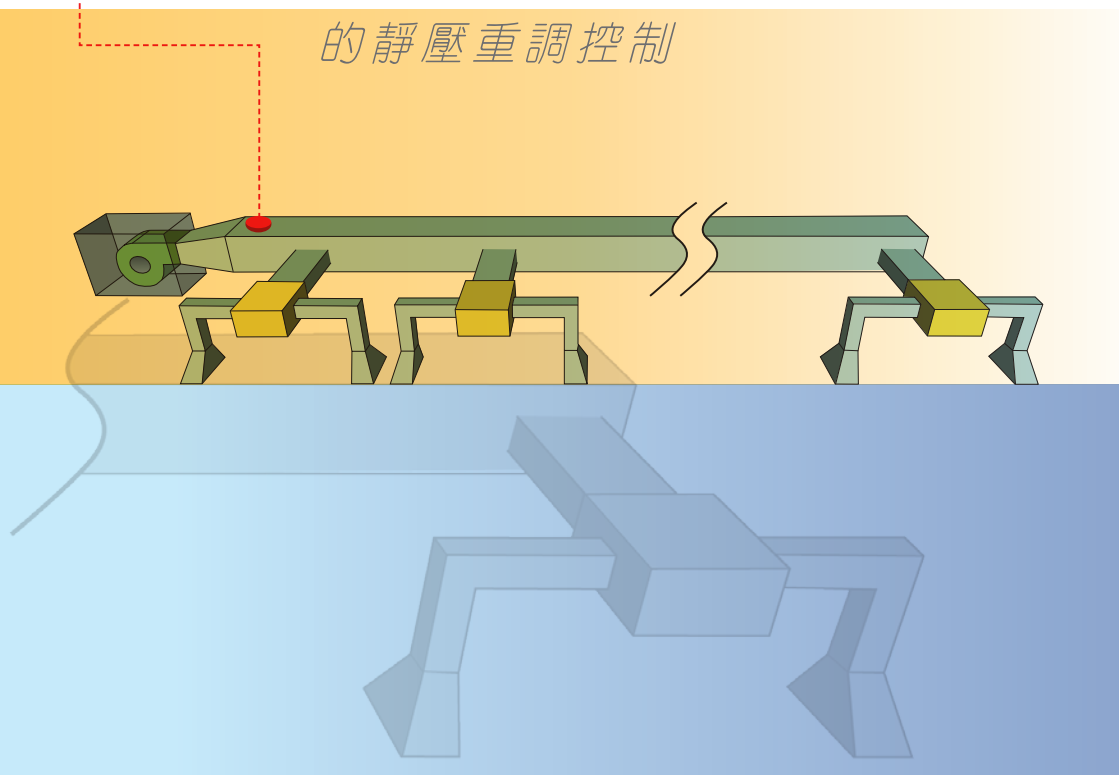
VAV System

Static Pressure Reset Control

可變風量空調系統的靜壓重調控制



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Introduction

Variable air volume (VAV) system is a common design for air distribution of a large central air conditioning system. The control enables the air distribution system to react more agile to the highly dynamic nature of cooling demand and hence lower the operating cost especially during part-load operations. However, the intricacies of the system control also post a challenge for engineers when energy efficiency is now one of the determinants for the design.

As one of the main components of VAV system, the supply air fan can account for 20 - 30% of the whole air conditioning system's year round electricity consumption. Thus optimizing the supply air fan operation saves both energy and operating cost. This pamphlet discusses an advanced static pressure reset control for optimising the operation of the VAV supply air fans.

Conventional VAV Fan Control

In VAV design, the air volume delivery varies with the cooling demand. The regulation of air delivery volume is usually achieved by adjusting either the position of an inlet guide vane in older design or the fan's running speed if it is driven by a variable speed drive (VSD).

