

Water cooled chiller plant (all-variable)

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

This guide covers: **9.561UK - Water cooled chiller plant (all-variable)**

9.562UK - Water cooled chiller plant (CP/VS)

9.563UK - Water cooled chiller plant with economiser

9.564UK - Ground source heat pump system (VP)

HEATING

9.565UK - Condensing boiler plant (VP)

9.566UK - Condensing boiler plant (CP/VS)

9.567UK - Closed circuit heat pump system (VP)

DISTRICT COOLING

9.568UK - Water cooled central plant (all-variable)

9.569UK - Water cooled central plant (CP/VS)

9.570UK - Water cooled central plant (VP/VS)

DATA CENTRES

COOLING

9.571UK - Water cooled chiller plant with economiser (VP)

9.572UK - Water cooled chiller plant (all-variable)

9.573UK - 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 discusses HVAC chilled water plants with between 1 & 5 chillers, utilising variable flow for the primary, secondary and condenser water loops. It is recommended for chiller plants with cooling loads of 1,700 kW and greater.

APPLICATION DETAILS

Equipment	Water-cooled chillers	1-5
Use	HVAC	▪
Configuration	Var. primary flow	▪
	Var. secondary flow	▪
	Var. tower flow	▪

DESIGN ENVELOPE BENEFITS SUMMARY

Design Envelope benefit	Design Envelope savings over conventional plant
Lowest installed cost	28%
Lowest operating cost	30%
Lowest environmental cost/impact	Annual reduction in greenhouse gas emissions (tonnes): 2,450
Total Design Envelope 1st year savings	25%

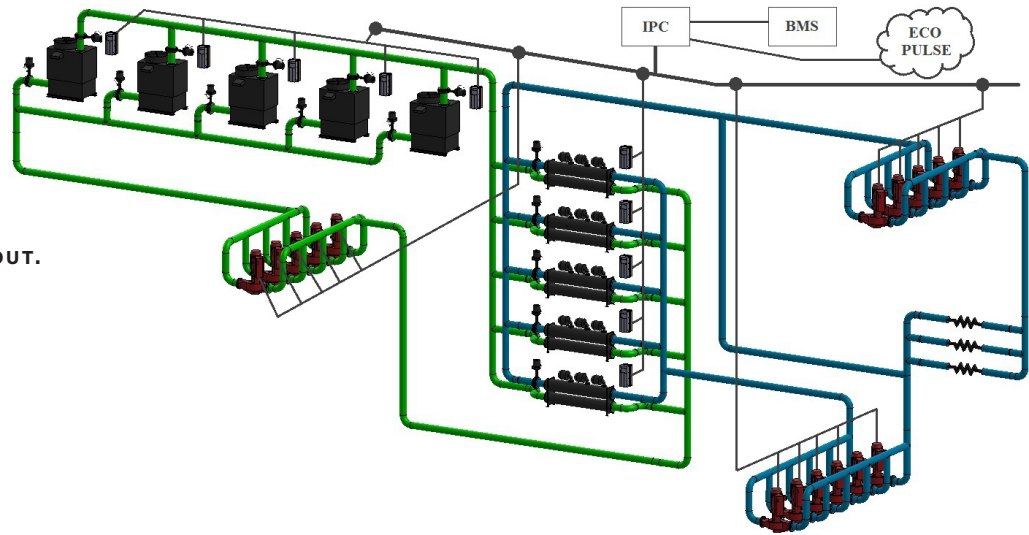


FIG. 1
DESIGN ENVELOPE PLANT LAYOUT.

