPUTED BY: WOW
CHECKED BY: HWJ
DATE 04/13/00

University of Wyoming
Chilled Water Study
2-Way Valve Conversion

PROJECT NO. 0003.00
DEPT. MECHANICAL
SHEET NO.

SUMMARY MECHANICAL	QUANTITY No. UNITS	UNIT MEAS.	MATERIAL PER UNIT	MATERIAL TOTAL	LABOR PER UNIT	LABOR TOTAL	EQUIP PER UNIT	TOTAL COST
4" Valve Conversion								
DEMOLITION								$ -
Contractor Set Up	1	ls			$300	$300		$ 300
Drain Chilled Water	1	ls			$50	$50		$ 50
Remove 3-way Valve	1	ea			$50	$50		$ 50
Demo Pipe/ Insulation	1	ls			$100	$100		$ 100
								$ -
								$ -
NEW CONSTRUCTION								$ -
4" 2-way Control Valve	1	ea	$865	$865	$160	$160		$ 1,025
Temperature Sensor	1	ea	$100	$100	$25	$25		$ 125
Temperature Well	1	ea	$38.50	$39	$19	$19		$ 58
Pete Plugs	2	ea	$5	$10	$25	$50		$ 60
4" Sch. 40 Piping, Welded	5	lf	$6.80	$34	$13.27	$66		$ 100
4" x1.5" Fiberglass Insulation	5	lf	$3.71	$19	$3.19	$16		$ 35
4" Flange	1	ea	$27	$27	$40	$40		$ 67
4" Cap	1	ea	$9	$9	$44	$44		$ 53
								$ -
Valve Adjustment	1	ls			$50	$50		$ 50
Fill/ Start Up	1	ls			$50	$50		$ 50
								$ -
								$ -

*** SUMMARY OF MARKUPS**

Overhead =	10%
Profit =	10%
Design and Project Mngt =	15%

Subtotals =	$ 2,122
Markups* =	831
Total =	$ 2,953
Total Project Cost =	**$ 3,000**

BUILDING VALVE CONVERSION AND PUMP REMOVAL

Building	Tons	Pumps	Air Hand	CHW Conn.	Bldg Inter. $	Ton/ AHU	Valve Conv. $	Notes
Biochemistry	26	1	1	4	$ 2,400	26.0	$ 2,600	
Bio Sciences	198	6	11	8	$ 4,000	18.0	$ 23,100	
Classroom	99	2	2	6	$ 3,500	49.5	$ 6,000	Number of AHU unknown.
Coe Library	65	2	1	4	$ 2,400	65.0	$ 6,000	
Earth Science	75	2	2	6	$ 3,500	37.5	$ 6,000	
Fine Arts	110	6	5	6	$ 3,500	22.0	$ 13,000	2-way valves installed w/ coil pumps
Geo Survey	25	1	1	2.5	$ 2,400	25.0	$ 2,600	
Geology	20	1	2	4	$ 2,400	10.0	$ 4,200	
Knight Hall	45	2	1	4	$ 2,400	45.0	$ 3,000	
Law	79	2	6	4	$ 2,400	13.2	$ 12,600	
Pharmacy	70	1	1	5	$ 3,000	70.0	$ 6,000	
Physical Sciences	198	5	6	6	$ 3,500	33.0	$ 15,600	Number of secondary units and univents unknown
					$35,400		$100,700	

Total Bldg CHW Interface Modifications = $ 35,400
Total 2-way Valve Conversion= $100,700
Total Construction Cost= $136,100