引言

可變風量空調系統是大型中央空調系統常用的配風設計。控制器令配風系統更迅速應付不斷改變的冷量需求，令在部份負載的情況下效果更佳，從而降低操作成本。不過，能源效益已成為設計空調系統時須考慮的其中一項重要因素，控制系統的詳細設計亦是對工程師的考驗。

送風風扇是可變風量空調系統其中一件主要元件，其全年耗電量佔整個系統耗電量的20%至30%，因此改善送風風扇的操作方式可節省能源及操作成本。本單張探討用作改善可變風量空調系統送風風扇操作方式的先進靜壓重調控制。

傳統可變風量風扇控制

按可變風量設計，送風量會隨冷量需求而改變。控制送風量的方法通常是調校進氣導流葉片的位置（舊式設計）或風扇的轉速（如風扇由變速驅動器驅動）。

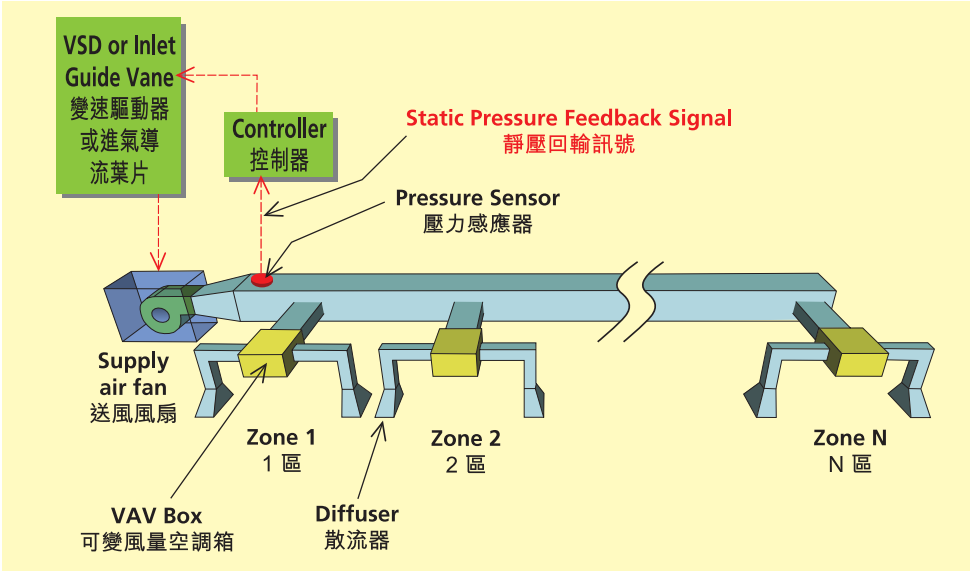

Fig 1 - Conventional constant static pressure control of VAV supply air fan
圖1 - 可變風量空調系統送風風扇的傳統固定靜壓控制器

The control of the inlet guide vane or variable speed drive is usually accomplished by a closed loop control which keeps track of the fan static pressure to achieve a predetermined pressure set point. A typical design arrangement is shown in Fig.1. The common design is to mount the pressure sensor immediately downstream of the fan outlet or at a distance downstream along the main air duct. When the cooling demand of a zone decreases, the VAV box damper will react by closing to reduce the supply air volume delivering to the zone. The throttling will build up a high static pressure in the air duct, and will actuate the fan control to trim down the supply air volume until the static pressure is brought down to its set point. This is known as constant static pressure control.

圖1顯示典型的閉環回路設計，該回路通常透過追蹤風扇靜壓來控制進氣導流葉片或變速驅動器，以達到預設的壓力指標。一般的設計是把壓力感應器安裝在風扇排氣口下游側，或離排氣口一段距離的主風槽下游位置。若某區的冷量需求下降，該區的可變風量空調箱風閘會關閉，以減少對該區的送風量。節流令風槽的靜壓上升，驅使風扇控制器減少送風量，直至靜壓下降到指定水平為止。這就是固定靜壓控制的原理。

Static Pressure Reset Control for VAV

Static pressure reset control for VAV is an advanced control scheme for controlling the static pressure set point of the supply air fan. For better results, the fan is recommended to be driven by variable speed drive. In this control scheme, the damper position of the VAV box in the "critical zone" is monitored. The critical zone is defined as the zone that requires the highest static pressure for supply air delivery. The objective of the control is to keep the damper of this VAV box open within a predetermined range, say between 70% and 90%.