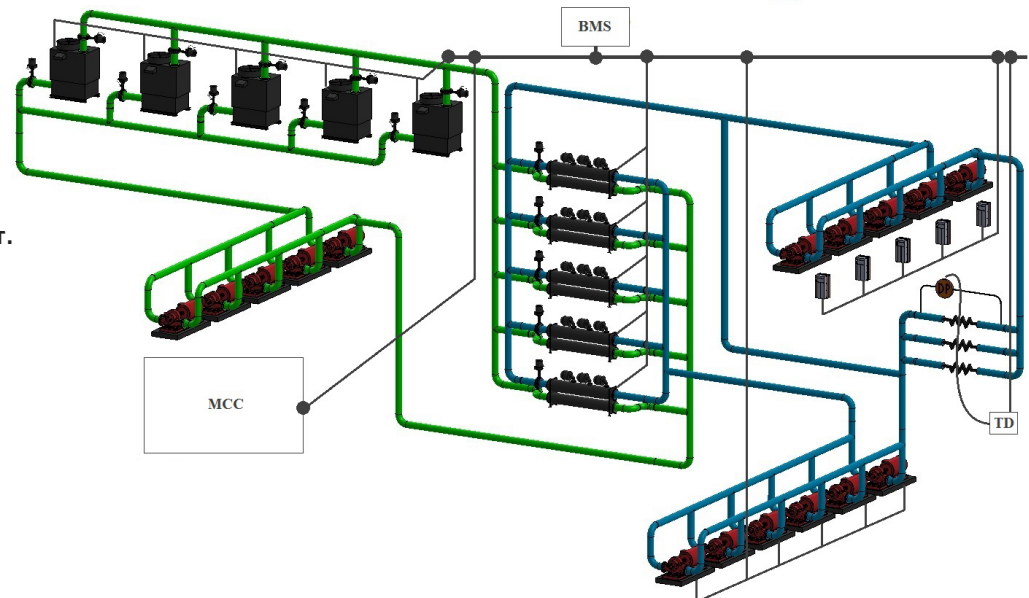


FIG. 2
CONVENTIONAL PLANT LAYOUT.

**PLANT LAYOUT
DESIGN ENVELOPE VS. CONVENTIONAL**

	Design Envelope plant	Conventional plant
Chiller & control	<ul style="list-style-type: none"> Variable speed chillers Integrated Plant Controller (IPC 11550) using demand-based control technology for ultra-high efficiency chiller plant optimisation <p>OR</p> <ul style="list-style-type: none"> OPTI-VISOR plant controller for ultra-high efficiency chiller plant optimisation 	Constant speed chillers controlled by building automation system (BAS). Typically staged on and off by speed
Primary water pump & control	<ul style="list-style-type: none"> Vertical inline Design Envelope pumps with integrated control <p>OR</p> <ul style="list-style-type: none"> Intelligent Fluid Management System (iFMS) 	<ul style="list-style-type: none"> Horizontal base-mounted pumps operating constant speed with soft-starts Separate flow meters to protect chiller from minimum flow
Secondary water pump & control	<ul style="list-style-type: none"> Vertical inline Design Envelope pumps with integrated control and Sensorless technology <p>OR</p> <ul style="list-style-type: none"> Intelligent Fluid Management System (iFMS) 	<ul style="list-style-type: none"> Horizontal base-mounted variable speed pumps operating with wall-mounted drives Differential pressure sensors across the building load for each zone
Cooling tower, condenser water pump & control	<ul style="list-style-type: none"> Variable speed cooling towers Vertical inline Design Envelope pumps with integrated control <p>OR</p> <ul style="list-style-type: none"> Intelligent Fluid Management System (iFMS) 	<ul style="list-style-type: none"> Horizontal base-mounted pumps operating constant speed. Cooling tower operating in constant speed Temperature sensor to control condenser water valve and cooling tower staging

An all-variable speed chiller plant uses the same equipment as a conventional plant - but variable speed drives are added to all the chillers, pumps and cooling towers. In addition, all of the equipment is coordinated through the building automation system (BAS) for optimised staging and speed control for superior energy efficient operation. The added investment of variable speed drives for the entire plant is generally not excessive and the energy savings can be very attractive to building owners for chilled water plants (see FIG. 2).

Design Envelope solutions use best-in-class design to provide lowest first cost, lowest life cycle cost, provide redundancy and reliability, and reduce project risk and complexity (see FIG. 2).

The benefits of the Design Envelope pump arrangement are space savings and low installation costs. The vertical inline pump design typically occupies less than half the footprint of a conventional floor mounted pump.

Ease of maintenance and reliability are also key design features. Vertical split-coupled pumps reduce maintenance headaches. The split-spacer coupling on the 4300 models means that a seal

can be serviced without having to move the motor or disturb the pump or piping. Furthermore the vertical pump has only one seal to replace. This gives the vertical pump a significant advantage over base mounted pumps. A horizontal (double suction) split case pump, for example, requires two sets of pump bearings and two sets of seals for a typical service call - the vertical pump only requires one seal. The coupling is also rigid in design so initial site alignment is eliminated and re-attachment of the coupling following maintenance brings the unit back to factory alignment specifications. The vertical nature of the pump provides inherent stability and vibration-free operation. Much as the stability of a spinning top increases with speed, the vertical rotating assembly is specially designed to take advantage of the lack of gravity-induced moments on the shaft to find its natural operating position and run practically vibration free.

Using vertical inline pumps also eliminates the need for concrete pads, inertia bases and flex connections. Furthermore, as less piping and fittings are involved, there are savings in pipe insulation, pipe painting, and reduced complexity.