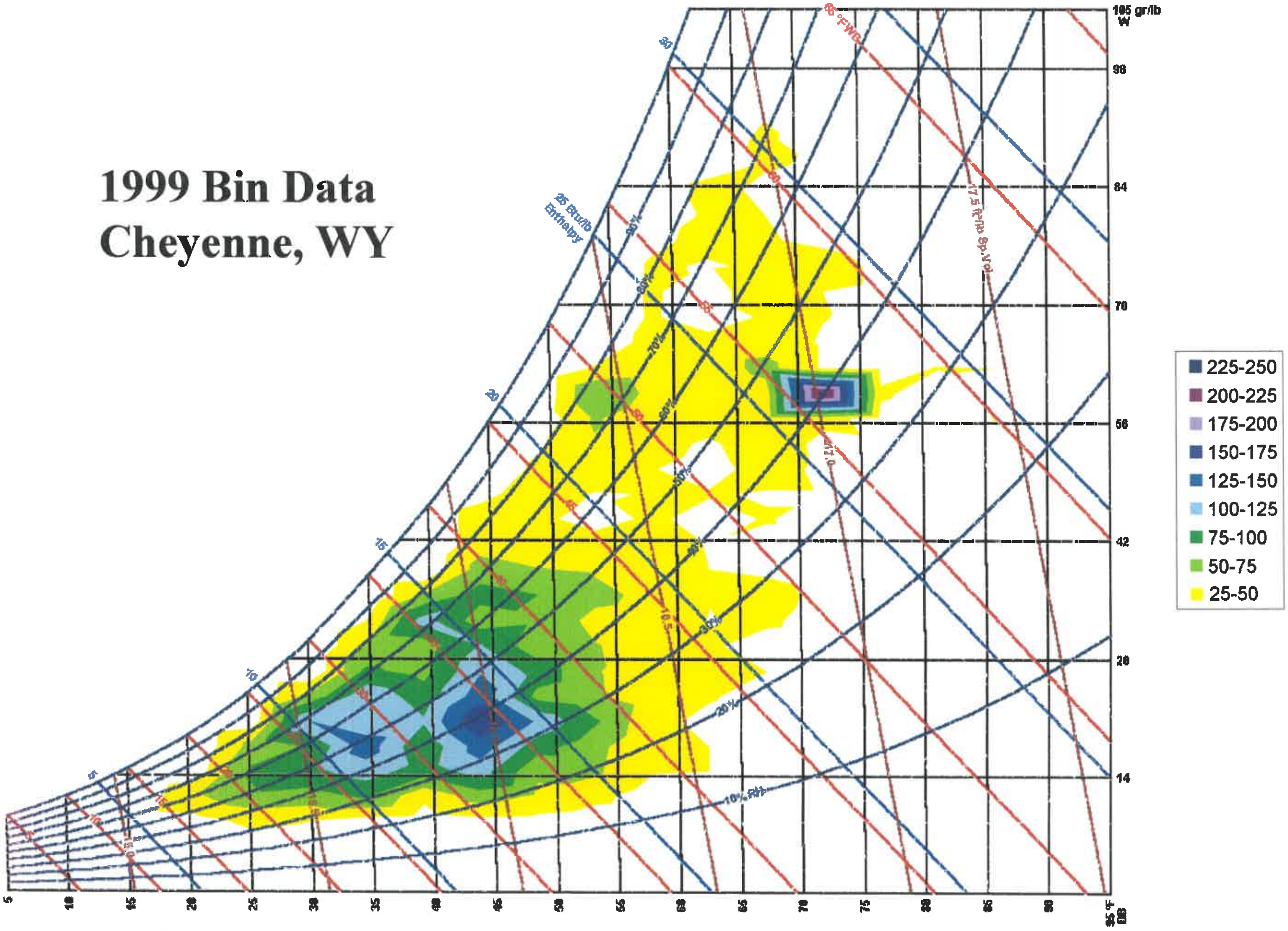
Bldg Interfaces	
Size	Cost
2.5	$ 2,400
4	$ 2,400
5	$ 3,000
6	$ 3,500
8	$ 4,000

Valve Conversions		
Size	Tons	Cost
	1	
2	21	$ 2,100
3	35	$ 2,600
4	50	$ 3,000
8	100	$ 6,000