Principle of Operation

By implementing static pressure reset control, the static pressure of the fan is no longer constant but continuously being reset according to the dynamics of the cooling demand so as to keep the critical zone VAV box damper open in the predetermined range. It is only with this kind of arrangement that the energy saving potential of a fan with variable speed drive can be fully unleashed.

In simple term, when the VAV box in the critical zone is operating with a damper opening below the lower limit of the predetermined range (i.e. excessive throttling occurs), the control will reduce the static pressure set point slowly. This will reduce also the supply air volume to the zone resulting in a slightly elevated room air temperature. The VAV box will then adjust its damper opening, relaxing the throttling, to allow more supply air to be delivered to the zone to maintain the room temperature at its set point.

On the other hand, if the VAV box damper is too widely opened (e.g. opening larger than 90% in our example) for a long enough period, it will be a beacon indicating insufficient supply air delivering

可變風量空調的靜壓重調控制

可變風量空調系統的靜壓重調控制是先進的控制系統，作用是控制送風風扇的靜壓設定點。如風扇由變速驅動器驅動，則效果更佳。在這控制系統中，「關鍵區」內可變風量空調箱風閘的位置會受到監察。「關鍵區」是指需要最高靜壓才能送風的區域。這系統的目標是令這個可變風量空調箱風閘的開啟幅度維持在預設範圍內（如70%及90%之間）。

操作原理

在採用靜壓重調控制後，風扇的靜壓不再固定，而是按冷量需求的變化不斷重調，使關鍵區的可變風量空調箱風閘的開啟幅度保持在預設範圍內。這種安排可以令由變速驅動器驅動的風扇充分發揮其節能潛力。

簡單來說，如關鍵區的可變風量空調箱的風閘開啟幅度在預設下限以下（即節流幅度太大），控制器會慢慢降低靜壓設定點，令該區的送風量下降，室內氣溫略為上升。可變風量空調箱隨後會調校風閘開啟幅度，減少節流幅度，讓更多冷風送到該區，令室溫保持在設定溫度。

另一方面，如可變風量空調箱的風閘開啟幅度過大（例如超過90%），並持續一段時間，則該區的送風量可能不足以應付冷量需求。控制器會提高靜壓設定點，讓

to the zone to meet the cooling demand. The control will increase the static pressure set point by speeding up the supply fan and deliver more supply air to avoid starving the zone. Provided the VAV box is correctly sized, increase in supply air will bring down the room air temperature and the VAV box damper will be reacting by closing its damper.