LARGE CHILLED WATER PLANT BASE CASE INSTALLATION

Phoenix Arizona, USA

Technical details:

- Constant speed chillers
- 6250 tons total cooling load
- Design ΔT : 6.5°C (11.7°F)
- Qty 5 chillers + 1 standby, 4,400 kW each
- Primary chilled water pumps: 568 m³/h (158 lps) at 20m (65 ft)
- Secondary chilled water pumps: 709 m³/h (197 lps) at 45m (148 ft)
- Condenser water pumps: 851 m³/h (236 l/s) at 28 m (92 ft)
- 2 Way valves

DESIGN ENVELOPE BENEFITS SUMMARY

Design Envelope benefit	Design Envelope savings over conventional plant
Lowest installed cost	£377,082
Lowest operating cost	Annual £388,915
Lowest environmental cost/impact	Annual reduction in greenhouse gas emissions (tonnes): 2,450
Lowest project and operating risk	(See table on page 9)
Total Design Envelope 1st year savings	£780,530 (25%)

By incorporating Design Envelope pumps and Integrated Plant Control a lower carbon footprint, more efficient and more economical first cost solution can be provided whilst also maintaining flexibility and lower life cycle costs.

With Armstrong Design Envelope solutions, customers will enjoy major savings on all levels: lowest installed and operating costs, lowest environmental impact and lowest project risks. In this example the savings amounts to a staggering **£780,530**.

A breakdown of the total savings is explained in detail in the following pages.

LOWEST INSTALLED COST

Savings area	Design Envelope plant installed savings
Material & installation	£88,879
Time (labour)	TBD
Power infrastructure	335 kW
Weight	46,964 KG
Space	£89,007
Utility rebates	£196,046
Commissioning & call backs	£3,150
Total installed savings	£377,082 (28%)

Through optimised Design Envelope pump selections, smaller equipment for the same flow and head duty can be selected, and sometimes with a smaller motor power and integrated controls.

The table above summarises the achieved savings for the example base case for the total lowest installed cost.

In this example, horizontal split case pumps with wall mounted VFDs are compared to Armstrong Design Envelope pumps.

The benefits of Armstrong Design Envelope pumps:

- Free up wall space by integrating the vfd onto the motor
- Wiring savings (material and labour) between VFDs on wall and pumps
- In many selections, a smaller sized pump motor for the same design conditions through Design Envelope load-limiting logic
- Eliminate the inertia base, grouting, concrete housekeeping pad, and flexible connections and coupling re-alignment for the base-mounted pumps
- Design flow can be balanced and verified right on the pump controller as it is now an integrated flow meter
- For secondary pumping, the use of Armstrong's Sensorless pump control can eliminate the need for differential pressure sensors to save more than £1,300 in first installed cost
- Reduction in mechanical floor space
- Commissioning savings (no DP sensors or VFDs on wall)

LOWEST OPERATING COST

Savings area	Design Envelope plant operating savings (annually)	
Energy		£361,413
Maintenance	(£50/hour)	£6,943
Reliability	(increased availability)	16.66%
Water		£21,640
Operator labour	(£50/hour)	N/A
Total operating savings		£388,915 (30%)

Chiller and control: The constant chilled water flow rate through the chiller guarantees optimum water-side heat transfer and prevents excessive fouling of the tubes. As for variable speed chillers, reducing the chilled water flow rate will obviously save on pumping power; but what is the effect on compressor power?

The effect of having less water flow go through the chiller tends to reduce the water-side heat transfer coefficient. That would cause a drop in evaporator saturation temperature thus increasing the required head the compressor has to deliver and therefore increase compressor power consumption. On the other hand, since for the same chiller capacity this reduced water flow rate means that the water returning from the air-handlers enters the chiller now at a higher temperature, the log-mean temperature difference (LMTD) between water and refrigerant increases.

This will increase the saturation temperature of the refrigerant in the chiller thus reducing the head the compressor has to deliver. The larger LMTD helps heat transfer more than the lower water-side flow rate hurts it. The main energy savings comes from a reduction in pump power requirement but net effect is a savings in overall plant power consumption.

IPC 11550: The IPC 11550 is chilled water plant controller that can be installed in a building mechanical room and connected directly to plant equipment to communicate serially with those devices. The IPC can send data to the resident building automation system (BAS) and can receive instructions from the BAS, while having full accountability for all automation sequences in the plant. Using demand-based control technology, the IPC optimises all the equipment in the plant to achieve ultra-high efficiency operation.

