Energy Research Institute @ NTU

Optimization of Chilled Water Systems using a Belimo Energy Valve™: A Case Study in the Tropics

This report studies the effect of limiting the water flow on a cooling coil at the Nanyang Technological University in Singapore. One Air Handling Unit (AHU) providing 100% fresh air to the Chemistry Lab in the Building of Physical and Mathematical Sciences was equipped with a Belimo Energy Valve™ and the flow was limited in order to optimize the hydraulic system performance. The data monitoring and logging capabilities of the Energy Valve were key success factors for this optimization project.

The peak chilled water flow through the cooling coil was reduced from 25 l/s to 18 l/s, and the overall reduction in average day-time flow from 18.5 to 15.1 l/s (18.4%). The minimum chilled water delta-T increased from 3.3 to 4.5°C and the average chilled water delta-T increased from 5.4 to 6.3°C. If the savings of reduced flow and increased delta-T were extrapolated to the entire chemistry block, annual pumping energy would be reduced by 76,700-90,500 kWh (12.8 – 15.0%) and annual cooling energy by 175,000 – 220,000 kWh (3.3-4.2%).

Figure 1: Building of Physical and Mathematical Sciences (SPMS) at Nanyang Technological University (NTU); Source: NTU

Air-Conditioning in Singapore

In Singapore's hot and humid climate it is important to maintain a comfortable indoor environment. Almost all non-residential buildings in Singapore are heavily air-conditioned and air-conditioning accounts for almost 50% of the energy consumption (NEA, 2010). Besides the high daily temperatures, which peak at around 35°C, ventilation systems also need to dehumidify the fresh supply air which results in a high latent load.

Sustainability is a key focus at the Nanyang Technological University (NTU Singapore), from the physical campus, to its research and also in the curriculum. The University's 2 km^2 campus is housing academic, office, residential and retail buildings with a total Gross Floor Area of 1,202,500 m^2. Being a research intensive university, NTU also has several laboratories which need a large amount of conditioned fresh air to comply with international safety standards (ASHRAE, 2010). Under NTU's EcoCampus initiative, the entire campus is being transformed into a living testbed for green technologies and innovations, with a target to reduce energy and water usage by 35% by 2020.

Low Delta-T Syndrome in Large Campuses

A common obstacle to achieving energy efficient cooling at the NTU campus, much like buildings in most large campuses with central cooling plants, is the degrading difference between supply and return chilled water temperature, commonly known as 'low delta-T syndrome'. Although the chilled water plants are designed to maintain almost a constant delta-T, in reality the delta-T falls short of the design intent. The result is high pumping energy consumption and decreased cooling efficiency of the cooling plant leading facility managers to believe that additional cooling capacity is required (Hyman L.B., 2004).

To overcome degrading cooling output, a Belimo Energy Valve™ was installed at an Air Handling Unit (AHU) supplying conditioned fresh air to a 1,000 m^2 research facility in the NTU campus. This paper presents the results of measuring the effective cooling energy transfer by the AHU cooling coil, before and after the installation of the Energy Valve.

Cooling Network

The 'Chemistry Block' of the School of Physical and Mathematical Sciences (SPMS) department, is one of the most air-conditioning intensive buildings in the NTU campus. The chilled water demand of the SPMS building, along with 2 surrounding buildings, is provided by a central cooling plant.
Multiple AHUs and FCUs use the chilled water to cool and de-humidify the air supplied to several laboratories and offices located within the building. For this study, the roof top unit AHU CR4-1, which supplies 100% fresh air to 8 laboratories and office spaces, was chosen as a test-bed.

Figure 2: Air handling unit (AHU) schematic of the Chemistry Block at SPMS NTU with the highlighted AHU CR4-1 used for testing

Air Handling Unit performance

AHUs typically cool outdoor air below dew point to control the moisture in the air supplied to the building. AHUs must then employ a reheat control strategy, to maintain set point supply air conditions and indoor thermal comfort. AHU CR4-1, supplies 100% fresh air at a Dry Bulb Temperature and Relative Humidity set point of 22.5°C and 55%. At peak demand, the AHU supplies 8 m^3/s (28,800 CMH) of fresh air and has a maximum cooling capacity of 500 kW. Sensors were installed to measure the performance of the AHU, including supply air conditions after the pre-cooling and the heat-recovery coils. Most of the cooling and the moisture removal is done by the Pre-Cooling Coil whilst the supply air conditions are controlled by the Heat-Recovery Coils. It was observed that the chilled water was supplied to the AHU at ~8°C and returned back between 12°C to 18°C.
It was also observed that the increase in chilled water flow rate, in response to a higher cooling demand, resulted in lower chilled water return temperatures, i.e. lower delta-T (*Figure 8*). As a result of decreasing delta-T, the cooling output of the pre-cooling coil enters the waste zone in which cooling capacity shows diminishing returns.

