Heat Pump Water Heaters

熱泵熱水器

機電工程署
EMSD

Introduction

Heat pump is a machine that would extract heat energy from a relatively cool medium (the heat source) and transfer it to a relatively hot medium (the heat sink) to make the cool medium cooler and the hot medium hotter. This is comparable to a machine producing two effects, one for heating and the other for cooling.

Moreover, heat pump is an energy efficient machine to provide heating and cooling in many applications. Normally, for one unit of electrical energy supplied to the heat pump, it would produce more than one unit of heating energy as well as more than one unit of cooling energy. This is far more efficient than other heating processes which normally produce less than one unit of heating energy due to losses.

The efficiency of heat pump will be superb in applications where both heating and cooling are required simultaneously so that heating energy and cooling energy from the heat pump could be fully utilized. This publication focuses on heat pumps adopted in water heating applications.

This pamphlet collates related information for reference by users and designers who would be benefitted from applying heat pumps in their daily water heating applications to save energy as well as running costs.

引言

熱泵這種機器，能從相對低溫的媒介（熱源）提取熱能，並將其傳送到一個相對高溫的媒介（熱庫），使低溫媒介更冷而高溫媒介則更熱。這樣的運作，就相當於一台機器，能產生供暖和冷凍的兩個效果。

不但如此，熱泵更是一種可廣泛應用於供暖和冷凍的節能設備。一般而言，供應一個單位的電能給熱泵，它會產生多於一個單位的熱能和多於一個單位的冷能。效能上遠高於其他的加熱方法，這些方法往往因損耗的緣故，一個單位的能源只能提供少於一個單位的熱能。

如能同時間將熱泵應用於供暖和冷凍，盡用它所產生的熱能和冷能，其能效則會更突出。本刊物將重點描述熱泵作為熱水器的應用。

本小冊子旨在提供相關資料予用家及設計者參考，使經常應用熱水者，能受惠於熱泵的應用，從而節約能源和減省營運成本。

Understanding about Heat Pump

WORKING PRINCIPLE

1 Heat Pump Cycle

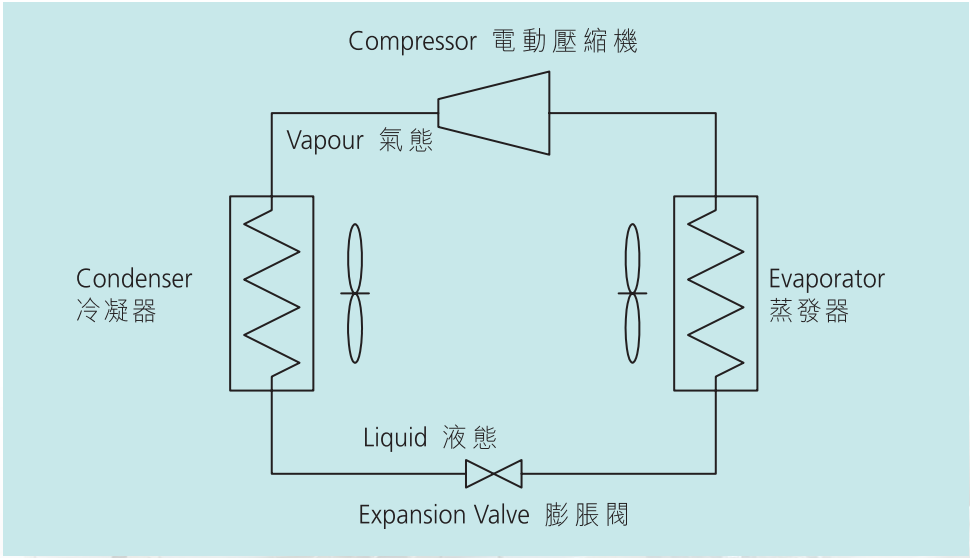
Like refrigeration machines, most heat pumps operate on either a vapour compression or an absorption cycle. Electrically driven heat pumps normally operate on the former cycle. It has an electrical compressor that circulates refrigerant between a condenser and an evaporator. At the condenser, heat energy is released when vapour phase refrigerant is condensed to liquid phase, whereas at the evaporator, heat energy is extracted (in other words, cool energy is produced) as the liquid refrigerant is vapourised.

