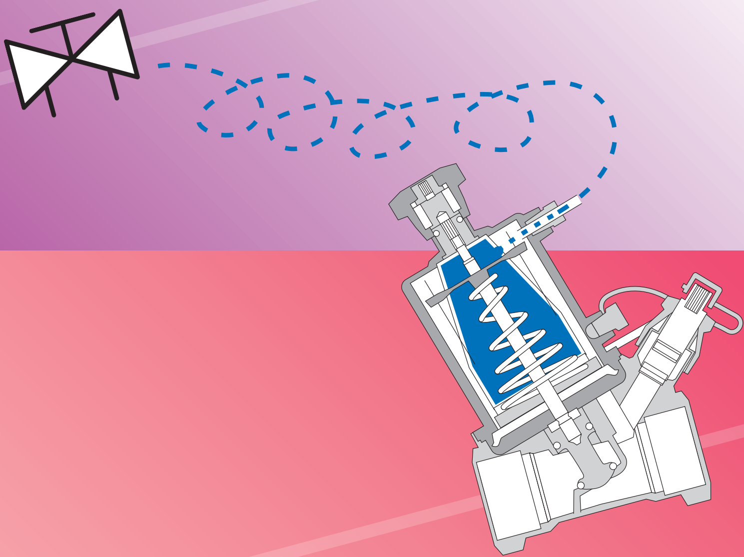
# Total Hydronic Balancing in Chilled Water System

# 空調冷凍水系統的全面水力平衡



機電工程署
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## Introduction

A typical chilled water distribution system consists of pumps and chilled water piping and air side equipment units regulated by control valves. Traditionally, manual hydronic balancing is performed using balancing valves based on the design chilled water flow at full load condition. However, when the system is at part-load conditions, for example, one or a few of the air side equipment units being at partial load or switched off, the hydronic balance may not be maintained due to interaction of different distribution circuits. Some air equipment units may get excess chilled water supply whereas others may get insufficient flow due to changes in differential pressure across different distribution circuits affecting the performance of the control valves. Energy saving opportunity may exist if the system could better match chilled water flow under partial load conditions.

This pamphlet aims to introduce the concept of total hydronic balancing, which encompasses control technologies to achieve chilled water system balancing at full load and part-load conditions.

## 引言

典型的冷凍水分配系統是由冷凍水泵、冷凍水管道和配備控制閥作調控的空調機組所組成。傳統上，水力平衡是根據冷凍水系統滿負載時的設計流量適當地調校手動平衡閥而達到的。然而，當系統處於部分負載的情況下，如有部份空調機組處於部分負載或關掉時，冷凍水系統各分支之間的互動關係會引致冷凍水系統的水力平衡有所改變。由於冷凍水系統的各分支壓差變化影響控制閥的表現，部份的空調機組可能得到太多或太少的冷凍水。因此，如果能調節冷凍水流量以更好地配合負載情況，便會有節能的空間出現。

本小冊子旨在簡述全面水力平衡技術的概念，當中包括冷凍水分配系統於滿負載時及部分負載時的水力平衡。

## Conventional Chilled Water System Balancing

Traditionally, balancing of a chilled water distribution system is based on design full load to ensure design water flow at the air side equipment units. However, in reality, all air-conditioning systems are mostly operating in the part-load conditions with modulating control valves to regulate the chilled water flow supply to air handling units (AHUs) and fan coil units (FCUs) with a view to achieving the design room temperature. This will result in differential pressure variations across different chilled water distribution circuits and as pressure drop at piping and coil accessories will be lower under reduced water flow conditions, the control valves will be subject to higher differential pressure affecting the operating control valve authority and hence hydronic control quality.

Control valve authority (β) can be defined as the ratio of "pressure drop across the fully opened valve (at design flow)" to "the maximum differential pressure in the circuit". To ensure reasonable flow control ability, β should range from around 0.25 to 0.5. When control valves are operating consistently at low authority values, this may result in unstable modulating control and larger temperature control band. As various distribution circuits in the chilled water system are interactive with one another, excessive chilled water flow may also be delivered to AHUs/FCUs on other distribution circuits due to increased differential pressure across control valves on some distribution circuits and this may cause pumping energy wastage.