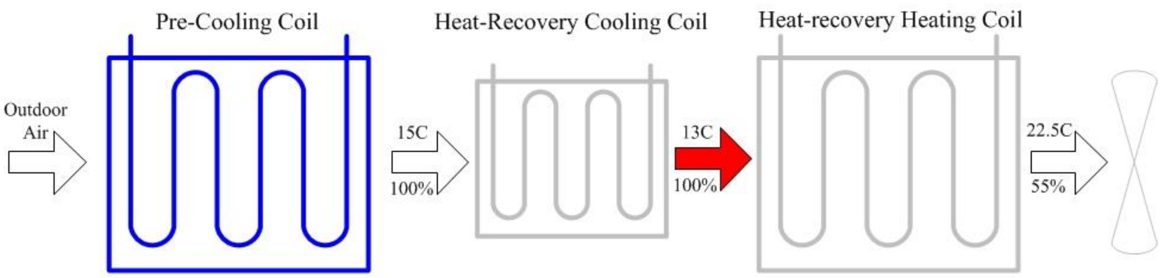

Figure 3: Control description of the AHU

The Belimo Energy Valve™

The Belimo Energy Valve ™, an intelligent control valve, was installed in the chilled water loop of the Pre-Cooling Coil in AHU CR4-1, as shown in *Figure 4*. The objective of this installation was to improve delta-T by optimizing the cooling coil of the AHU.

The Energy Valve has a built-in web server used to monitor performance and easily configure the device. For example the maximum flow and the delta-T Manager can be adjusted. The integrated data logger stores data with a resolution of 30s for one month and a compressed dataset for a whole year. This helps to observe system performance and offers many possibilities because flow rate, Delta-T, transferred energy and other values are available in order to diagnose and optimize the system. In this report, all the data which is related to the waterside of the cooling coil was recorded by the Energy Valve.

Figure 5: Belimo Energy Valve™ installed on the SPMS building rooftop

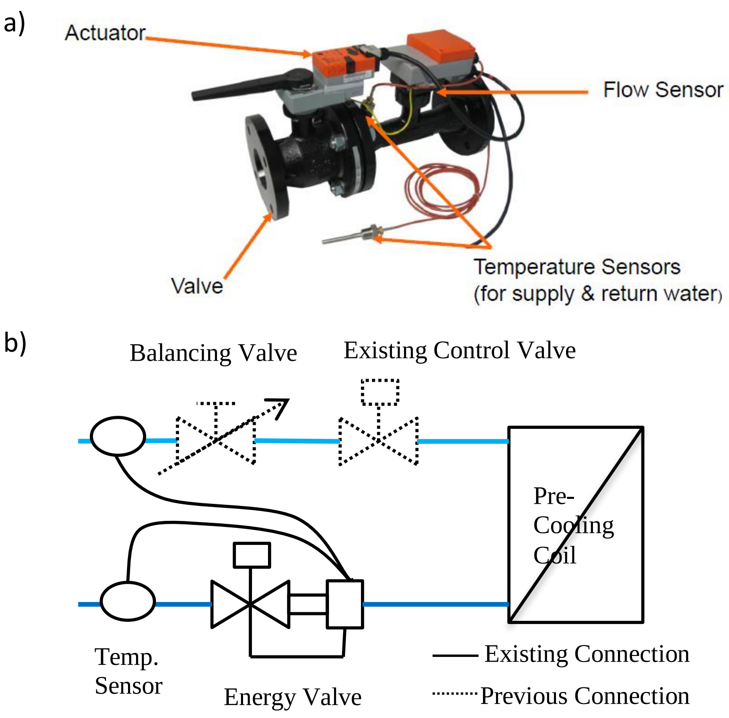

Figure 4: a) The Belimo Energy Valve™;
b) Installation schematic of the pre-cooling coil