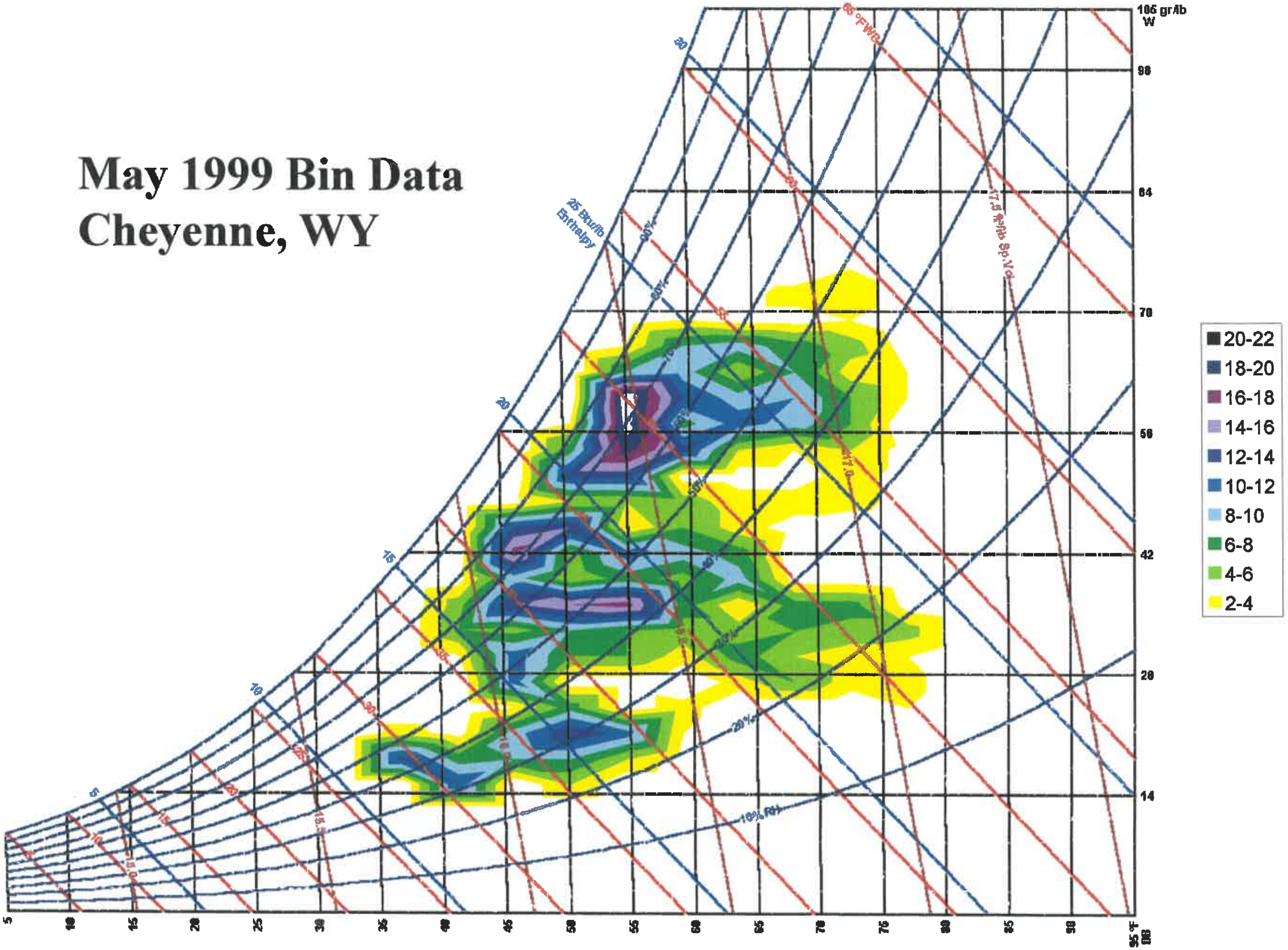
VII. Appendix

e) Weather Charts

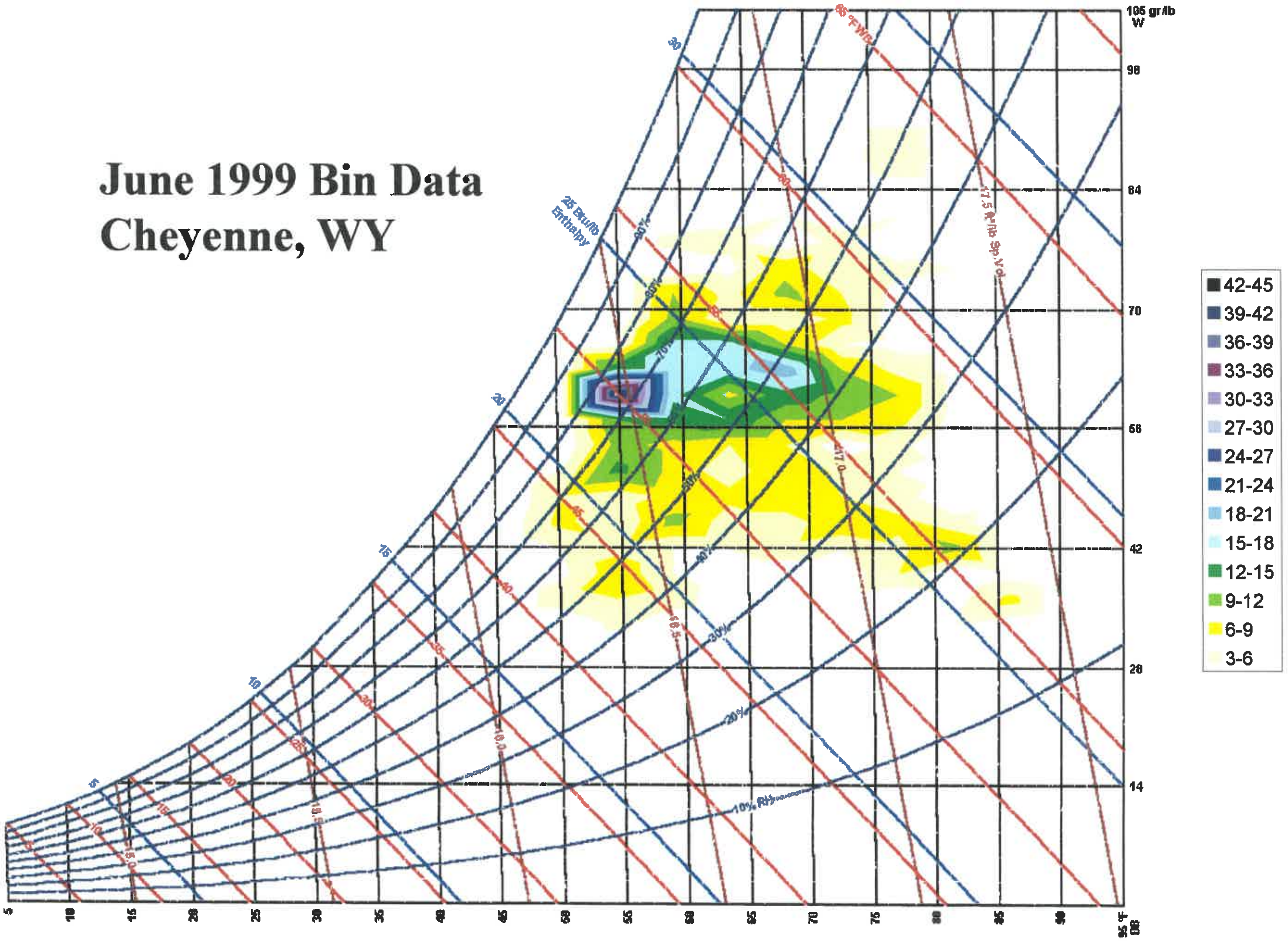
1999 Bin Data
Cheyenne, WY