送風風扇加速，供應更多冷風，以免該區送風不足。若可變風量空調箱的大小設計正確，送風量增加會降低室溫，而可變風量空調箱會因應此情況而局部關閉風閘。

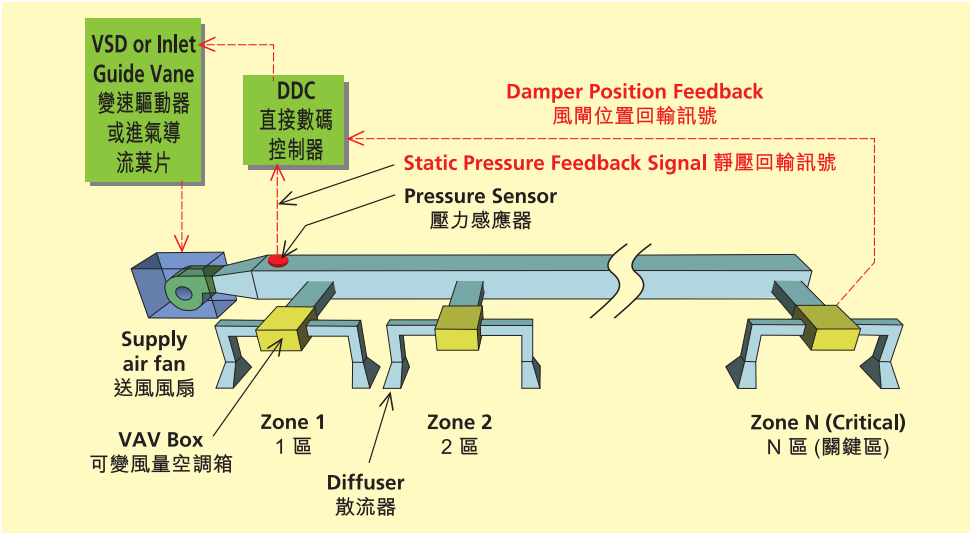

Fig 2 - System with static pressure reset control
圖2 - 採用靜壓重調控制器的系統

Energy Saving Mechanism

The power consumption of the VAV supply fan is proportional to the volume of air delivering as well as the static pressure lift of the fan. A reduction of either the air volume or the static pressure lift will reduce the fan power consumption. Static pressure reset control saves energy by reducing the static pressure lift of the supply air fan while delivering the same amount of supply air into the zones. This is achieved by appropriately relaxing the throttling of the VAV box in the critical zone. Figure 3 illustrates the pressure profile of the supply air along its delivery path.

節能原理

可變風量空調送風風扇的耗電量與送風量及風扇的靜壓升幅成正比。送風量下降或靜壓升幅減少都會減少風扇耗電量。靜壓重調控制有助節省能源，方法是減少送風風扇的靜壓升幅，但卻能把同等風量送到有關區域。透過適當減少在關鍵區域可變風量空調箱的節流幅度，便可做到這點。圖3顯示氣壓如何沿送風途徑變化。

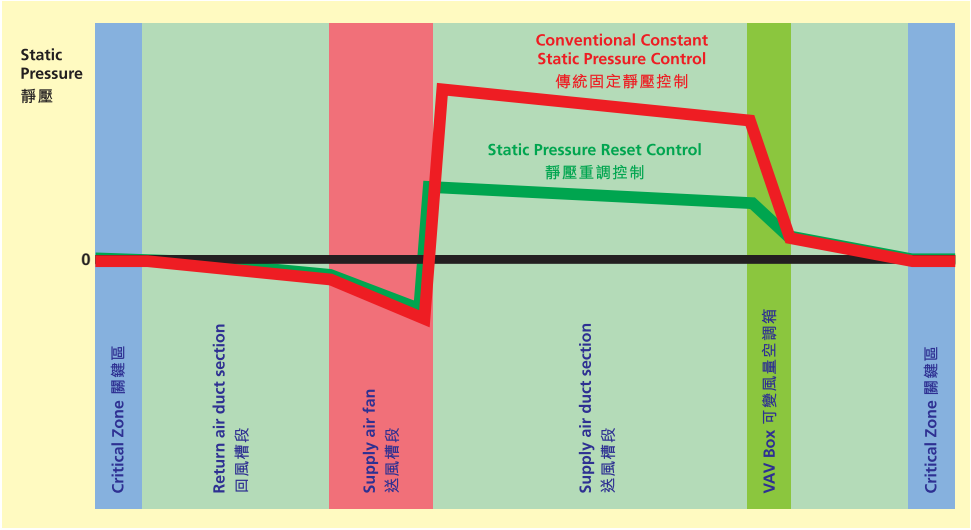

Fig 3 - Static pressure profile along the air path
圖3 - 靜壓在送風途徑中的變化

By relaxing the damper position in the VAV box, the fan can deliver the same amount of air with less static pressure and hence achieves energy saving. The extent of static pressure trim varies with the cooling demand as well as the characteristics of the system.