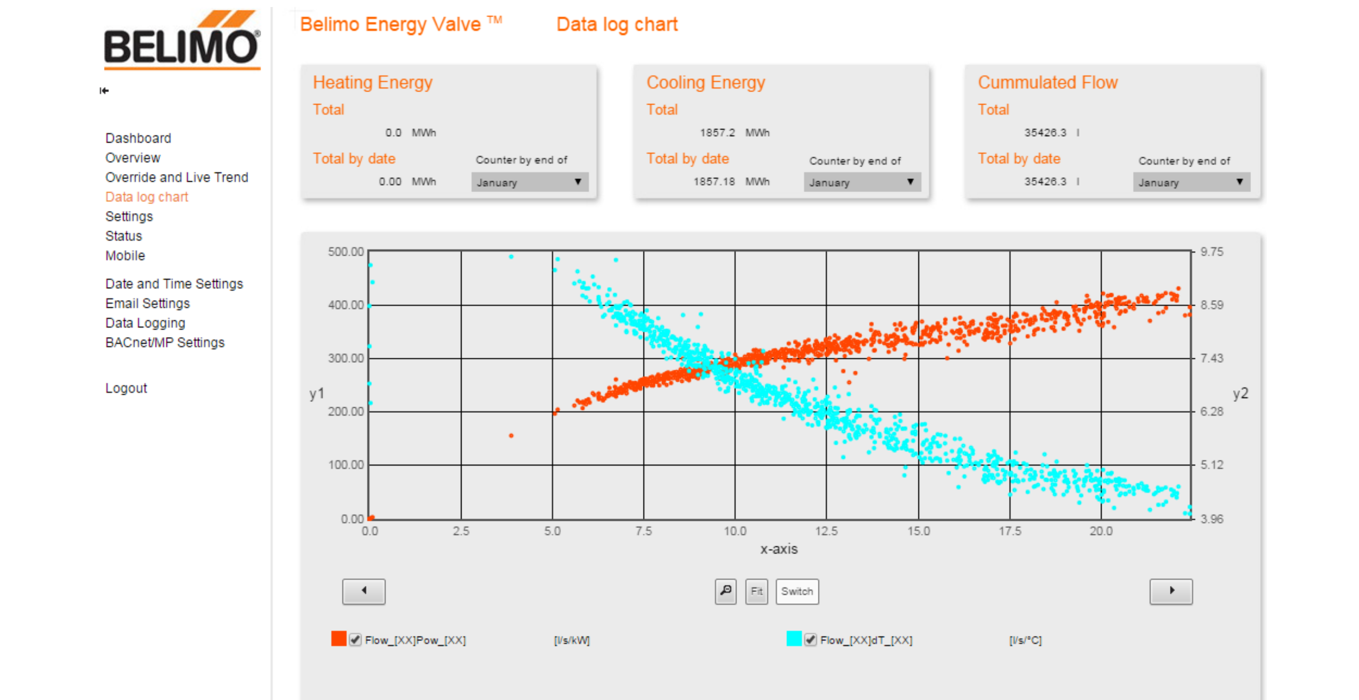

Figure 6: Integrated Web-Interface for configuring the Energy Valve and visualizing the current performance and recorded data

Effect of Flow Limitation on Cooling Output and Supply Air conditions

The objective of the flow limiting exercise was to observe the cooling power output of the Pre-Cooling Coil in the AHU when the maximum flow (Vmax) was decreased from 25 l/s to 18l/s. The supply air conditions were monitored to ensure that the set points were achieved to avoid occupant discomfort or disruption to laboratory operations (*Figure 7*).

The decrease in Vmax resulted in a higher delta-T during peak load conditions as shown in *Figure 9*, which complies with heat-exchanger physics. By avoiding low delta-T during peak cooling demand, load-flow mismatches could be reduced and the cooling capacity of the cooling plant could be maximised. By limiting flow to one AHU, additional capacity is made available to possibly starved units further along in the hydraulic network. Since AHU CR4-1 represents only a small fraction of the total cooling output of the central cooling plant, it is unlikely that the efficiency of the plant will be affected by this study. System savings were therefore estimated by extrapolating the savings from the studied AHU.