## 傳統的冷凍水系統平衡

傳統上，水力平衡是根據冷凍水系統設計滿負載時冷凍水的流量而作出的，使系統可以於滿負載時提供足夠的冷凍水給各空調機組使用。但是，現實上所有的空調系統大部份運作時間都是處於部分負載，相關空調機組和盤管式風機內的控制閥會適當地調節冷凍水流量以調節空調機組的輸出，從而使溫度達致設計的室溫。與此同時，這也會引致冷凍水分配系統各分支有不同的壓差變化，因為在冷凍水流量減少時，水管和盤管附件的壓降也會相應地下降，引致空調機組端的控制閥壓差增加而影響其控制能力及在調節水流量的質素。

控制閥控制能力值(β)可以定義為閥門全開時所下降的壓力與有關水線路的最大壓差之比率。為確保有合理的流量控制能力，β的數值應該介乎0.25至0.5之間，如果控制閥持續處於低控制閥控制能力值的水平運作，這可能引致不穩定的調控和較大的的溫度控制帶。由於冷凍水系統不同分支之間的互動，其他分支內的空調機組/盤管式風機可能基於其控制閥壓差的增加而獲得過多的冷凍水，結果浪費了泵水所需的能耗。

## Total Hydronic Balancing

Total hydronic balancing refers to a set of devices and methods for making hydronic systems readily controllable under different load conditions. Self-acting differential pressure control valves are used to stabilize the local differential pressure variations and make distribution circuits independent of each other.

A differential pressure control valve is installed at return pipe of the circuit to be stabilized which senses water pressure of the supply side through an interconnecting capillary pipe anchored at the partnering balancing valve at the supply pipe. The varying upstream head pressure is taken up by the spring action of differential pressure control valve to maintain a stable differential pressure on the downstream load side. This provides the necessary stable differential pressure environment for control valves to perform flow modulation effectively. Figure 1 shows the mechanism of a typical differential pressure control valve.

## 全面水力平衡技術

全面水力平衡是透過一系列的裝置和方法去維持冷凍水系統在不同負載情況下的可控性，當中透過自動壓差控制閥去穩定各分支的壓差變化，並使這些變化不會影響其他分支的壓差。

壓差控制閥是裝設於分支回水管的，它利用小管道與相關供水分支的平衡閥連接，並藉以感應該供水分支的水壓，壓差控制閥內的彈簧會隨著相關供水分支的水壓而動作，以維持穩定壓差給其後的負載設備，從而提供所需穩定壓差的環境給空調機組端的控制閥，有效地調節流量。典型壓差控制閥裝置如圖1所示。

