

Water cooled chiller plant with economizer

Design Envelope application guide

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DESIGN ENVELOPE APPLICATION GUIDES

Performance improvements are among the top priorities of many building professionals today. Whether you are a developer, design consultant, engineer, contractor, facility manager or owner, chances are that you face increasing demands to not only reduce costs, but also deliver performance improvements. Public awareness on multiple levels - from the individual all the way through to government bodies - has grown to the point that energy conservation, carbon reduction, tenant comfort, and other health and environment-driven practices are key objectives for any prominent, sizeable building project.

To support and sustain this paradigm shift, Armstrong has developed a suite of advanced fluid flow and HVAC offerings that we call 'Design Envelope solutions'. Design Envelope solutions integrating intelligent demand-based control to deliver optimal performance and the lowest possible cost, both at commissioning and throughout their full operating life.

This document is one of our Design Envelope Application Guides, a set of booklets that discuss a broad range of real-world HVAC scenarios. In each scenario the use of Design Envelope technology can result in tremendous improvements in performance of your HVAC installation (compared to standard industry practice) and ultimately your building - technically, financially, and environmentally.

The intent of this Application Guide is to present HVAC System designers with an alternative to standard practices for design layout, configuration, and design calculations and help you leverage the full potential of Armstrong Design Envelope solutions. Each Application Guide addresses a specific system configuration for HVAC or data center applications. The system configurations cover heating and cooling scenarios, including circuit configurations ranging from all constant flow, to full variable flow and variable speed plant configurations. The Application Guides will present piping arrangements, valving requirements, de-coupler configurations, instrumentation locations, control system options, and the associated impact on first cost and life-cycle costs. The full series of application guides is available for download from Armstrong's website at www.armstrongfluidtechnology.com

APPLICATION DIRECTORY

HVAC

COOLING

9.561 - All-variable water cooled chiller plant

9.562 - Water cooled chiller plant (CP/VS)

This guide covers: 9.563 - Water cooled chiller plant with economizer

9.564 - Ground source heat pump system (VP)

HEATING

9.565 - Condensing boiler plant (VP)

9.566 - Condensing boiler plant (CP/VS)

9.567 - Closed circuit heat pump system (VP)

DISTRICT COOLING

9.568 - Water cooled central plant (all-variable)

9.569 - Water cooled central plant (CP/VS)

9.570 - Water cooled central plant (VP/VS)

DATA CENTRES

COOLING

9.571 - Water cooled chiller plant with economizer (VP)

9.572 - Water cooled chiller plant (all-variable)

9.573 - Water cooled chiller plant (CP/VS)

VP = Variable primary flow

CP/VS = Constant primary flow / variable secondary flow

VP/VS = Variable primary flow / variable secondary flow

All-variable = All variable chiller plant, variable primary flow, variable secondary flow, variable condenser flow

This application guide analyzes a Water Cooled Chiller plant with the following features:

- Variable Primary pumping configuration,
- Variable Speed Condenser pumps,
- an Economizer
- Variable Speed Cooling tower Fans.

The guide will also examine the effect of the pumps (in terms of sizing) and the controls for the overall plant. With the utilization of Engineering principles and applying Armstrong Design Envelope solutions, we will further examine the effect of these solutions in terms of first cost, life cycle cost and the effect on the Environment in terms of CO₂ emissions.

An example will be provided for this application within this paper; this should provide the reader with a better understanding of how the selections were completed and why one option was selected over the other.

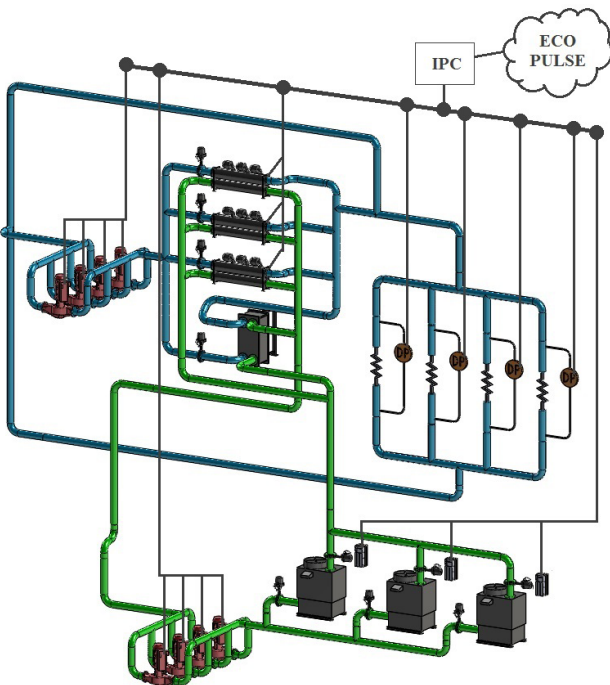


FIG. 1
DESIGN ENVELOPE PLANT LAYOUT.