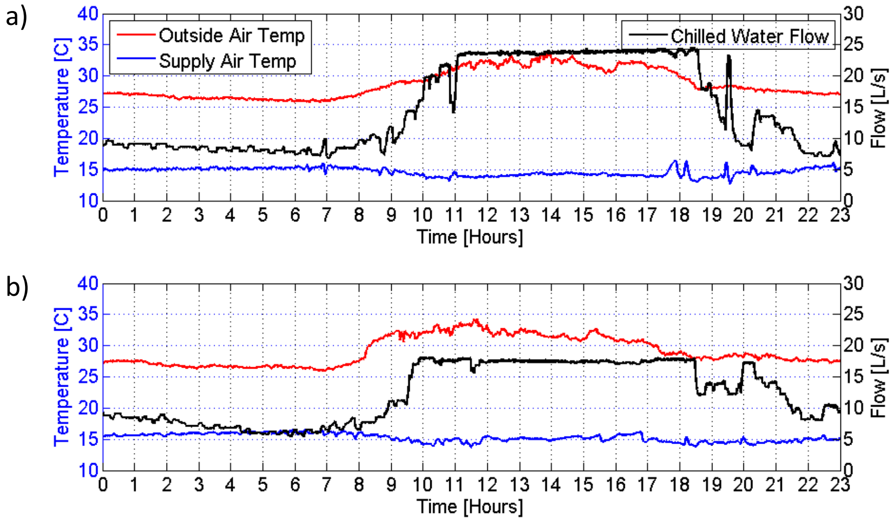

Figure 7: The influence of a) 25l/s flow limit and b) 18l/s flow limit on supply air temperature

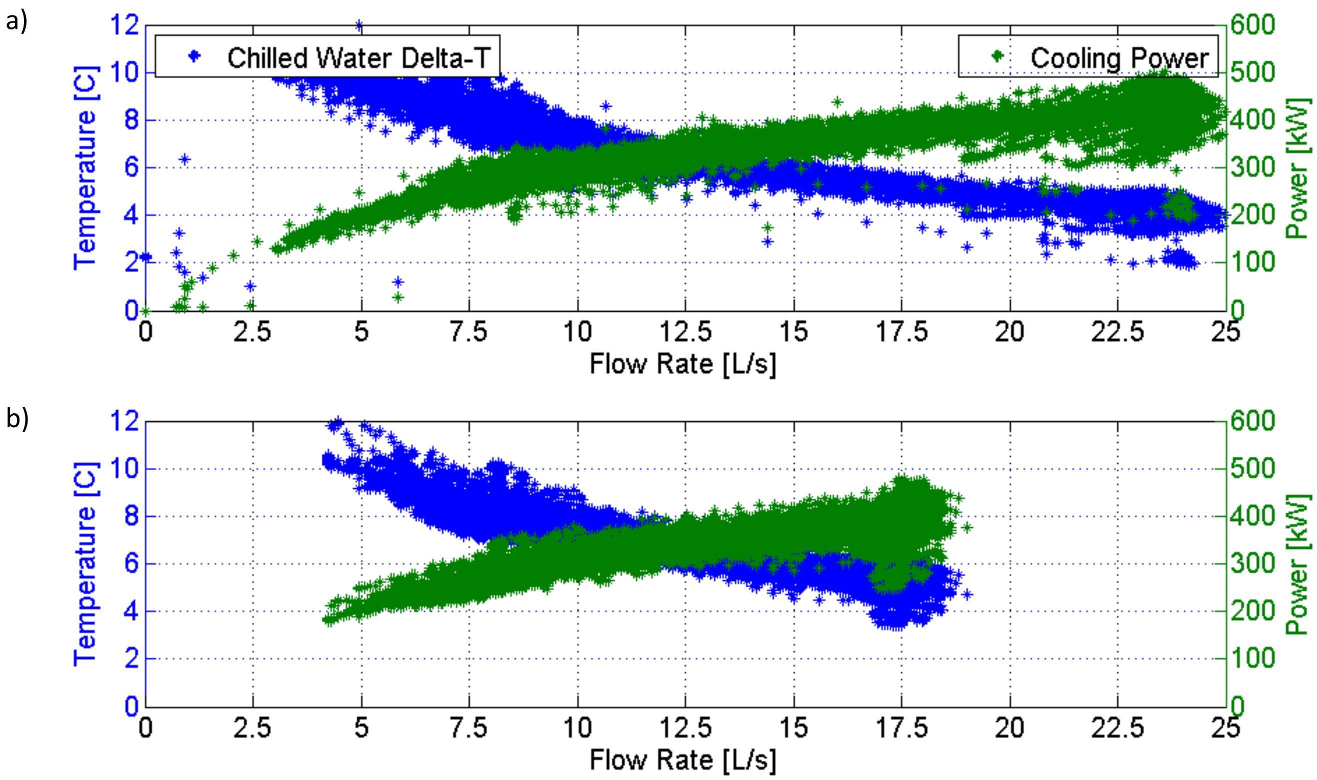

Figure 8: Heat exchanger performance with a flow limit of a) 25l/s and b) 18l/s, shown as delta-T and power versus flow