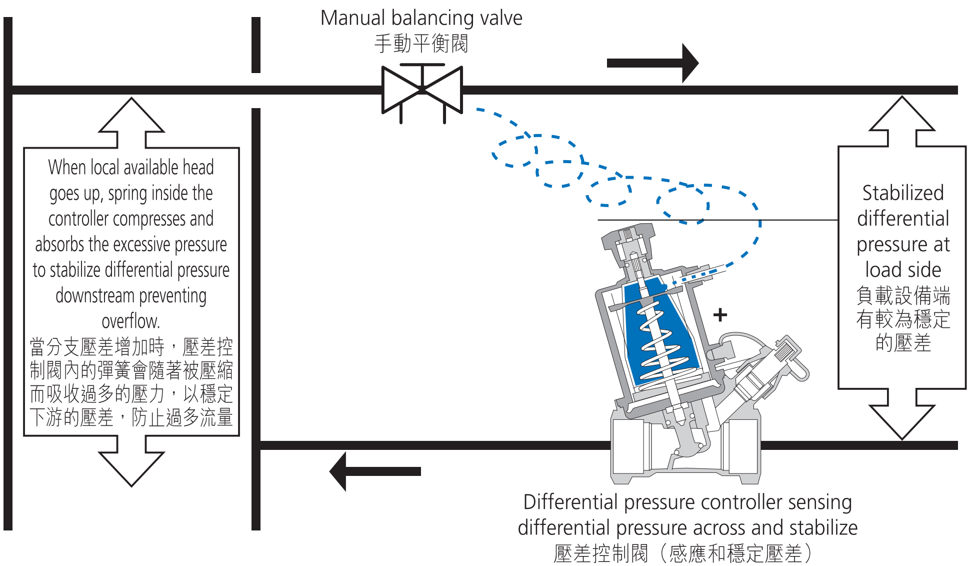


*Figure 1: Mechanism of differential pressure control valve for total hydronic balancing*
*圖1: 用於全面水力平衡技術的壓差控制閥裝置*

To optimize the use of differential pressure control valves, differential pressure distribution at the piping circuits under full load and various part-load conditions should be evaluated. Pressure distribution profiles of a typical chilled water system under full load and part-load conditions are shown in Figure 2 to illustrate the changes in differential pressure across air side equipment near main circuit and on far end distribution circuit under different load conditions. Apart from manual calculation, the evaluation process could also be assisted by appropriate hydronic design software. Properly sized differential pressure control valves could then be incorporated to provide local differential pressure stabilization at distribution branches and terminal circuits as necessary. A typical application of this technology in a chilled water system is shown in Figure 3.

為優化壓差控制閥的使用，首先需適當地評估冷凍水系統於不同負載時各分支線路的壓差分佈情況。典型的冷凍水系統於滿載和部份負載時分支線路壓力分佈狀況如圖2所示，圖中展示了近主線路和遠端分支線路的空調機組壓差在不同負載時之轉變。除以人手計算外，也可使用適當的液體循環系統設計軟件輔助有關評估。然後可著手在有需要的分支水路上加設適當的壓差控制閥去穩定該分支和終端線路的壓差。該技術於冷凍水系統的典型安裝配置如圖3所示。