打開可變風量空調箱的風閘多一點，風扇便可以在較低靜壓下傳送同等風量，並可以節能。靜壓調整幅度隨冷量需求及系統特徵而改變。

Implementing the Control Scheme

The control scheme can be implemented with traditional analogue circuits or with direct digital control (DDC) circuits. VAV box equipped with damper position feedback signal is a prerequisite for implementation of the control. The difficulty mainly lies on the identification of the critical zone. Thus, VAV system with zonal DDC is more preferable because of its capability to monitor all the VAV boxes within the zone which can eliminate the need to identify which particular VAV box in control is the critical zone. A simplified arrangement is shown in figure 4 below.

實施控制系統

控制系統可由傳統的模擬電路或直接數碼控制電路操作。實施控制系統的先決條件是可變風量空調箱具備風閘位置回輸訊號。在這方面最大的困難是如何辨別出關鍵區。具備分區直接數碼控制的可變風量空調系統可以監察區內所有可變風量空調箱，無須辨別哪個受控制的可變風量空調箱為關鍵區，因此這種系統效果較佳。下面圖4為控制布置簡圖。

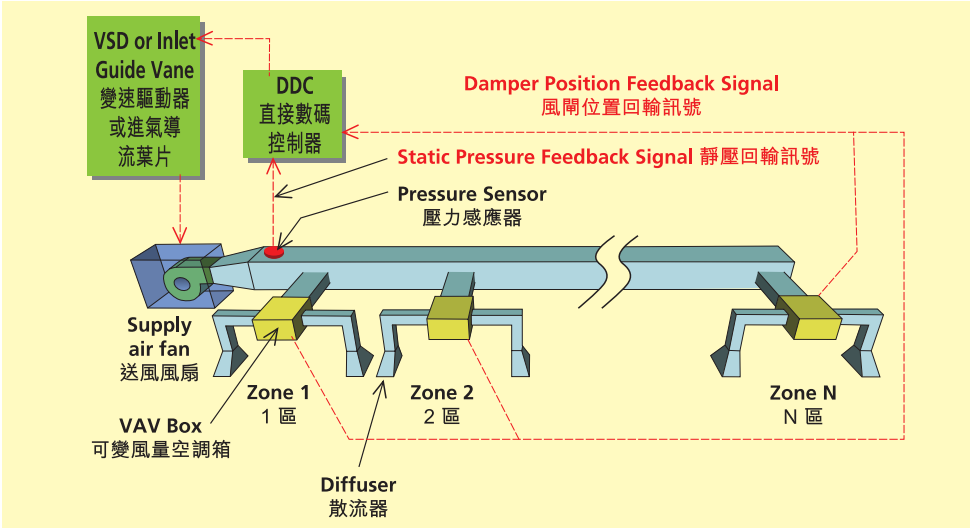

Fig 4 - Simplified schematic of static pressure reset control with a zonal DDC
圖4 - 具備分區直接數碼控制的靜壓重調控制器簡圖

In the DDC implementation, the control objective is to keep at least one of the VAV boxes damper opens in the predetermined range. When all the VAV box damper positions are under monitoring, the one that is most widely opened is treated as the critical zone. Its VAV box damper position is used for determination of the supply air fan's static pressure set point. The set point is then passed on to a closed loop control to alter the fan speed to accomplish the control objective.

Although the control objective seems very simple, cautious system commissioning is essential for successful implementation. According to experiences, there are two main difficulties to handle:

1) Stability

The scourge of instability is the rapid interactive oscillation between the VAV box control and the static pressure reset control, especially in system that employs pressure-independent VAV

就直接數碼控制而言，控制目標是至少保持其中一個可變風量空調箱風閘按預設幅度開啟。當所有可變風量空調箱風閘的位置都受到監察，開啟幅度最大者就會視為關鍵區。有關系統會利用其可變風量空調箱風閘位置來決定送風風扇的靜壓設定點，然後把設定點輸入閉環路控制電路，以改變風扇速度，從而達到控制目標。

