CHILLER PLANT CFC, ENERGY, AND OPERATIONAL IMPROVEMENTS....or, *Killing Three "Birds" with One Stone*

James P. Waltz, P.E., C.E.M.
President, Energy Resource Associates, Inc.
Charter Member, AEE

ABSTRACT

This paper explores the hidden opportunities that exist when planning CFC abatement or modernization projects for central cooling plants, both small and large.

It is critically important to perform an in-depth, comprehensive, and integrated re-evaluation of the entire cooling plant, its auxiliaries and its distribution system. By doing so, numerous system improvements can be identified and implemented which will reduce operating costs, simplify maintenance, improve plant operations, enhance plant reliability and even improve building comfort. Among the improvement measures are more efficient chillers, cooling tower replacement and optimization, plant re-sizing, optimizing primary and auxiliary equipment "mix", chilled water variable flow conversion, multiple-plant integration, installation of dedicated cooling systems and fuel substitution. These measures can all independently, or concurrently, contribute to dramatically improved cooling operations.

The paper refers to numerous actual projects that have already employed these techniques and also discusses the major CFC abatement compliance dates.

The hidden opportunities presented and explained in this paper can do much to take the "sting" out of an otherwise onerous regulatory "predicament" and, perhaps most significantly, help to secure funding from management for much-needed projects sooner rather than later.

THE ESSENTIAL ALTERNATIVES

Given the unattractive nature of the likely scenarios, facility managers face a few basic alternatives when it comes to CFC abatement. These include:

1. Stockpile refrigerant, "tighten up" leaking machines (systems containing over 50 pounds of refrigerant are restricted to 15% per year leakage, including extensive record-keeping) and "ride it out" for as long as you can - we call this the "head-in-the-sand" approach.
2. Retrofit the refrigeration machine to a non-CFC refrigerant -- sometimes a feasible alternative.
3. Retrofit the plant with new, non-CFC refrigeration equipment.

The first alternative is clearly limited in its applicability. However, even the second alternative is limited in that many of the central cooling plants in existence in buildings across the United States are too old to be realistically retrofitted for use with the non-CFC refrigerants available today. This is because the considerable expenditure in both parts and labor are not justified by the remaining life expectancy of the equipment. Facilities with equipment in excess of 15 years of age are probably considering the possibility of replacing their aging refrigeration equipment rather than converting it. Many facilities, therefore, are faced with a large capital expenditure in the near future -- no matter which approach they choose.

INTEGRATION -- A SUCCESSFUL APPROACH

As mechanical, electrical and control systems engineers specializing in existing facilities (rather than new construction), our firm has been asked by many building owners to help them face the CFC abatement dilemma which is forcing them to plan for major expenditures on their central cooling plant. Since the process of "replacing" a central cooling plant is a large and complicated process it needs to be planned carefully. The planning process allows a facility manager and his engineering team the opportunity to carefully examine the system as a whole and uncover many possibilities to modernize their plants and make them more energy efficient, provide added capacity and reliability, improve plant operations and maintenance, and maybe even improve comfort! By uncovering these "hidden" opportunities, not only can we produce "more bang for the buck", but also present a well-thought-out, comprehensive modernization project which offers enough attractive benefits and features so as to take some of the "sting" out of CFC retrofit for management, and allow more willing project funding than might otherwise occur.

While the above might seem somewhat idealistic, our experience over the years has demonstrated a couple of "truths" about our business.

First of all, those of us who work a lot in the energy conservation business tend to get "hung-up" on the notion that return on investment is the prime motivator of facility owners. In other words, unless there's a really attractive payback, the owner won't proceed with a project. However, what is sometimes lost sight of is that there are many goals and objectives that a facility owner may have in mind. Our experience in particular has shown that facilities with unmet deferred maintenance and repair needs (and nearly all facilities have them) are excellent candidates for projects which combine both energy conservation work (with a good return on investment) and facility repair and restoration work (with little or no return). By combining the projects, the owner can fix up his facility while simultaneously making a modest return on his investment -- when in fact they were not anticipating a return at all on the restoration work!

Secondly, in the forms of energy conservation referred to as "energy services" or "demand side management", heating ventilating and air conditioning (HVAC) is the "tough nut" to crack in improving the overall efficiency of our nationwide inventory of facilities. That utility companies tout "compact fluorescent" demand side management programs is proof enough that making deep reductions in HVAC energy use requires a highly organized, highly skilled and highly experienced infrastructure (which is not easily or quickly assembled). Anyone can "slap" in an incandescent-to-fluorescent conversion fixture or an energy management computer, but it takes a systemic, inside-out system re-engineering to transform the nature of an HVAC system's energy use.