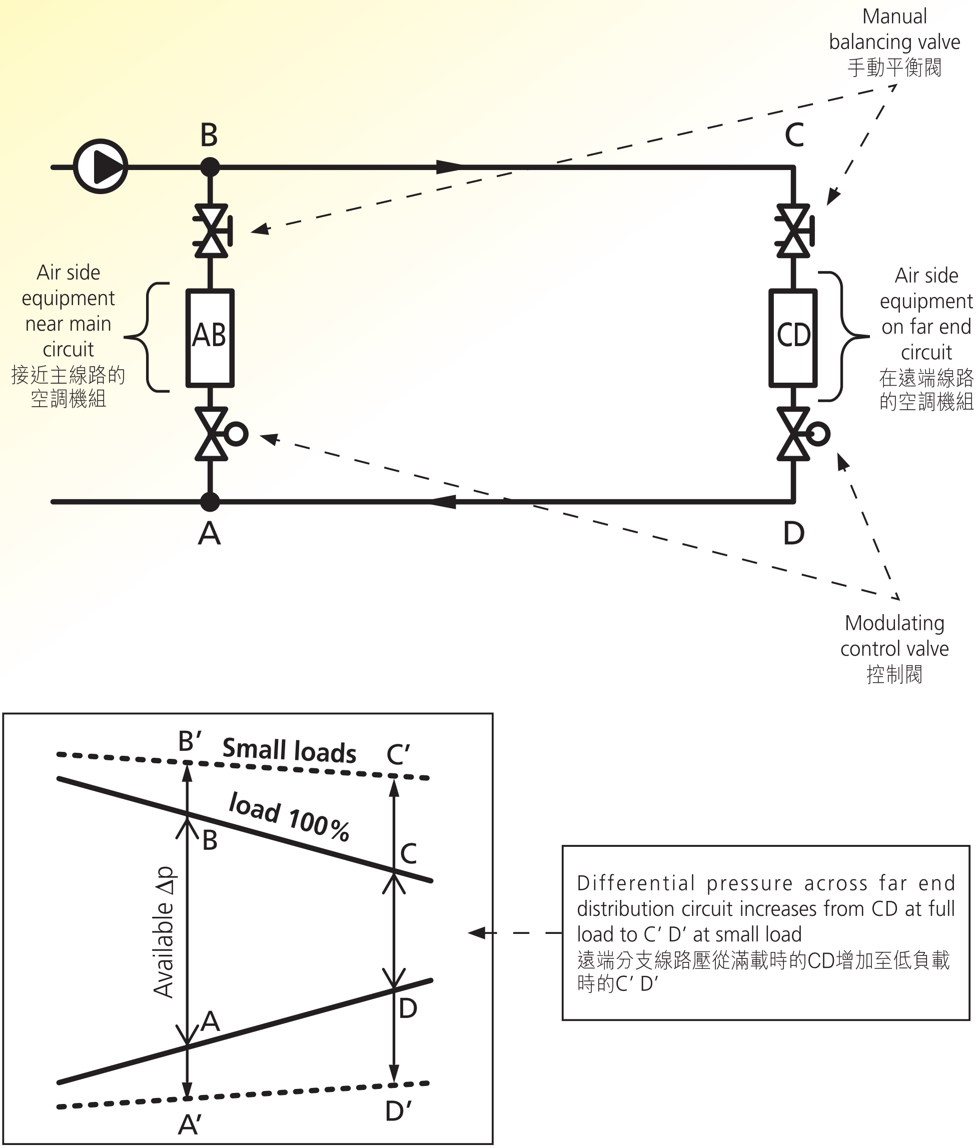


*Figure 2: Changes in differential pressure across main and far end distribution circuits for constant speed pump system under different load conditions*
*圖2: 恆速水泵系統內主線路和遠端分支線路壓差在不同負載時的轉變*