Energy Savings Potential

The peak flow was reduced from 25 l/s to 18 l/s, and the overall reduction in average day-time flow from 18.5 to 15.1 l/s (18.4%). The reduction in average flow results in a significant reduction of pumping energy consumption. However, since the 3.4 l/s reduction is only a small fraction of the flow supplied by the secondary pumps, the overall effect could not be measured. At the same time, a 1°C increase in the average supply air temperature is observed. Because this coil needs to dehumidify, the impact of limiting was considered with respect to humidity. The result is an increase of less than 5% of relative humidity at the set point temperature of 22.5°C. In other words limiting the flow has a large impact on energy but a very small impact on the room comfort according to ASHRAE Standard 55.

The reduction in average flow results in an increased average chilled water delta-T because the two parameters are inversely related in water-to-air heat exchangers. The minimum chilled water delta-T during daytime operating hours increased from 3.3 to 4.5°C and the average chilled water delta-T increased from 5.4 to 6.3°C. For a given cooling load, there is a significant improvement in the chiller efficiency caused by a decrease in the temperature difference between the condenser loop and the evaporator loop. Due to the small fraction of chilled water consumption by AHU CR4-1, the impact on the central plant cannot be observed directly.

If the savings of reduced flow and increased delta-T were extrapolated to the entire chemistry block, annual pumping energy would be reduced by 76,600-90,500 kWh and annual cooling energy by 175,000-220,000 kWh with a high efficiency centrifugal chiller.

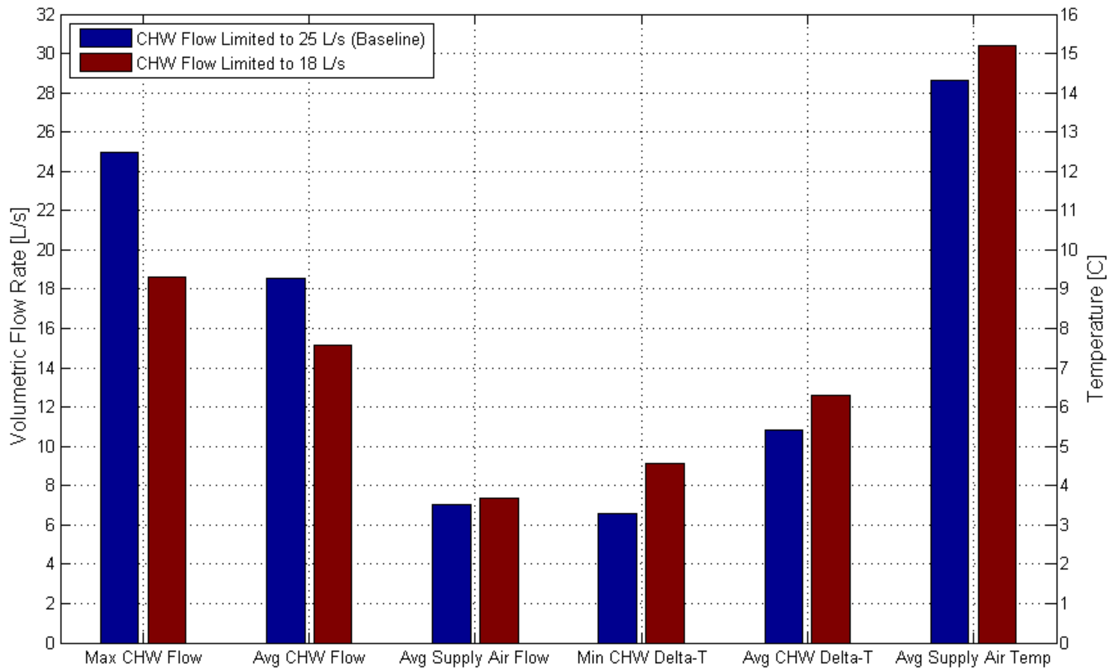

Figure 9: Comparison of cooling performance between the baseline case and flow limitation during daytime operating hours (0800hrs – 1900hrs)

Summary

The effect of the Flow Limitation control strategy using the Energy Valve was assessed during this study. It is evident that the Energy Valve has reduced the excess water flow and improved the cooling performance of the chilled water system. The limiting exercise effectively reduced the maximum chilled water flow rate of the AHU by 28%, while minimally impacting comfort. This improvement in chilled water system operation not only reduces pumping energy consumption, but the reduced chilled water flow also creates greater flow capacity for other zones, particularly zones which are far away from the pumps.

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