The transformation of central cooling plants, in our experience, tends to follow these same "rules". In order to develop a project which will both result in significant reductions of the level of energy use and offer benefits which capture managements interest and support (read: "funding"), it takes a thoughtful, integrated approach, and a complete re-thinking of cooling operations -- to develop a blend of system upgrades and modifications which are mutually complementary and beneficial.

CHILLED WATER PLANT MODERNIZATION OPPORTUNITIES

Actually, quite a few opportunities exist which are mutually complementary and work to produce attractive benefits and outcomes from an otherwise disagreeable prospect. Some of the ones we've managed to incorporate into our projects are discussed below.

More Efficient Refrigeration and Heat Rejection Equipment.

The first and most obvious opportunity is the ability to replace older, less-energy-efficient machines with new, energy-efficient equipment. Much of the equipment in production today is far more energy efficient than its predecessors. A central chiller and optimally sized cooling tower of current vintage in many cases will use nearly half the energy consumed by an older less optimally configured system. Most modern chillers also have integrated control systems which allow a direct interface with building automation systems. This ability to communicate directly with the chiller allows for more simplified and effective automated reset of chilled water temperature, allowing additional energy conservation.

For example, central cooling plants designed and built 15 to 30 years ago generally employed refrigeration machines that operated in the range of 0.8 to 0.9 kw/ton. Modern machines are custom-assembled from a range of computeranalyzed evaporators, condensers, motors and compressors. Manufacturers can easily evaluate a whole range of component combinations to meet various flow rate restrictions (say the condenser water piping would be prohibitively expensive to replace, but is a little undersized), electrical and installation space constraints. One recent project was constrained to a basement chiller room with very limited "real estate" available for the chillers themselves - yet very efficient chillers were found that would fit in the available space. Even a constrained chiller selection will result in a refrigeration machine that can operate at 0.6 kw/ton even at ARI standard conditions - roughly a 30% reduction from typical existing equipment.

Generally, if the chillers are near the end of their life expectancy, so will the cooling towers. This is the perfect time to re-evaluate cooling tower sizing. While design wet bulb temperature is very constraining in many climates, in many it is not. Yet traditional "rules of thumb" have resulted in a great many cooling towers being selected to provide 85°F condenser water to the refrigeration equipment. Recently the potential for greater use of the evaporative cooling process has received greater attention, with the result, especially in relatively "benign" climates such as northern California, of cooling tower sizing being value engineered to provide the most cost-effective combination of approach and cost. Simply stated, "approach" of "approach temperature" is how close the cooling tower can get the water it cools to the design wet bulb temperature (which is the equilibrium temperature of the evaporative cooling process - and can be directly measured with a sling psychrometer). While an 18 degree approach would be traditional in northern California (85° condenser water with a 67° design wet bulb), 5 to 8° approaches are relatively easily achieved! With condenser water at 75° instead of 85°, much lower chiller kw/ton can be achieved, down to 0.5 or even lower! Given the fact that a cooling tower is in its essence just a big box full of corrugated plastic, the added cost to increase the size of a cooling tower (rather than just increase the fan speed and motor size - which would be counter to energy efficiency) is relatively cheap compared to the reduction in chiller power consumption and cost of operation. Obviously the longer the annual operating hours and the hotter the climate, the faster a bigger tower will pay for itself. On one hospital project, for example, the added cost of a larger tower was approximately $10,000 (for equipment only), while the annual reduction in chiller operating cost was nearly $20,000.

Increase Plant Capacity.

An added benefit of modern chillers is their physical size. Many of today's chillers are much smaller in size than their predecessors of equal capacity. In addition, the newer chillers operate at a much lower kw/ton. The implication of both these factors is the ability to install greater cooling capacity in the same space and without increasing the connected electrical load or the electrical service equipment. This can prove to be very beneficial if the existing system is under capacity or if there are plans for increased demands on the cooling plant, say, perhaps the addition of a new wing in the near future. Building in additional capacity into the central cooling plant may obviate the need for installing peripheral, ancillary cooling equipment as an afterthought to meet future needs.

Decrease Plant Capacity.