熱泵常識

工作原理

1 熱泵循環

如一般的製冷機器，大部分的熱泵都透過氣體壓縮或吸收循環而運作。而電力驅動式的熱泵則通常採用前者的運作原理。它有一個電動壓縮機，將製冷劑循環於冷凝器和蒸發器之間。在冷凝器端，熱能量因氣態製冷劑冷凝為液態而釋放出來。而在蒸發器端，熱能卻因著液態製冷劑被揮發為氣態而被抽取（即冷能被釋放）。



Vapour Compression Cycle 氣體壓縮循環

2 Operation Efficiency - Coefficient of Performance

The amount of heat energy and cool energy produced at the condenser and evaporator respectively depends on a number of factors such as temperature of the media surrounding the condenser and evaporator, type of refrigerant, and working pressure of refrigerant vapour entering the condenser.

For electrically driven heat pumps, the coefficient of performance (COP) which is the ratio of thermal energy output from a heat pump to electrical energy input to its compressor, is an operation efficiency indicator for the heat pump. Energy output of a heat pump depends on how one utilizes its heat and cool energy output. For heating only applications, the COP is the ratio of the heat energy output to the electrical energy input. For applications that utilize both heat and cool energy, the COP is the ratio of the total heat and cool energy output to the electrical energy input, and would be higher as shown in the equation below.

2 效率——效能系數

在冷凝器端和蒸發器端分別產生的熱能和冷能的多少，取決於多個因素，如圍繞冷凝器和蒸發器的媒體溫度，製冷劑類型，和氣態製冷劑在進入冷凝器時的工作壓力等。

效能系數（COP）是電力驅動式熱泵的一個運作效率指標，它是熱泵輸出的能量和壓縮機輸入的電能的相比值。熱泵之能量輸出為何，則取決於使用者如何利用其產生的熱能和冷能。若僅作供暖用途，其效能系數就等於其熱能輸出和電能輸入比。若能一併使用所產生的熱能和冷能，則它的效能系數就會更高，如下列的公式所示，效能系數是所產生的熱和冷的總能量，與輸入的電能量之比。

$$COP = COP_{Heating} + COP_{Cooling} = \frac{E_{Heat} + E_{Cool}}{E_{Electrical}}$$

$$效能系數 = 效能系數_{供暖} + 效能系數_{冷凍} = \frac{熱能 + 冷能}{電能}$$

Theoretically by definition, $COP_{Heating}$ is greater than $COP_{Cooling}$ by 1. It is because heat energy delivered by a heat pump is the sum of the heat energy extracted from the heat source at the evaporator and energy to drive the compressor.

按定義，供暖效能系數，理論上是比冷凍效能系數高於1，原因是熱泵所產生的熱能，應是蒸發器從熱源所提取的熱能和驅動壓縮機能量的總和。

Generally, heat pump can achieve a $COP_{Heating}$ of 3 and the corresponding $COP_{Cooling}$ would be around 2. Hence, the overall COP of a heat pump for both heating and cooling can be up to around 5.

3 Performance at Different Temperature Conditions

A conventional heat pump for hot water heating applications usually raises water temperature by 5 to 10°C at its designed hot water flow rate and temperature lift conditions. So water is needed to be circulated through the heat pump a few times to build up the required hot water temperature.

The COP given by heat pump manufacturers is usually referring to a given set of operating temperature conditions. When water is re-circulated, the COP of heat pump will drop in successive stages when inlet water temperature is getting hotter and hotter. Hence quoted COP may need to be discounted based on the heat pump performance curve to reflect the overall efficiency for applications in different systems.

DESIGN CONSIDERATIONS

1 Upfront and Recurrent Cost

For venues where the total electrical power consumption is large, people would normally opt for bulk tariff scheme. Under such scheme, electricity charge is split into 2 parts namely the energy charge and the kVA demand charge.