雖然控制目標似乎很簡單，但是必須小心校驗系統，才能達到此目標。根據經驗，有兩個難題需要解決：

1) 穩定性

系統不穩定，可導致可變風量空調箱控制器及靜壓重調控制器之間互相影響，在兩個狀態之間擺動。控制系統應用於

box control which is a design norm in modern VAV system nowadays. Pressure-independent VAV boxes employ a cascaded control which uses the temperature reading of the room thermostat to establish an air flow set point for the VAV box. The VAV box will control the damper opening by an air velocity sensor feedback signal to accomplish the set point requirement. Compared with older pressure dependent VAV box in which the air volume delivery may be influenced by the upstream static pressure, pressure-independent control modulates the VAV boxes more accurately according to the cooling demand. However, combining with a badly tuned (in terms of the response timing and speed) static pressure reset control system, the two control systems disturb each other and may oscillate in a very unstable manner as shown in figure 5.

2) Zones with VAV box undersized

Undersized VAV box will provide insufficient supply air to the zone and starving the zone. The temperature set point for the zone is usually not achievable most of the time during cooling season. This is usually known as "rogue zone". VAV box undersize may be a result of either a bad VAV box selection process or an unexpected large heat load in the zone. This leaves the VAV box damper opened most of the time without allowing much chance for part loading. That is, the VAV box loses its controllability to respond to cooling load fluctuations. Static pressure reset control will see this as a sign showing static pressure request and will speed up the fan trying to make up for the

採用壓力無關型可變風量空調箱的系統（這是可變風量空調系統現在常用的設計）就更容易出現不穩定情況。壓力無關型可變風量空調箱採用級聯控制器，這種控制器根據房間恆溫器的溫度讀數，為可變風量空調箱設定流量。可變風量空調箱會利用流速感應器回輸的訊號控制風閘開啟幅度，以符合有關設定點的規定。較舊式的依壓力調整可變風量空調箱的送風量可能會受上游靜壓影響，而壓力無關型控制則可更準確地根據冷量需求來調整可變風量空調箱。不過，該控制系統一旦與調校得不好（就回應時間及速度而言）的靜壓重調控制系統結合，就會互相干擾，並有可能出現以圖5所示的極不穩定方式擺動。

2) 可變風量空調箱冷量不足的區域

如可變風量空調箱的冷量不足，將不能為該區供應足夠冷風。這種區域在需要冷量季節的大部分時間都達不到溫度設定點，通常稱為「失常區」。可變風量空調箱冷量不足的原因，可以是選用了不合適的可變風量空調箱或該區熱負荷較預期大，令可變風量空調箱的風閘長期開啟，幾乎沒有機會處於負荷未滿的狀態，亦即失去回應冷量負荷變化的能力。靜壓重調控制會把這情況視為

demand. The result is underperformance of the static pressure reset control and the static pressure of the system is staggering on the high side.