Perhaps your chiller water plant was adequately sized when it was originally built....., or even oversized. By combining retrofit projects such as lighting fixture retrofit, make-up air evaporative pre-cooling or air-to-air heat recovery with the chilled water plant replacement, the refrigeration equipment can be downsized, thereby decreasing the total cost of retrofit -- and potentially providing even more efficient plant operation. For example, reducing the condenser water flow in an existing piping system by 10% can reduce the power required for pumping the condenser water in the neighborhood of 30% - even more if the chiller condenser selection is optimized for water pressure drop.

Improve "Mix" of Primary and Auxiliary Plant Equipment.

Generally new construction design is rightly focused on peak design conditions and operations. However, light load conditions occur with much greater frequency. The result, at times, is that the mix of cooling equipment is such that a very large machine is actually the smallest machine available and its auxiliaries (chilled water pump, condenser water pump, cooling tower, etc.) may actually exceed the refrigeration machine itself in terms of total power draw on light load days. Not only does having "oversized" auxiliaries in operation waste energy, but a less than optimal mix of equipment may actually provide less reliability and redundancy than is needed. For example, a 500 ton plant with two 250 ton centrifugal chillers is very vulnerable should one machine be lost. Increasing the total number of machines to 3, of perhaps 125, 225 and 225 tons capacity would provide some additional capacity, allow the entire facility to operate normally on all but the hottest days if the smallest chiller were lost and would even allow 70% operation on the hottest day if the largest chiller were lost to service. Depending upon the nature of the operation, having a "spare" chiller may be of great value and could potentially be easily incorporated into a CFC retrofit project quite easily (though at increased cost of course).

Furthermore, depending upon the variety of type of loads being supported (perhaps a computer center as well as general office space), it may make sense to select one or more of the refrigeration machines so that it is very well suited for the critical load, particularly with regard to turn-down and cycle-time capabilities. For example, a 250 ton centrifugal attempting to carry a 25 ton minimum computer room load in cold weather might cycle off and not be restartable for 30 minutes, which might allow the computer room to overheat -- whereas a smaller rotary screw or reciprocating machine would be able to carry a smaller load continuously and be able to cycle off and on more quickly.

Again, a CFC retrofit project may be the ideal time and place to correct operational weaknesses or flaws in the central cooling plant.

Plant Simplification.

Most central cooling plants in existence are not in their original configuration. Systems evolve over the years into a complex multiplicity of pumps, chillers and cooling towers. As additions and reconfigurations of a building occur, piping is added to the system to accommodate new requirements. Since the central systems are complex the size of an individual reconfiguration project does not always justify the expenditure of time to fully analyze the effect of the piping addition on the entire system. Often a pump or even a separate chiller is added to ensure adequate flow of chilled water in the new addition. The end result is often an overly cramped and complicated central plant. Many such secondary pumps and chillers can be eliminated in a newly designed, properly sized and efficiently piped system.

Variable Flow Conversion.

Facilities with widely varying cooling demands may also obtain tremendous energy savings from converting the chilled water system to variable flow. During periods that the cooling demand is less than the total capacity of the cooling system, the amount of chilled water actually required to be pumped through the piping system is also less. Slowing the operating speed of a centrifugal pump in response to this lessened demand provides dramatic pumping energy savings.

While variable flow is common in new construction, few older systems are so configured. In order to implement a variable flow scheme of operation, a few things are needed:

- First, <u>create a dual-loop system</u> to allow constant flow through the chiller while varying the flow through the cooling coils in air handling units - alternatively, a single loop system may be maintained if provisions for minimum flow through the lead chiller are provided, either by leaving some control valves as 3-way, or by installing an automated bypass valve which is shut off once total system flow demand has exceeded minimum flow needs
- Second, <u>convert to 2-way control all the control valves</u> on the cooling devices (such as air handling unit cooling coils) by closing the bypass balancing valve and installing a larger actuator (if required to give the valve sufficient close-off capability - beware, large valves frequently have close-off capabilities as low as 10 psi differential and will be pushed open by the head of the circulating pump), replacing the valve, or abandoning the control valve and converting a butterfly shut-off valve to control use by installing an actuator and positioner
- Third, install differential pressure controls by installing a sensor at the most "distant" control valve (multiple sensor locations may be required) and adjusting pump speed to maintain a constant differential pressure (or reset setpoint based on load or pseudo load indicator such as outside air temperature)