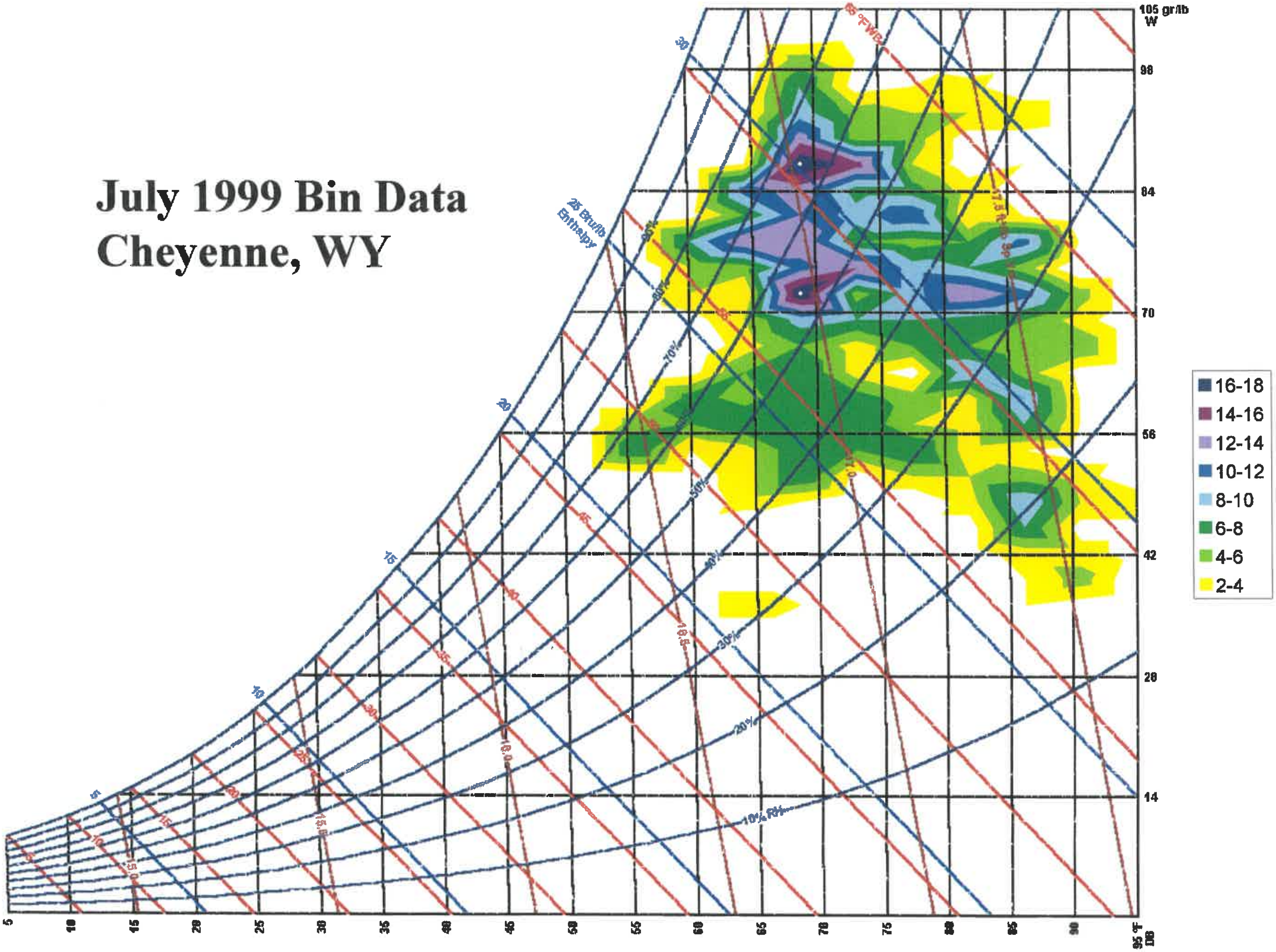
May 1999 Bin Data
Cheyenne, WY



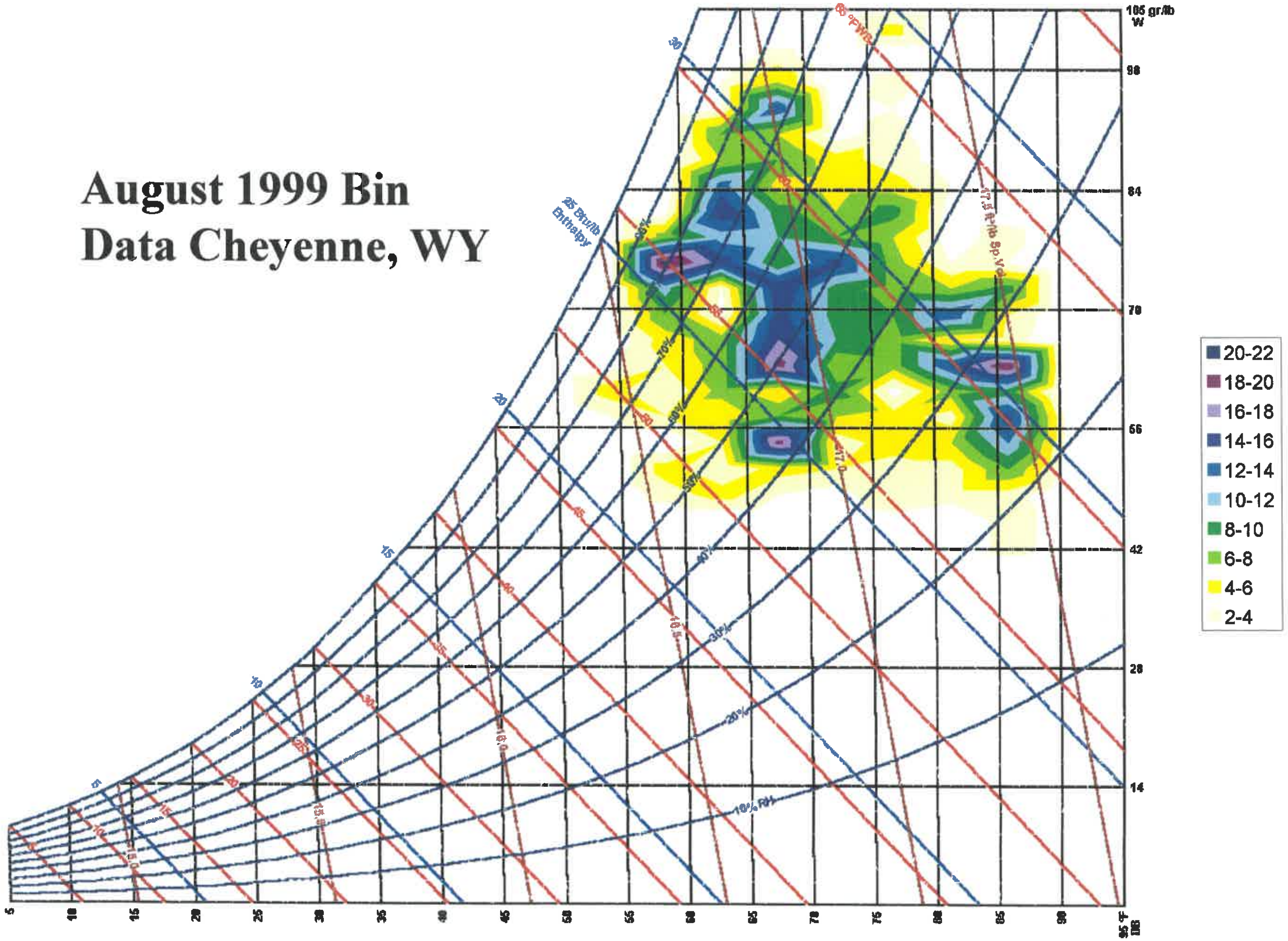
June 1999 Bin Data
Cheyenne, WY



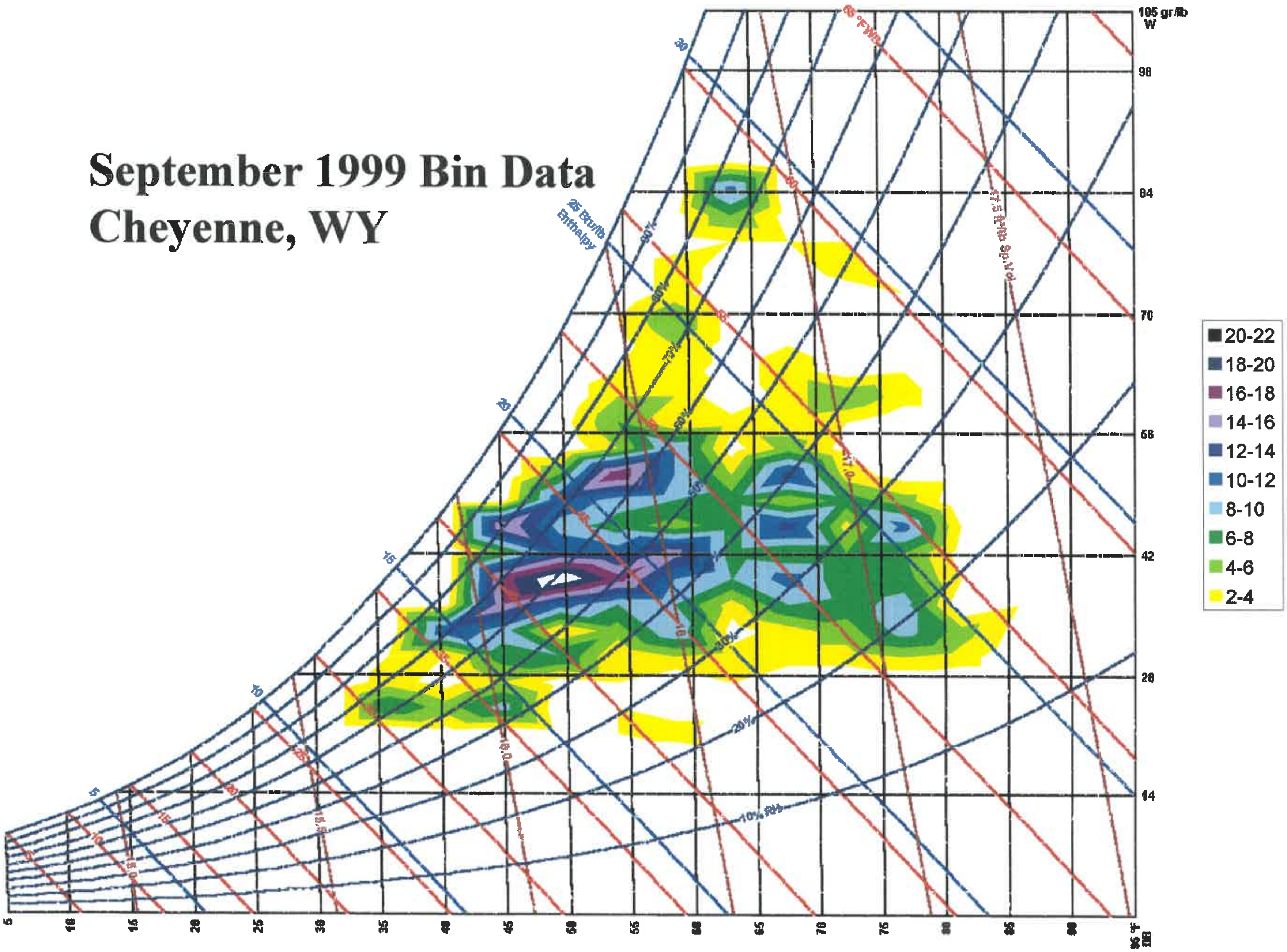