需要增加靜壓的訊號，於是令風扇加速，以滿足需求，結果是靜壓重調控制表現欠佳，而系統的靜壓徘徊在高範圍內。

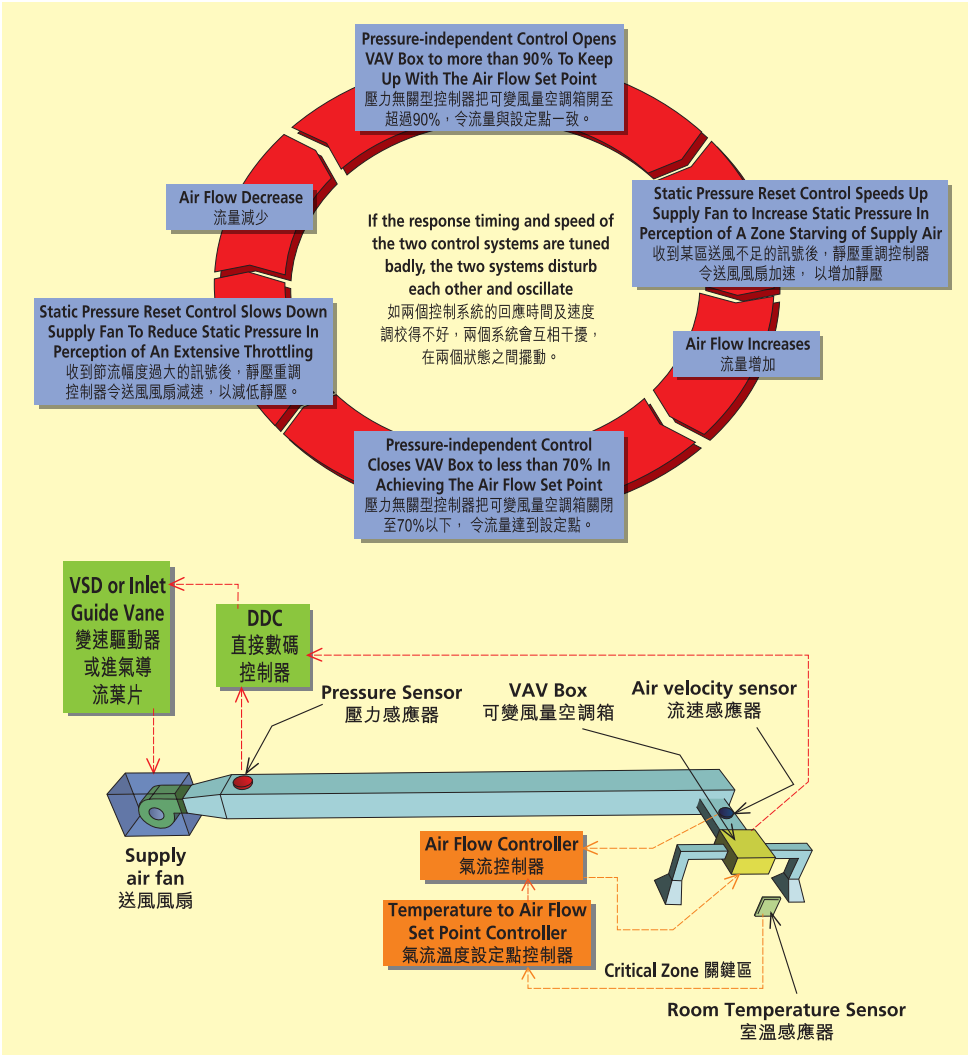

Fig 5 - The possible oscillating cycle when pressure-independent VAV box control is working with static pressure reset control

圖5 - 壓力無關型可變風量空調箱控制與靜壓重調控制一起運作時可能出現的擺動循環

Resolving Problems in Static Pressure Reset Control

To combat these issues, good control logic can be developed to achieve the control objective. The details can be worked out with the control specialist contractor provided the control objective is clearly stated. Despite the logic employed, a precise commissioning process is inevitable.

The stability issue can be resolved by adjusting the speed of set point reduction to slow down the oscillation to an acceptable level. The implementation logic should allow slow static pressure set point trimming in order to avoid instability during the course. However, one may also want to keep the speed of set point increment reasonably fast in order not to compromise the indoor environmental comfort when the cooling load is picking up quickly. Thus a logic allowing trimming down and picking up of the set point at a different pace can be considered. To illustrate the response of such an arrangement, the response of a hypothetical system is shown in figure 6 below.