While it is not always an intended byproduct of a variable flow conversion, it is frequently the case that comfort is improved in the process of converting to variable flow. When it occurs, it comes about for a number of reasons including the fact that one air handling unit, for example, may serve a largely internal load and require nearly full cooling capacity at all times. If only one-third of the plant equipment is placed on line, the total chilled water flow may match the total load quite well, but, due to the nature of constant flow systems, this internal air handling unit only gets a proportionate share of the total chilled water available, even though its actual cooling load is proportionately higher than the rest of the air handling units on line. By converting to variable flow, the chilled water goes where it is needed, not where the test and balance contractor decided to send it. Another comfort problem that can be corrected by conversion to variable flow is when the original water balance was incorrectly performed, or when loads have shifted from one area/air handling unit to another and some areas of the building are short of cooling on "design" days, even though the plant capacity is adequate. Finally, many systems are added on to over the years and, even though there is enough plant cooling capacity, the "design" chilled water flows for all the air handling units combined exceed cooling pump capacity -- and the last project installed "robbed" all the others in order to get its needed flow (sound familiar?). In each of these cases, variable flow conversion will almost always cure the problems, in some case, providing comfort for the first time in "ages".

Though conversion to a variable flow chilled water system is not directly related to the issue of CFC abatement, the extensive construction project required to accomplish the abatement affords us the opportunity to expand the project only minimally to achieve significant energy conservation through variable flow.

Install Dedicated Cooling Systems.

Many times in the "crush" of day-to-day building operations, short-sighted approaches are taken to solving critical immediate problems. In one hospital, the need for air conditioning a CAT-Scan computer room in a former "basement" area of the building was solved by installing a small fan-coil unit and interconnecting it to the central chilled water piping. Unfortunately, because of its location, it was not physically feasible to provide an outside air economizer, so the central cooling plant consisting of one large chiller was forced into service on a 24-hour-per-day, 365-day-per-year basis! While this solved an immediate problem, the wear and tear on this chiller resulted in its premature demise. The best solution, in this case, was to install a small dedicated chiller with an adjacent dry cooler to provide a waterside economizer during cold weather (in this relatively cold climate). Not only did the small dedicated chiller and waterside economizer allow the central plant to be subsequently shut down for a major overhaul, but the waterside economizer was found to work successfully at ambient temperatures much higher than expected (up to 60°F !).

Integrate Multiple Cooling Plants.

Just as central plants grow and evolve like "cancer" and become overly complex, sometimes entire additional plants are added because the design professionals don't want to take the time to "tackle" the larger problem, or because their scope of engagement is limited. The result frequently is that the operating engineers end up "saddled" with two (or more!) central cooling plants which they must operate and maintain -- and frequently the plants are not even in close proximity to each other. Not only is this an O&M headache, but the fact that two sets of plant auxiliaries must be started up at the point that only a very small total cooling load exists is very energy wasteful, and increases wear and tear on all the equipment. While a CFC retrofit project may not be able to afford to physically integrate multiple plants, it is often feasible to tie the plants together by means of an interconnecting chilled water pipeline and operate the plants by means of a building automation system as though they are one. Obviously a variable flow conversion would generally need to be a part of such a retrofit project if the systems were not already configured as variable flow systems. Because the largest portion of the energy savings comes from single auxiliary operation during light load conditions, the interconnecting pipeline need not be sized to handle the full capacity of either plant, but perhaps just to handle the equivalent of one chiller's capacity should the pipeline need to be pressed into service to provide a form of redundancy should a chiller be "lost" during peak load conditions.

In addition, even though dedicated cooling equipment may make sense, depending upon its plant operation implications. It may also make sense to interconnect small dedicated systems to central plants. This allows the central cooling plant to supply its low kw/ton cooling when it is in operation, as opposed to the likely high-kw/ton cooling of the dedicated equipment (most likely air-cooled, reciprocating equipment).

Fuel Substitution.