OPTI-VISOR: The OPTI-VISOR control panel links directly to building automation systems (BAS) that have responsibility for automation of the chiller plant. The OPTI-VISOR receives plant operating data from the BAS network, determines the optimal plant equipment settings and communicates these optimal settings to the BAS. The BAS plant automation module executes plant

automation sequences to achieve the recommended equipment settings. Essentially, the OPTI-VISOR control signals are providing the BAS with control advice for the optimisation of the chilled water plant, providing up to an additional 25% over conventional variable primary flow systems.

A conventional chiller plant may operate at 5.0 COP whereas the IPC 11550 and OPTI-VISOR can optimise a plant to 7.0 COP – the annual energy savings amount to hundreds of thousands of pounds. Both of these controllers include plant analytics through embedded software called ECO-Pulse. BAS that are integrated with plant analytics are becoming popular due to the ability of these solutions to track and predict energy consumption patterns, pinpoint defective modules, and measure compliance to building efficiency standards. The ECO-Pulse software is active for the first year with the IPC 11550 and OPTI-VISOR, and available for annual renewal.

Primary water pump and control: The leaving water temperature of the chiller is fixed by the user requirements and has to remain constant independent of load in order to enable proper dehumidification. Given this requirement for constant leaving chilled water temperature the evaporator saturation temperature does not change much with load conditions whether the chilled water flow rate has its constant high flow value or varies with load and there is an opportunity to optimise overall power consumption by reducing the primary water flow rate, thus reducing pump power without significantly increasing compressor power.

The only area of caution is to ensure that the chilled water flow rate does not fall below its minimum value where excessive fouling will occur. The industry recommends a minimum water side velocity inside the tubes of 1 m/s. Depending on the specific chiller selection this allows maximum chilled water flow reductions between 30 to 60% at lower load conditions.

Design Envelope Pumps: Design Envelope pumps operate at reduced speed to save 15% in energy costs compared to operating at full speed or throttling to match the design flow. As VFDs have become more economical, many designers are specifying them as “soft” starters for primary pumps; Design Envelope pumps are equipped with integrated controls that can slowly ramp up speed to protect your equipment from hydraulic, mechanical, and electrical surges.

iFMS: Armstrong's Intelligent Fluid Management System (iFMS) is a pre-fabricated all variable speed pumping system. It has all the advantages of Armstrong Design Envelope solutions in an integrated approach offered with various level of control either through the BAS system or through onboard control using Sensorless technology, multiple zone and pumping controls with a full chiller plant control incorporating the IPC 11550. By

integrating the controls into a pre-fabricated pump station, the solution is factory tuned for on-board equipment ensuring that there are no commissioning complications, delays, or future well intended adjustments on site.

Secondary water pump and control: While a building’s HVAC system is designed for peak-day requirements, they operate at part-load the vast majority of the time. Secondary pumps which serve the building loads, are the greatest opportunity for pump energy savings. In a hydraulic system, flow rate is proportional to speed - and power is proportional to the cube of the speed. So small changes in pump speed result in huge savings to energy consumption. The Non-Domestic Building Services Compliance Guide requires pumps on variable flow systems (greater than 750 W) to be fitted with variable speed controls.

Design Envelope Pumps: At partial loads, control valves in the secondary loop are throttled to limit the flow across the cooling coils. In turn, the secondary water pumps react to change in differential pressure of the system by slowing down in speed. Rather than using a differential pressure (DP) sensor, Design Envelope pumps use Sensorless control technology to vary the speed of the secondary pumps. Sensorless control emulates the performance of a single zone DP sensor through an algorithm embedded in the integrated control - eliminating installation cost and potential problems such as sensor location, maintenance, and wiring. Commissioning is also simplified as the pumping unit with integrated control is factory pre-wired and pre-programmed by Armstrong.

Cooling tower, condenser water pump and control: Reduced speed operation of the condenser water pump and the cooling tower fan will result in higher condenser entering water

temperatures and larger condenser water temperature rise over the condenser, thus resulting in a higher condenser saturation pressure of the refrigerant and therefore the power required by the compressor.

To achieve best-in-class chiller plant efficiencies, the IPC 11550 and OPTI-VISOR require the cooling tower fans and condenser water pumps to be variable speed. While installing VFDs can incur higher initial costs, the energy savings over conventional variable primary flow plants allow for paybacks of 1 to 3 years. The all-variable speed plant lowers the chiller’s condenser pressure requirement and thus further lowers the chiller’s energy consumption. Also, using a variable flow cooling tower enables higher tower performance and better system efficiency through improved balancing of air and water flow ratios, providing up to an additional 30% over conventional variable primary flow systems.