July 1999 Bin Data
Cheyenne, WY



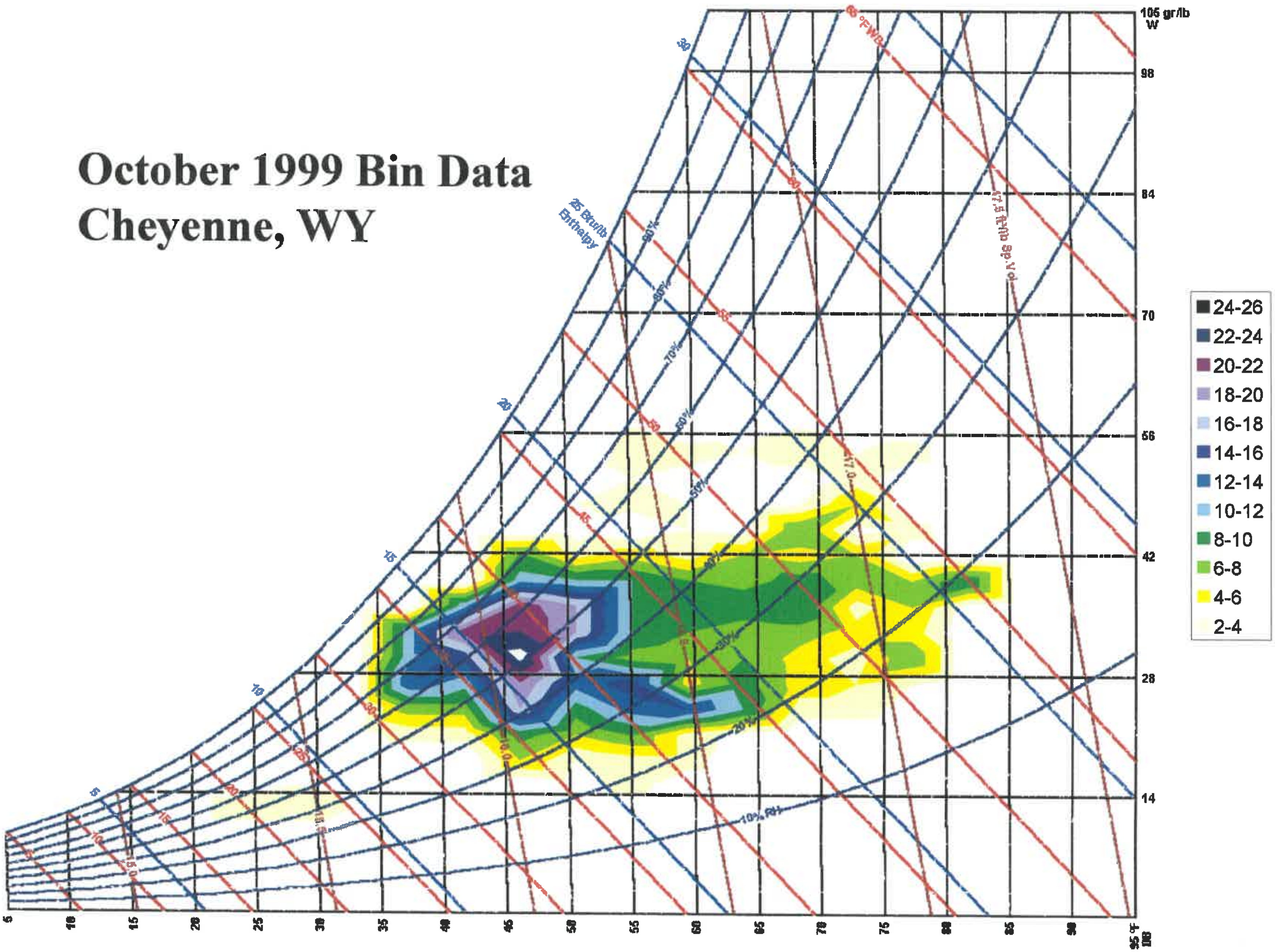
August 1999 Bin Data Cheyenne, WY



September 1999 Bin Data