A fairly obvious way to get away from CFC-based refrigeration equipment, is to switch to a form of refrigeration that does not employ vapor compression. Obvious examples of this are gas-fired and steam/hot water-fired absorption refrigeration. High efficiency gas-fired absorption machines have a COP of around unity, versus a COP of 6 to 7 for centrifugal/rotary, electric-driven chillers. While the electric machine appears to have a dramatic advantage, the cost of electricity (which varies by a 2 or 3 to 1 ratio across the country), is 10 times the cost of natural gas on a per-btu basis, meaning that the operating cost of an absorption chiller might be 30 to 40% less than an electric machine. Given the likelihood that demand charges will continue to rise as free energy markets (as have and are being brought about through natural gas deregulation and retail wheeling of electricity) cause the real cost of electrical capacity to be passed through to the end user, it may be an excellent long-term strategy to construct non-electric cooling plants (assuming $3,000/kw to build a power generating station versus a cost differential of $600 to $1000/kw for absorption over electric, it would seem only a matter of time). However, absorption chillers take up a lot of real estate and, in particular, can't be broken down into pieces to squeeze them into a basement or penthouse equipment room. In addition, they are 2 to 3 times the cost of equal capacity electric machines. Finally, the cooling towers required for absorption machines are much larger than that required for an electric machine (remember, the absorber uses heat to cool). The bottom line here is that demand charges are going to need to rise a lot before absorption machines will appear to be economically more attractive than electric-driven machines.

CONCLUSION

A great many possibilities exist for improving the efficiency and operation of a central cooling plant while on the way to CFC abatement. As shown in Table #1 below, many building owners are availing themselves of many of the opportunities that present themselves in this environmentally-motivated program. As can be seen in Table #2, below, these owners are clearly motivated by the rapidly narrowing time window for action.

Table #1
Sample Project Summary

Facility	JMMC	SNMH	MCCC	FNMA	CPMC
Type of Facility	Hospital	Hospital	Office	Office	Hospital
Project Features	Features Included in Project:				
Optimized Chiller KW/Ton	X	X	X	X	X
Optimized Cooling Tower(s)	X	X	X		X
Increase Plant Capacity	X	X	X		X
Decrease Plant Capacity				X	
Improve Equipment "Mix" and/or Redundancy	X	X		X	X
Plant Simplification	X	X	X	X	X
Variable Flow Conversion	X	X	X	X	X
Install Dedicated Systems	X	X	X		
Multiple Plant Integration	X	X	X	X	X
Fuel Substitution					

Table #2. MAJOR CFC RULE COMPLIANCE DATES	
EQUIPMENT CONTAINING MORE THAN 50 POUNDS OF REFRIGERANT MUST HAVE SUBSTANTIAL LEAKS REPAIRED	June 14, 1993
RECYCLING AND RECOVERY EQUIPMENT MUST BE CERTIFIED	August 12, 1993
ALL TECHNICIANS MUST BE CERTIFIED	November 14, 1994
SALES RESTRICTIONS GO INTO EFFECT	November 14, 1994
CFC'S (R-11, R-12, etc.) CEASE PRODUCTION	December 31, 1995
HCFC'S CEASE PRODUCTION	R-22, January 1, 2020 R-123, January 1, 2030

ABOUT THE AUTHOR

James P. Waltz, President of Energy Resource Associates, Inc., is an acknowledged pioneer in the field of energy management. Prior to the Arab Oil Embargo of 1973, Mr. Waltz made a personal commitment to energy management as a principal focus of his engineering career. Since that time, he has served as energy management program manager for the Air Force Logistics Command and the University of California's Lawrence Livermore National Laboratory. In addition he has worked as an energy management engineer for consulting and contracting firms. In 1981 he founded Energy Resource Associates for the purpose of helping to shape the then-emerging energy services industry - and did so through a multi-year assignment to create a successful energy services business unit for a Fortune 500 temperature controls manufacturer.