解決有關靜壓重調控制的問題

為了解決這些問題，可制訂良好的控制程序，以達到控制目標。有關細節可與控制專門承造商商討，惟須清楚述明控制目標。就算採用較佳程序，也要有精確的校驗過程。

要解決穩定性問題，可透過調整設定點降低的速度，把擺動減慢至可接受水平。操作程序應容許靜壓設定點慢慢降低，以免出現不穩定情況。不過，也許大家亦希望設定點的上調速度不要太慢，以免一旦冷量負荷急增，室內環境就變得不舒適。因此，可容許設定點的下降及上調速度有所不同。下面的圖6顯示一假設系統，以說明在這種安排下有關系統的回應方式。

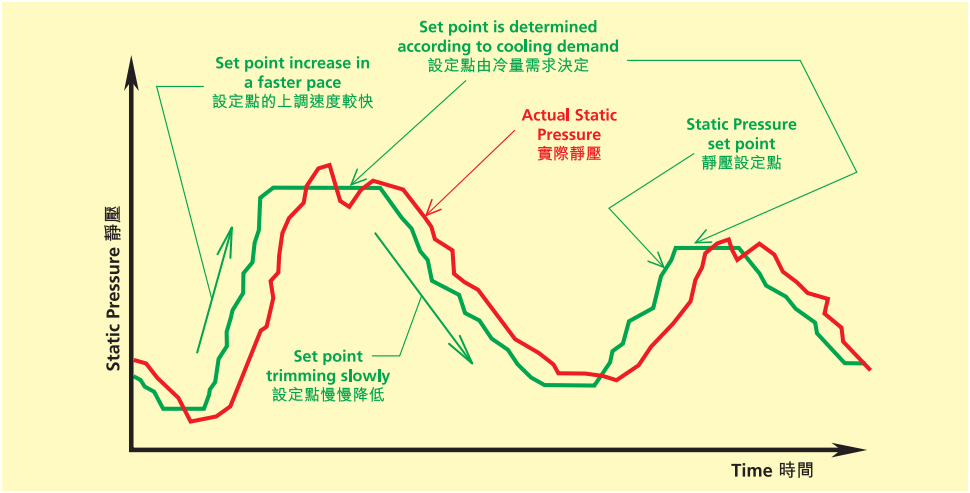

Fig 6 - Diagram illustrating the response of a hypothetical system.
圖6 - 假設系統的回應圖

For the rogue zone, undersized VAV box should be identified during the commissioning. This can be done by logging the static pressure set point and the actual measured static pressure in the duct. If the static pressure set point is found operating in the middle or lower range of the static pressure band, the static pressure reset control should be working properly without any noticeable undersized zone and the system should generate reasonable saving. If however, the data indicated that the set point is staggering in the high range most of the time, there may be zones with undersized VAV box. In this case, one may choose to ignore these zones if the supply to these zones is not essential after reviewing.

Energy Saving Potential

Static pressure reset control saves VAV supply fan energy, if properly implemented. The energy saving can be remarkable. However, the saving is also site and system specific. For illustration, in our trial project for an office building, the year round saving was found to be about 17.5% fan electricity consumption with conventional constant static pressure control as the base for comparison. The payback period was estimated to be around 3 years.

For further information, please contact the Energy Efficiency Office of the Electrical and Mechanical Services Department.

至於失常區，應在校驗期間找出冷量不足的可變風量空調箱，方法是記錄靜壓設定點及在管道內量度到的實際靜壓。如靜壓設定點是在靜壓帶的中或低範圍內，靜壓重調控制器應操作正常，並且沒有明顯的可變風量空調箱冷量不足的區域，而有關系統應可節省一定能源。不過，如數據顯示設定點大部分時間都徘徊在高範圍內，則可能有些區域的可變風量空調箱冷量不足。在這種情況下，如經過檢討後，發覺向這些區域送風並非必要，則或可不理會這些區域。

節能潛力

如實施得宜，靜壓重調控制可節省可變風量空調系統送風風扇所需的能源。所節省的能源可以相當多，但數量須視乎地點及系統而定。例如本署在一幢辦公大樓進行試驗時，發現與傳統的固定靜壓控制器比較，靜壓重調控制全年可節省風扇用電量大約17.5%，而回本期估計為大約3年。

如需更多資料，請聯絡機電工程署能源效益事務處。

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