Cheyenne, WY

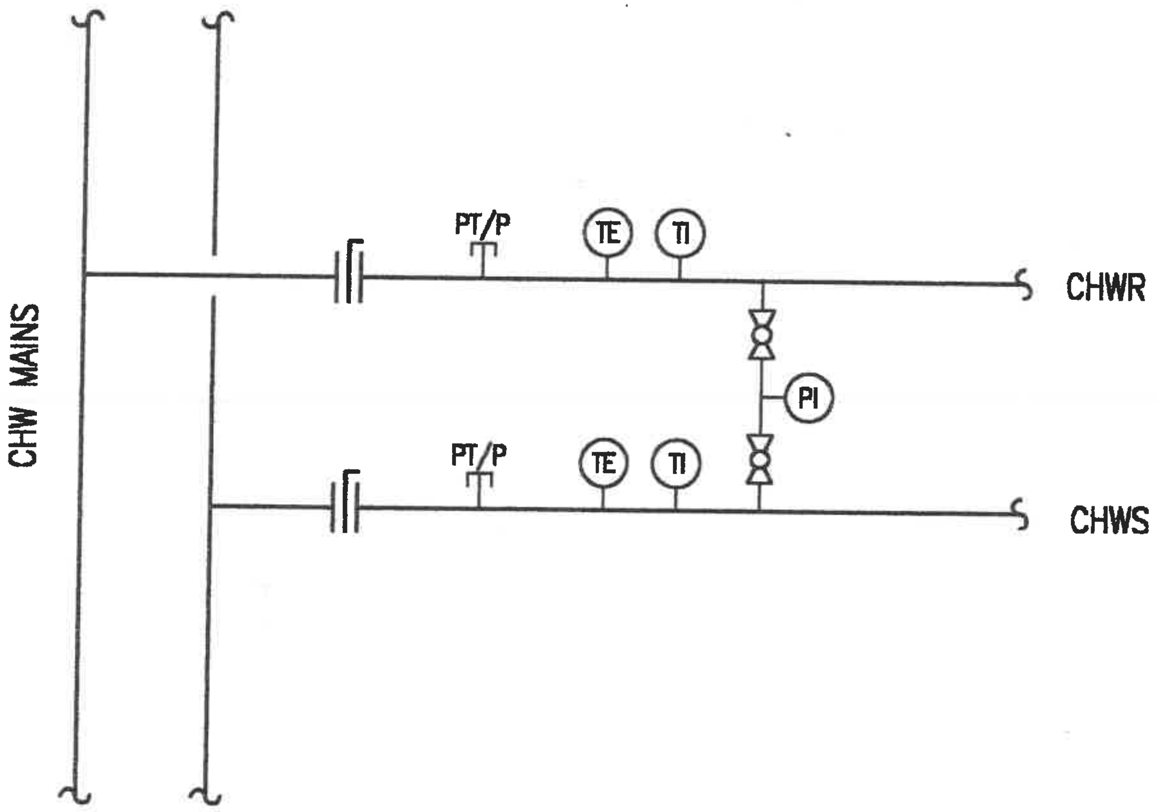


October 1999 Bin Data
Cheyenne, WY



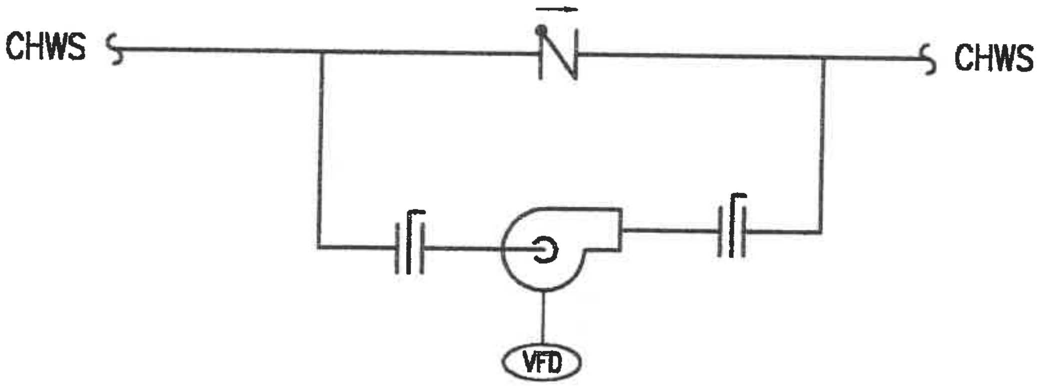
VII. Appendix