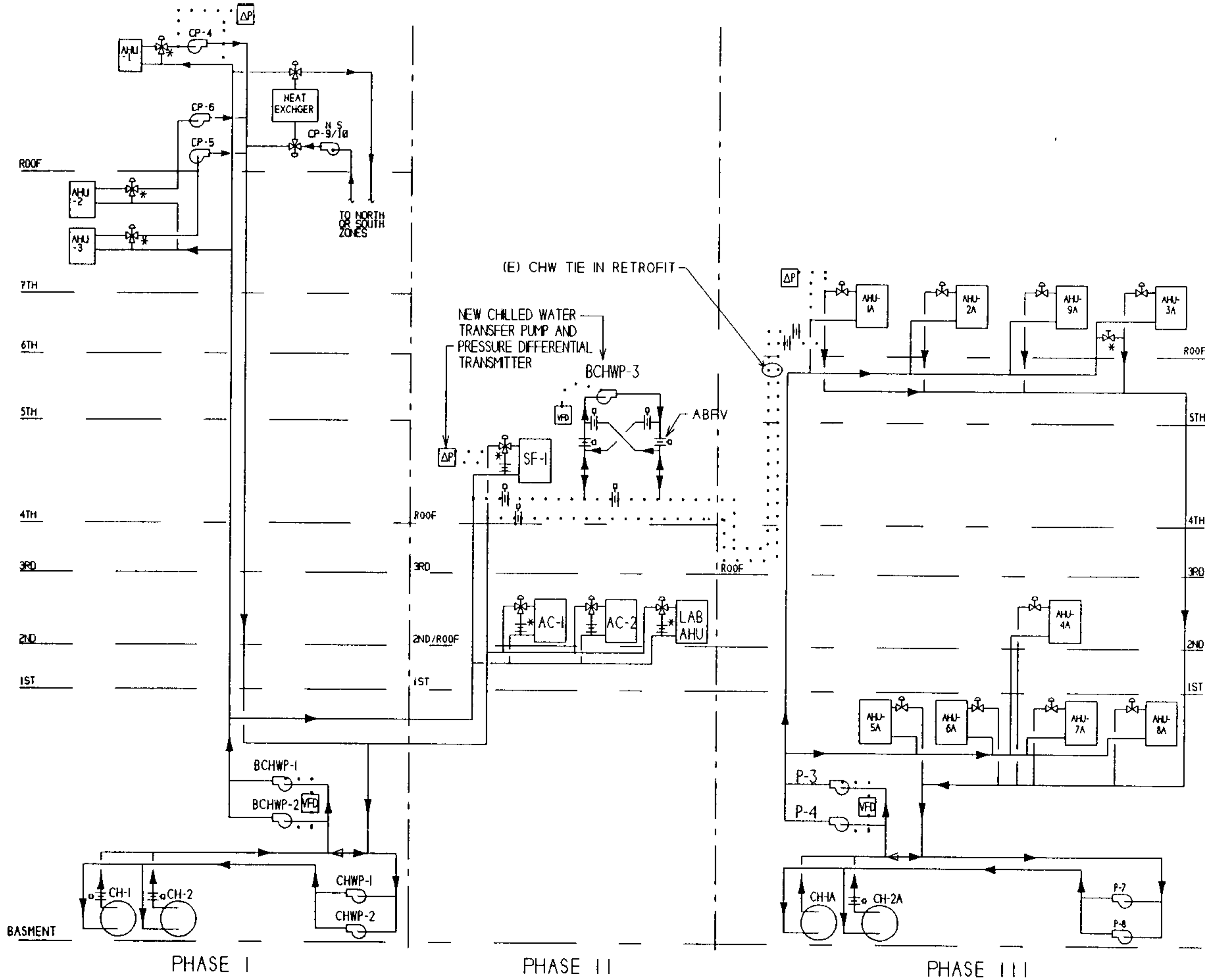
Specializing in the mechanical, electrical and control systems of existing buildings, Mr. Waltz's firm has accomplished a wide variety of facilities projects, recently including a corporate-wide energy management program review for a major hospital chain, design of replacement chilled water plants for two northern California hospitals and a world-famous county civiic center, on-site recommissioning of the entire building automation system for another large northern California hospital, audit and expert testimony relating to a failed energy services contract for a large southern California hospital, and DSM project quality control and performance review and HVAC training for a California utility company.

Mr. Waltz's credentials include a Bachelors Degree in Mechanical Engineering, a Masters Degree in Business Administration, Professional Engineering Registration in three states, charter member of and Certified Energy Manager of the Association of Energy Engineers (AEE), member of the Association of Energy Services Professionals (AESP, formerly ADSMP), Demand Side Management Society (DSMS) and the American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE).

Mr. Waltz was named International Energy Engineer of the Year in 1993 by the Association of Energy Engineers.

DESCRIPTION OF CADD DRAWING

The accompanying drawing is a schematic of the chilled water system at one of the example projects, and shows the integration of two chilled water plants by means of an interconnecting pipeline, and the addition of a transfer pump to allow sharing of plant capacity between the buildings even during peak load conditions (it presently provides single plant operation only during low load operation). This plant is fully automated and the Phase-1/2 plant is currently undergoing conversion to non-CFC refrigeration equipment.



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CHILLED WATER SYSTEM

INCLUDING REVISIONS FOR NEW PH-1/2 CHILLED WATER PLANT