APPLICATION DETAILS

Equipment	Water-cooled chillers	▪
	Economizers	▪
Use	HVAC	▪
Configuration	Var. primary flow	▪
	Var. tower flow	▪

DESIGN ENVELOPE BENEFITS SUMMARY

Design Envelope benefit	Design Envelope savings over conventional plant
Lowest installed cost	25 %
Lowest operating cost	16 %
Lowest environmental cost/impact	Annual reduction in CO ₂ emissions (tonnes): 1,297
Lowest project and operating risk	4.9 %
Total Design Envelope 1st year savings	19%

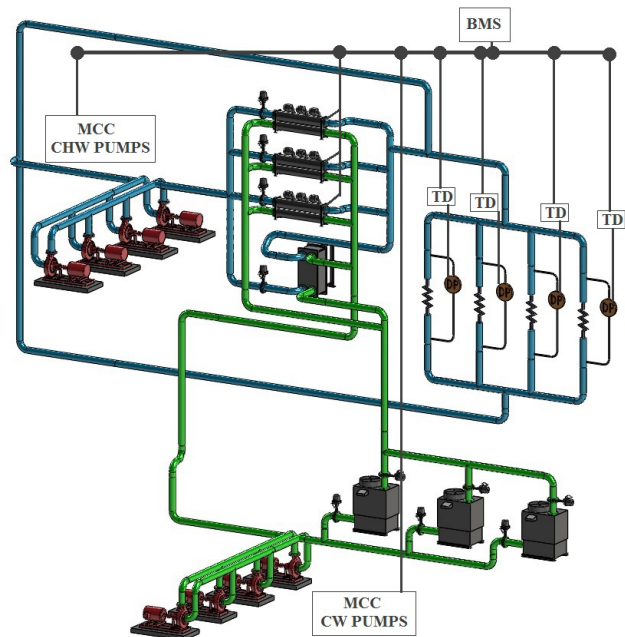


FIG. 2
CONVENTIONAL PLANT LAYOUT.

PLANT LAYOUT DESIGN ENVELOPE VS. CONVENTIONAL

Design Envelope plant	Conventional plant
3 x VS Chillers	3 x VS Chillers
4 x Design Envelope CWP VS (n+1)	4 x end suction CWP VS (n+1)
3 x VS Cooling towers	3 x VS Cooling towers
4 x Design Envelope CHWP VS (n+1)	4 x end suction CHWP VS (n+1)
Bypass valve	Bypass valve
Approximately 4 zones (DP sensors)	Approximately 4 zones (DP sensors)
Economizer (free cooling)	Economizer (free cooling)
Design Envelope IPC 11550 Controller	BMS Controls

Before beginning the analysis we should consider some points:

Economizers are a must: ASHRAE standards 90.1 & 189.1 mandate that each cooling system with a fan shall include either an air or water economizer meeting the requirements of sections 6.5.1.1 through 6.5.1.6 (some exceptions apply).

Beware of the maximum Pressure Drop: This is dealt with in ASHRAE Section 6.5.1.2.2. Pre-cooling coils and water-to-water heat exchangers used as part of a water economizer system shall either have a water-side pressure drop of less than 15ft of water, or a secondary loop shall be created so that the coil or heat exchanger pressure drop is not seen by the circulating pumps when the system is in the normal cooling (non - economizer) mode.

Economizers have to be integrated in the plant control: Section 6.5.1.3 deals with Integrated Economizer Control and lists as the requirements that they shall be integrated with the mechanical cooling system and be capable of providing partial cooling even when designed to maintain inside humidity at a dew point temperature greater than 35°F shall use a water if an economizer is required by section 6.5.1. We shall examine this section later on the paper when we compare traditional control systems versus a dedicated plant control. In addition using variable speed drives on cooling tower fan motors and water pump motors is beneficial during times when the heat rejection load is lower.