f) Proposed Building Interface Drawings and Coil Connection Detail



S BUILDING CHW CONNECTION DETAIL

NTS

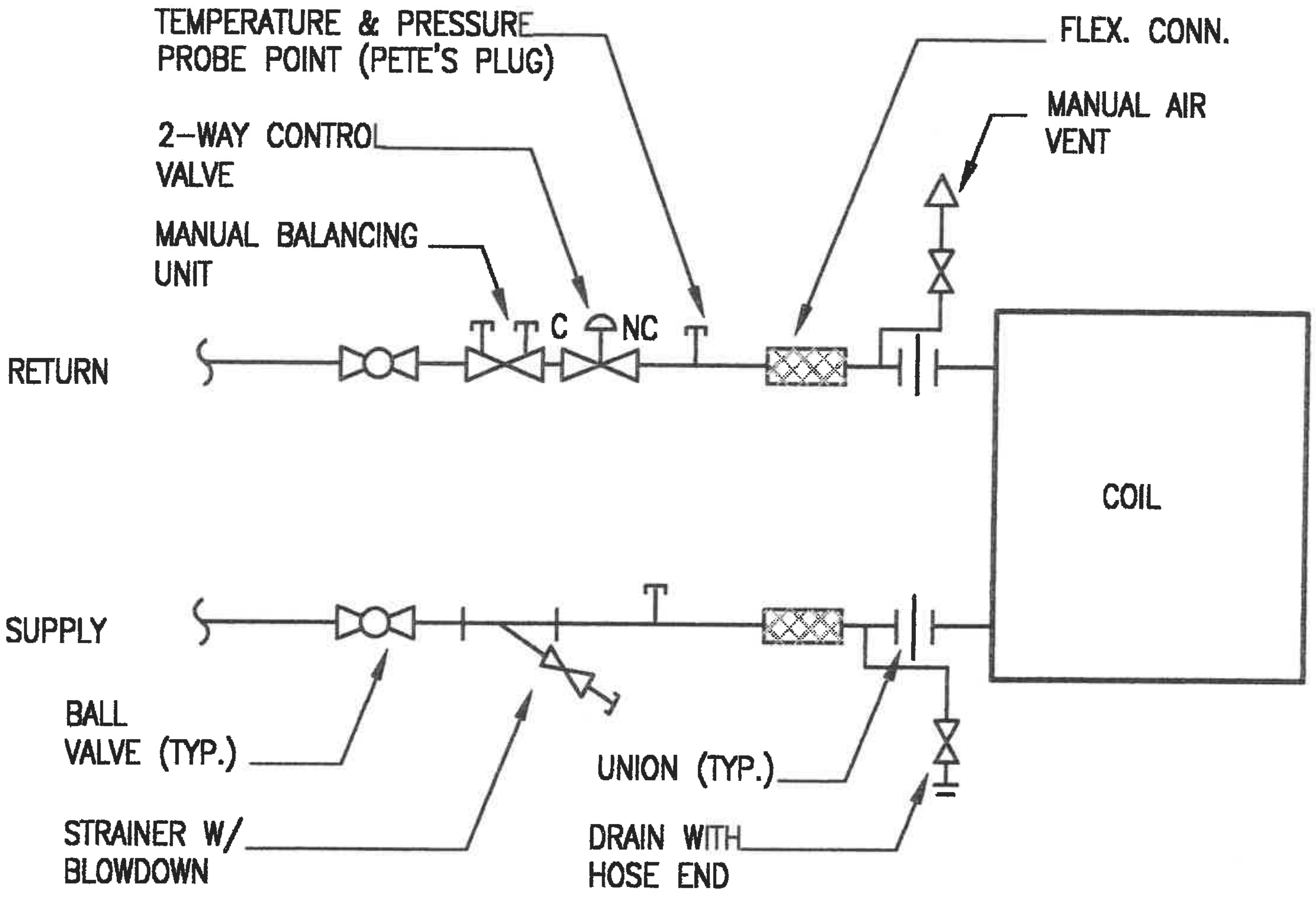


NOTES:

1. CONTROL PUMP VFD TO MAINTAIN A PRESSURE DIFFERENCE (ADJUSTABLE) BETWEEN THE BUILDING CHWS AND CHWR.

S BOOSTER PUMP DETAIL

NTS



S Coil Piping w/ 2-Way Valve

NTS

P154