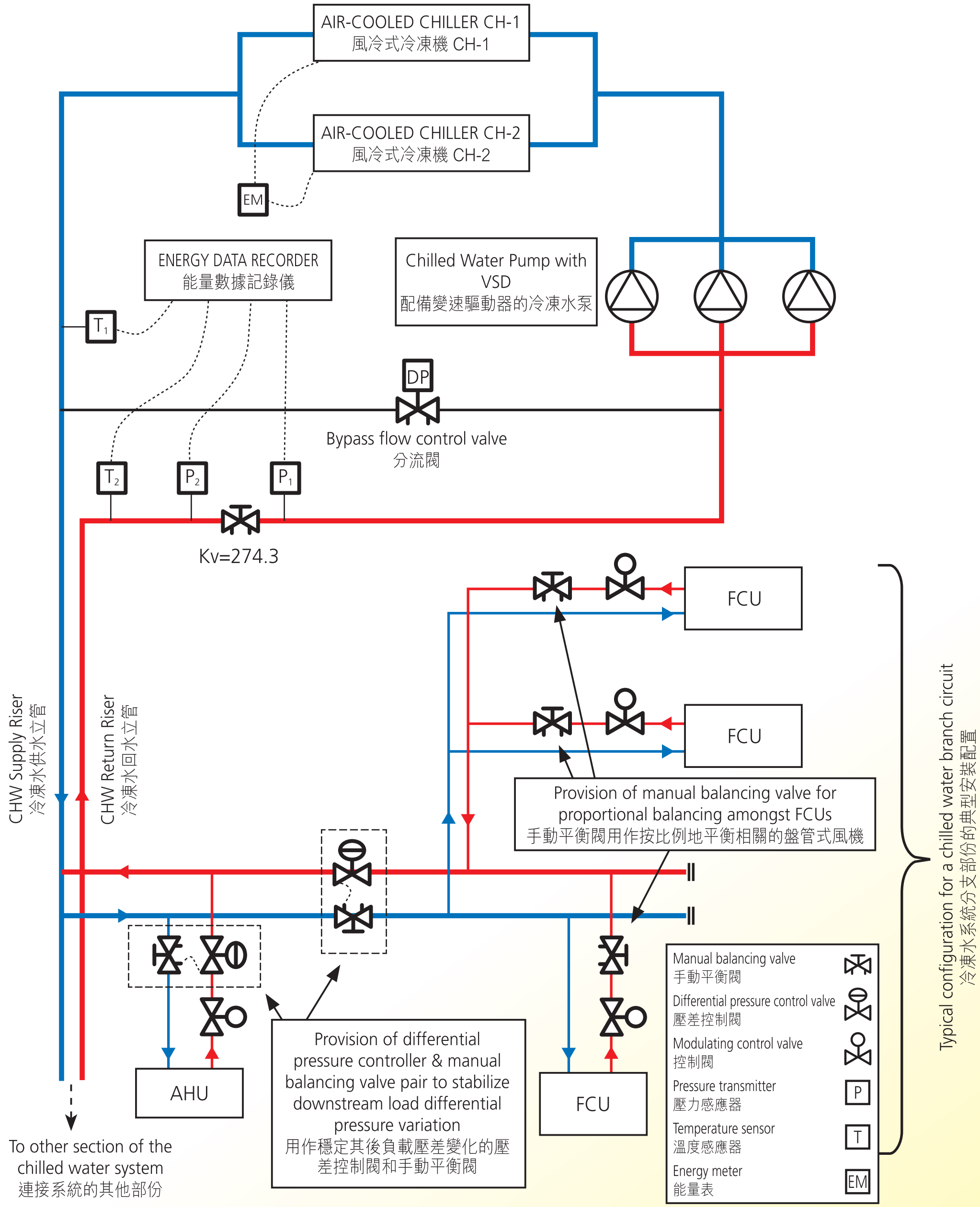


*Figure 3: Typical system configuration of total hydronic balancing in chilled water system*
*圖3: 全面水力平衡技術於冷凍水系統的典型安裝配置*

## Energy Saving Mechanism

This technology saves energy mainly by reduction of total chilled water flow during part-load conditions in which less chilled water flow will be required to meet the cooling load demand. In turn, chilled water pumps could be run at a lower speed, say, by means of variable speed drives (VSDs), to achieve energy saving. For retrofit projects, actual saving in pumping energy will depend on the configuration of the chilled water system, control strategy for the chilled water pumps as well as part-load pattern as highlighted below.

## 節能原理

此節能技術的原理主要是當系統處於部分負載需要較少冷凍水來滿足冷凍負載需求時，相應地減低冷凍水的流量，從而把冷凍水泵運行速度減慢（如採用變速驅動器），以節省能源。對於改裝工程項目，實際節省的冷凍水泵能源將取決於冷凍水系統的配置，如以下所列的冷凍水泵控制策略以及部分負載模式。

## Implementing Control Strategy

This technology can be implemented with minor retrofit work in the chilled water distribution system if the chilled water pumps are already operating with VSDs. It could also be incorporated into a new system quite easily. The followings are some general considerations for implementation of the technology:

- If the original system is not equipped with VSDs, technical requirement of installing VSDs for the pumps should be considered.
- Long operation hour system provides more opportunities for energy saving with such technology.

## 實施控制策略

若冷凍水泵已裝有變速驅動器，只要為系統進行小型改裝工程，便可以採用該項技術，把該方案設置於全新的系統亦頗為簡單。以下是實施這技術時一般要考慮的項目：

- 如果原系統未裝有變速驅動器，需同時考慮為水泵安裝變速驅動器的技術要求。
- 這技術於長運作時間的系統可提供較多的節省能源機會。

- The overall saving in chilled water flow under part-load conditions depends very much on the control strategy of chilled water pumps as well as the pump head requirement of the chilled water distribution circuits. In some circumstances, if certain air side equipment units are particularly far away from the pumps, the overall potential saving may be less because the system has to maintain sufficient pump head to ensure adequate chilled water be delivered to the air side equipment units on the far end circuits.
- Selection and installation locations of differential pressure control valves are important, which may affect the saving potential of chilled water flow. Usually, a differential pressure control valve should be installed at each tee-off from the main chilled water pipes and the main branches for groups of AHUs/FCUs. However, the actual installation location and selection should be determined through evaluation of differential pressure distribution at the piping circuits under full load and various part-load conditions.
- The setting of each differential pressure control valve is also important to ensure thermal comfort. In general, the setting should allow the air side equipment units on the distribution circuit to be stabilized to have adequate chilled water supply at design full load condition.