LOWEST ENVIRONMENTAL COST

Savings area	Design Envelope plant environmental savings
Carbon footprint (energy)	(ton GHG) 2,450

The carbon footprint calculation is based on Armstrong’s Eco:nomics calculator tool for greenhouse gas emissions reductions. It is based on the kW/hr energy saved as well as the annual electricity fuel mix for the local power utility. The 2,450 tons of greenhouse gas savings is equivalent to 516 cars off the road.

LOWEST PROJECT AND OPERATING RISK

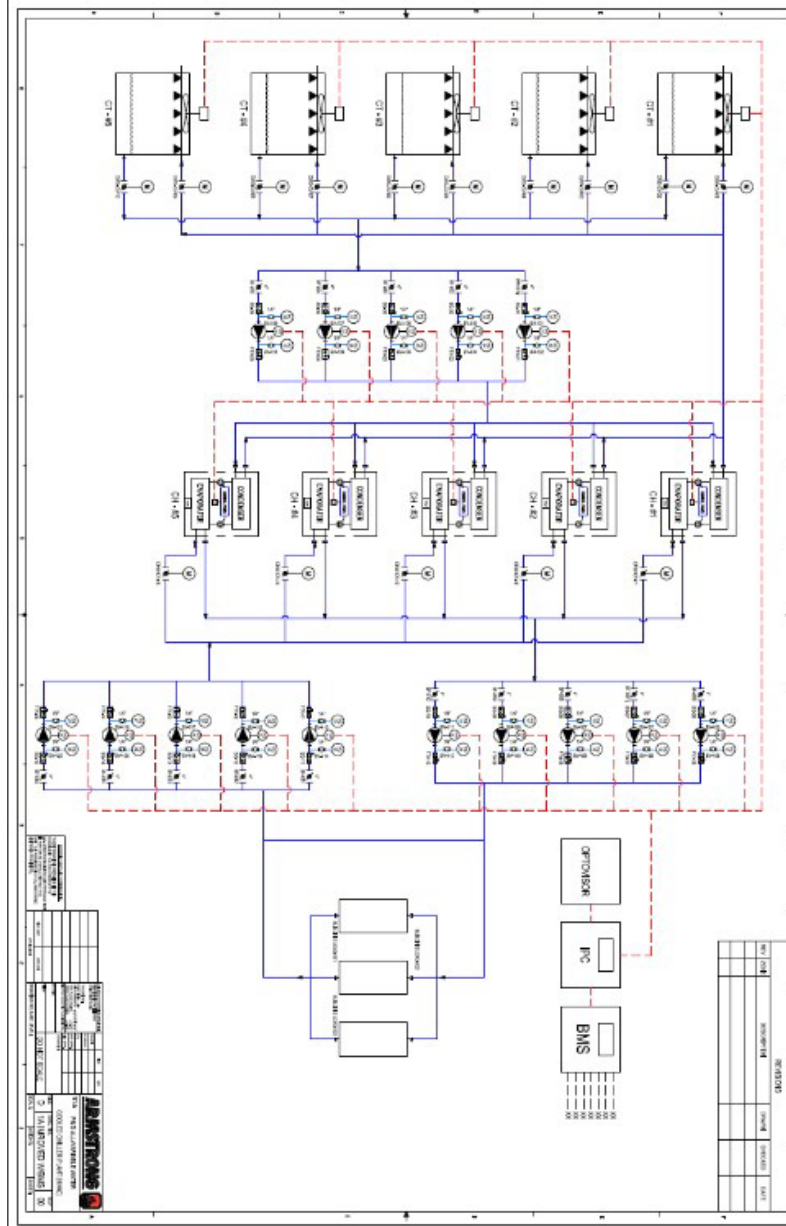
Risk to	Risk source	Design Envelope plant risk reduction	% of total mechanical project
General contractor	Commissioning delay and payment delay of hold back amounts	£37,114	1.27%
Owner (capital projects)	Inevitable design changes by different stakeholders	£16,197	0.56%
Owner (operations and maintenance)	Energy and operational savings not achieved	£389,996	13.38%
Engineer	Reputation deterioration and losing new business	£43,716	1.50%
Mechanical contractor	Commissioning delay and payment delay of hold back	£7,532	0.26%

The project risk has been approximated on the amount of time that the general contractor and engineer would have to spend on installing and troubleshooting remote differential pressure sensors, coordinating the electrical installation of the VFDs to the traditional horizontal pump motors, time spent as risk in balancing the system flow traditionally verses utilising the De-

sign Envelope pumps to measure and balance the design flow at the pump.

Additionally, commissioning via the Design Envelope IPC 11550 controls will further reduce the risk of commissioning traditional BMS systems.

PROCESS & INSTRUMENTATION DIAGRAM



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