The purpose of the chilled-water pump is to circulate chilled water within the loop. Generally, the pump must overcome the frictional pressure losses caused by the piping, coils, and chiller and the pressure differential across open control valves in the system. The pump, while working at the system static pressure, does not need to overcome this static pressure. For example, in a forty-story building the pump need not overcome the static pressure due to those forty stories. The pump is typically located upstream of the chiller, however it may be anywhere in

the system, provided that the pump:

1. Meets the minimum pump net positive suction-head requirements. That is, the system pressure at the pump inlet must be both positive and high enough to allow the pump to operate properly;
2. Maintains the minimum dynamic pressure head at critical system components (usually the chiller). If the dynamic pressure head is not high enough at these components, proper flow will not be established through them;
3. Accommodates the total pressure (static head plus dynamic head) on system components such as the chillers' evaporator, valves, etc.
4. Should not exceed the chiller barrel pressure limits (usually on larger building with high pressure systems).

Selecting the pumps for a large or strategic project should be more than simply looking at existing drawings and entering the flow & head from the pump schedule. For original project selections or to check that the schedule produces the best customer LCC (Life Cycle Cost) look at pump numbers in parallel one number less or more than the specified number. A better combination than specified should be discussed with the system designer for the best customer value.

One of the many Design Envelope values is that there is generally inherent increased flow & head capability, above the design conditions, to the maximum speed and/or motor size. One use for this extra capability for customer value is to review the added flow capability at the design head. By understanding the maximum flow there is a possibility that n+1 flow (The flow that the number of operating and standby pumps, should one pump fail) may be produced by the number of operating pumps only. For example, the maximum Design Envelope model flow at the design head is 150% of the design flow, then 3-pumps will

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produce the equivalent of 3+1 selected conventional pumps, saving the pump, motor, controls, piping, SG, FTV costs + electrical & labor for installing that unit. The required added flow capability ratio will reduce as the number of operating pumps increase.

Effect of condenser-water flow rate

Since the condenser is a heat exchanger, it is sensitive to water flow rate. For example, excessive flow may result in high water velocity, erosion, vibration, or noise, while insufficient flow reduces heat transfer efficiency and causes poor chiller performance. Therefore, condenser-water flow through the chiller should be kept within a specific range of limits, except during transient start up.

However, the same selection thoughts applied to the chilled water pumps can be applied to the selection of condensing water pumps.

Considering Controls ...

In a traditional system the chiller controls should communicate with a BMS system. There are many system aspects that are outside the chiller direct control, such as condenser-water temperature and the amount of fluid flowing through the evaporator and condenser. To minimize the system energy costs, the system controls must coordinate chiller, pump, cooling-tower, and terminal-unit controls. This can only be done if adequate information is communicated from each system component to the main system control (Traditionally a BMS system). However with this approach extensive programming is needed to ensure proper and energy and cost efficient operation of the chiller plant.

A better approach is to consider the chiller plant as a separate system. This allows a building manager to take

advantage of the control and automation functions available in a dedicated cooling management solution. Ultimately this leads to better integration of cooling system components and makes the chiller plant more efficient.

Armstrong offers the Design Envelope IPC 11550 as an automated control system designed specifically for energy efficient control of chilled water plants. The IPC 11550 manages the sequencing, operation, positioning, and/or speed control of the devices.

The IPC 11550 includes Hartman LOOP™ control methodology which is able to further enhance tower performance with “Hartman Loop” sequences to trade off lower leaving tower water temperature against chiller lift for the load and weather situation being experienced. The IPC will also sequence parallel primary variable pumps based on Best efficiency staging. This is all achieved through advanced control sequences listed below:

1. Demand Based Control
2. Natural curve sequencing
3. Equal Marginal performance principal.

The Sequences are used to control pump speed, fan speeds, by-pass valve position, the chilled water supply temperature, the condenser water flow, the cooling tower flows, and the entering condenser water temperature all for the best performance and within acceptable range.

It is a pre-engineered, factory commissioned control system, therefore no site programming is necessary. Furthermore it is field configurable and adjustable which gives a lot of flexibility on site and make the system simple to implement. For example, if the number of pumps or chillers of the system change, there will be no back charge or expensive fee as it usually happens with a BMS. It gives a separate user interface for the mechanical team opposed to using a BMS.