- 整體節省的冷凍水流量多取決於冷凍水泵的控制策略以及冷凍水配置系統對水壓的要求。在某些情況下，如果一些空調機組比較遠離冷凍水泵，系統為了維持足夠水壓以確保充足的冷凍水供給這些遠端的空調機組，整體節能潛力會相應降低。
- 壓差控制閥的選擇和安裝位置是重要的，會影響節省冷凍水量的潛力。一般而言，壓差控制閥應安裝在每個主冷凍水管上的分支點和空調機組/盤管式風機群的主分支處。但是，實際壓差控制閥的安裝位置和選擇應該透過評估管道線路在不同負載時壓差的分佈而作出。
- 為確保空調舒適度，壓差控制閥的設定亦是重要。一般而言，該設定應能使到那些需穩定壓差分配線路上的空調機組於滿載時有足夠的冷凍水供應。

## Benefits from Better Control Strategy

This technology enables chilled water pumps to be operated more closely with the cooling demand of the building and reduces energy wastage due to pumping excessive chilled water flow. With better chilled water flow control at air side equipment units under different cooling demand conditions, the technology could also help better maintain the indoor air temperature for thermal comfort. It should however be noted that the achievable energy saving is site specific which depends on the load pattern and conditions of the plant equipment. For further information, please contact the Energy Efficiency Office of The Electrical and Mechanical Services Department.

## 較佳控制達致的益處

該項技術能使冷凍水泵更緊貼大廈的冷凍需求而運作，減少因過多的冷凍水流量所導致的能源浪費。該項技術亦使空調機組於不同負載時能把冷凍水的流量控制得更好，亦有助更好地維持室溫，以達到空調舒適度。不過，需留意節能效果會因個別大廈的系統裝置而有所不同，這取決於大廈的負載模式和製冷系統的情況。有關更多資料，請與機電工程署能源效益事務處聯絡。

## Case Study

Total hydronic balancing for chilled water distribution was applied in one of the government premises as a pilot project.

### Basic Information

| | |
|---|---|
| Cooling capacity of the HVAC system | : 2 nos. of 370kW air-cooled chillers |

Number of chilled water pumps: 3 Nos.

Rating of pump motor: 12 kW

Pump operating hour: 24 hours x 7 days

### Result of the Pilot Project

Chilled water is teed off at each floor from the main chilled water pipe branches to supply air side equipment units (e.g. AHUs and FCUs). Differential pressure control valves were retrofitted in the tee-offs of the chilled water distribution piping for groups of air side equipment units on each floor.

Performance of the chilled water distribution system controlled by this technology was analyzed. From September 2008 to August 2009, the estimated monthly saving of chilled water flow was found to be ranged from 18% to 44%, with an annual average of about 24%. In general, the chilled water flow saving was more significant during winter period. However, the actual saving in electricity consumption of chilled water pumps due to reduction in chilled water flow may vary depending on the locations of the part-load conditions in the chilled water system and the control scheme of the chilled water pumps, which are site specific.

## 個案研究

我們於一座政府樓宇的空調冷凍水系統應用了全面水力平衡技術，作為試驗計劃。

### 個案的基本資料

空調系統容量：2x370千瓦 風冷式冷凍機

冷凍水泵數量：3台

冷凍水泵電動機功率：12千瓦

冷凍水泵運行時間：24小時x7天

### 試驗計劃的結果

冷凍水是從主冷凍水管於每層分流到空調機組的，壓差控制閥則安裝於冷凍水分配系統的每層空調機組群的分流處。

經過分析該試驗個案中冷凍水分配系統的表現，估計該項技術於2008年9月至2009年8月的一年內可為該系統平均減少約24%的冷凍水流量，按月冷凍水流量節省範圍則由18%至44%不等。一般而言，在冬天的節省冷凍水量會比較顯著。但是，冷凍水泵因冷凍水流量減少而實際節省耗電量，則取決於冷凍水系統出現部份負載的位置，和冷凍水泵的控制模式，這些都是按個別場地而有所不同。

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