**PLANT AUTOMATION / CONTROL STRATEGY
DESIGN ENVELOPE VS. CONVENTIONAL**

Design Envelope plant	Conventional plant
Design Envelope pump with integrated controls	Pump drives on the wall
IPC 11550 chiller plant controls with BMS communication	BMS controls <ul style="list-style-type: none"> ▪ Chiller start/stop ▪ Chilled water pump start/stop ▪ Cooling tower start/stop ▪ Condensing water pump start/stop ▪ Bypass valve
ECO*Pulse	

WATER COOLED CHILLER PLANT WITH ECONOMIZER BASE CASE INSTALLATION

Beijing, China

Technical details:

- Three Variable speed Chillers that produce chilled water (3 x 2,000T units), design day tonnage of 6,000 tons of cooling
- Four zones of loads with differential pressure sensors, often satisfied by coils, that transfer heat from air to water
- Four chilled-water distribution pumps (n+1) and pipes that send chilled water to the previously mentioned loads
- Four condenser-water pumps (n+1), pipes, and three variable speed cooling towers that reject heat
- Controls that coordinate the operation of the mechanical components together as a system. We will assume a typical capacity based control strategy operated by a Building Management System (BMS).
- Water side economiser to precool some or all of the return water in a chilled water loop with the cooling tower, substantially reducing or even eliminating the need for mechanical cooling at low temperature periods. Through the use of plate and frame heat exchanges the building heat is transferred from the chiller water loop into the cooling tower loop and then dissipated to the atmosphere.

When considering the Design Envelope IPC 11550 controls for this application (especially the size of the tonnage), we can simulate a kW/ton consumption and create a return on investment calculation on the savings.

With an all variable speed plant, we can estimate the IPC 11550 can perform around 0.56 kW/ton (or better) with annual savings of around 1,838,000 kWh. Converting the cost of electricity in China to US Dollars, we could estimate that savings to be around \$183,800 USD.

Please note that the savings also include Free-Cooling Mode in which the operation of the chillers is replaced by the Plate and Frame Heat Exchanger (at wet-bulbs less than 46 F).

The large savings justifies the use of the IPC 11550 as opposed to the Armstrong Design Envelope OPTI-VISOR. IPC 11550 can also control the free-cooling mode (use of the economizer). To continue on the analysis, the amount spent on a BMS control strategy for the chilled water plant would be transferred now the purchase of the IPC 11550.

Looking at Table (1), we can summarize the above analysis.

Table (1) Summation of Chiller Plant Analysis

Application	Qty	DE plant	
Chiller pumps	4	4300-1015-200	\$169,540
System VFDs	4	IVS included	Incl
Cond water pumps	4	4300-1415-150	\$170,172
CW VFDs	4	IVS included	Incl
Elbow & spool		SGxx	Incl
Check valve & Isolation	4	FTVx	Incl
Total			\$339,712
Installation	8	-	\$83,000
	8	-	incl
Total Installed cost			\$422,712
DE savings			\$276,534

We can use the subsequent tables to analyze each area of importance in terms of Installed cost, life cycle costs and risk management.

LOWEST INSTALLED COST

Savings area	Design Envelope plant installed savings
Material & installation	\$126,000
Time (labour)	\$6,222
Power infrastructure	400 hp (298 Kw)
Space	\$37,000
Civil structure	\$3,252
Utility rebates	N/A
Commissioning & call backs	\$1,200
Total installed savings	\$173,674 (25%)

The benefits of Armstrong Design Envelope pumps:

- The Vertical In-line design eliminates the need for inertia bases, housekeeping pads, and flex connectors and reduces piping requirements.
- The Integrated intelligent controls eliminate separate mounting of variable frequency drive (VFD) as well as procurement, installation (incl. wiring), calibration and upkeep of differential pressure sensor.
- The Vertical motor positioning requires up to 60% less floor space compared to other pump configurations.

LOWEST OPERATING COST

Savings area	Design Envelope plant operating savings (annually)
Energy	(1,838,290 kWh @ \$.1/kWh) \$183,829
Maintenance	(\$75/hour) \$4,200
Reliability	(increased availability) 20%
Water	(104,538 us gal @ \$0.013/gal) \$1,359
Operator labour	(\$75/hour) N/A
Target Mtce avoids failure (E*P)	N/A
Total operating savings	\$189,388 (16%)

The benefits of Armstrong Design Envelope pumps:

- Design Envelope Pump selections frequently recommend a smaller motor and/or pump which reduces installed cost.
- Split coupled design of the Design Envelope 4300 ensures quick mechanical seal change (compared to backward-pull-out base-mounted pumps).
- Optimum plant control for up to 50% higher energy efficiency over same age, constant speed chilled water plant.
- Lower evaporative cooling for 5%+ in water savings

- More effective and gentle equipment operation for up to 10% in extended equipment life and reduced maintenance expenditures.
- ECO*Pulse™ HVAC health management (including predictive maintenance) for reduced plant failure and downtime.
- Intuitive user interface for expedient operator training and simplified, safer plant operation.

LOWEST ENVIRONMENTAL COST

Savings area	Design Envelope plant environmental savings
Carbon footprint (energy)	(metric ton CO2 reduced) 1,297
Waste reduction on site	\$400

N.B. An average car consumes around 5.1 metric tons of CO2 per year. This is from the United states Environmental and protection agency. Therefore this would equate to 254 cars off the road.

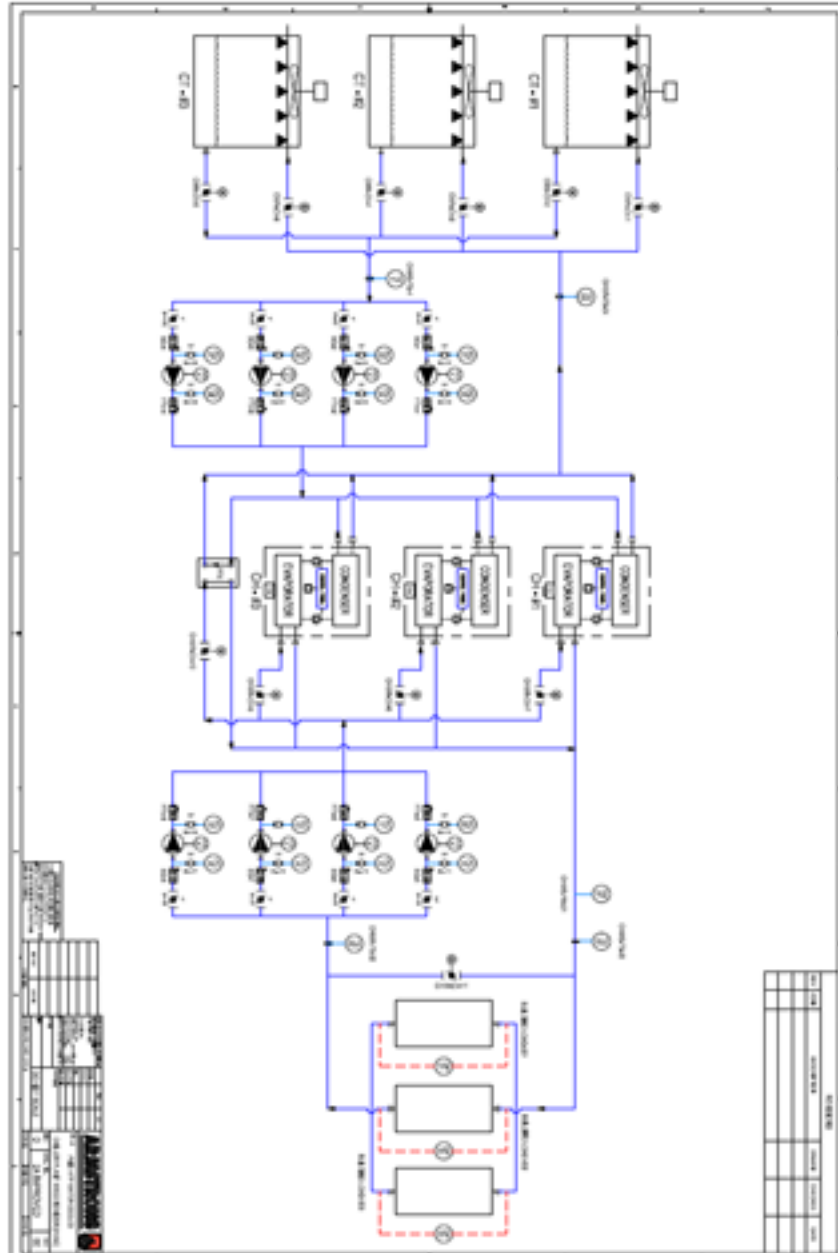
LOWEST PROJECT AND OPERATING RISK

Risk to	Risk source	Design Envelope plant risk reduction	% of total mechanical project
General contractor	Commissioning delay and payment delay of hold back amounts	\$66,000	0.7%
Owner (capital projects)	Inevitable design changes by different stakeholders	\$33,000	0.4%
Owner (operations and maintenance)	Energy and operational savings not achieved	\$190,000	2.1%
Engineer	Reputation deterioration and losing new business	\$138,000	1.5%
Mechanical contractor	Commissioning delay and payment delay of hold back	\$20,000	0.2%

Considering the variable frequency drives are located on the motors - as part of the Design Envelope feature, harmonics that may be produced with long cabling lengths are eliminated.

The IPC controller, tested at the factory also provides risk mitigation compared to the conventional building management system (BMS).

PROCESS & INSTRUMENTATION DIAGRAM



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