一般來説，熱泵的供暖效能系數可達3，而相應的冷凍效能系數則可達2。故此，能同時應用於供暖和冷凍的熱泵，其總效能系數是可高達5。

3 不同溫度下的效能

傳統用於製造熱水的熱泵，在其額定的熱水流量及溫度提升的條件下，往往只能一次過將水溫提高約攝氏5至10度。要達到所需的熱水溫度，通常需將水循環流過熱泵數次。

唯熱泵製造商所提供的效能系數，通常是在特定的運作溫度條件下才能達到。當水多次循環流過熱泵，熱泵的效能系數會因進水溫度愈來愈高而下降。因此，在估算不同系統的整體效能時，需按熱泵的性能曲線，將聲稱的效能系數調整，才能如實反映有關表現情況。

設計要素

1 前期和經常性費用

對於總耗電量大的場所，人們通常會選擇「大量用電」的收費計劃。該等收費計劃，將電費分為兩部分，即電能量收費和千伏安需求量收費。

Should a central hot water system be installed in these venues, the designer may use a heat pump of heating capacity much smaller than that of a direct instantaneous electric heating system. This would not just reduce the upfront capital cost but also save the recurrent kVA demand charge.

2 Storage Tank

To match the hot water demand with the smaller heating capacity of heat pump, normally a hot water storage tank is required. The size of the tank is mainly determined by the consumption profile but shall not be oversized to avoid imposing excessive loading on building structure. If there is no structural loading constraint, a larger storage tank may help reducing the kVA demand charge of the venue by shifting the operating hours of the heat pump system to light load periods such as night time.

For preventing the risk of legionnaires' disease, hot water storage device should be designed to operate at over 60°C.

3 Recovery Time

With the tank size finalised, a heat pump of suitable rating can then be selected to ensure adequate recovery time for heating the tank of water to the target temperature after full consumption. Critical review of the consumption profile is necessary to determine the design recovery time.

4 Hygiene

For applications where hot water hygiene is a concern, designers should use heat pump with double-walled heat exchanger to prevent contamination of hot water by refrigerant should there be pipe burst.

如果要在這些場所安裝中央熱水系統，設計者通常可使用加熱功率遠比即熱式電熱器為低的熱泵。這不僅可降低前期投資成本，而且能節省千伏安需求量方面的經常性收費。

2 儲水箱

如果安裝一加熱功率較小的熱泵，要配合場所的熱水需求，一般需要配置熱水儲水箱。然而，儲水箱的大小，應能符合場所的實際熱水需求情況，但也不應過大，以免過份增加建築結構的負荷。如果沒有建築結構承載的限制，大一點的儲水箱確有助於減少場地的千伏安需求量收費，因熱水可於每日的非高峰耗電期（如夜間）製造並加以儲存。

為避免退伍軍人症的風險，熱水儲存裝置的設計溫度應在攝氏60度或以上。

3 蓄熱期

在熱水儲水箱的大小確定後，熱泵的熱功率便取決於系統所需的蓄熱期，即是將儲水箱中的水從來水溫度加熱到目標溫度所需的時間。這蓄熱期要嚴謹考慮場所的熱水消耗情況，才能決定。

4 衛生

對熱水若有嚴格的衛生要求，設計者應考慮使用有雙層式熱交換器的熱泵，以防止製冷劑喉管一旦破裂，而令熱水被污染。

TYPES OF HEAT PUMP WATER HEATERS

1 Air-to-Water

Air-to-water heat pumps are those which extract heat energy from ambient air (the heat source) and reject it to water media (the heat sink). This type is quite common as cool air and hot water so produced are more versatile in applications. For instance, an air-to-water heat pump installed for kitchen, where the environment is hot, can provide spot cooling to occupants as well as hot water for catering service efficiently.

The temperature of hot water that can be produced by a heat pump depends on the refrigerant and the temperature of the heat source. Conventional heat pumps are designed to be efficient for generating water of around 40˚C. For water temperature as high as 90˚C, it can be produced by heat pumps that use carbon dioxide (CO_2) as refrigerant and such products have already emerged in some overseas countries. However, the main concern in using CO_2 heat pump is the extremely high working pressure (around 4 to 5 times higher than conventional refrigerants).

A new heat pump technology, using conventional refrigerant (i.e. normal refrigerant pressure) for producing adequate flow of higher temperature water, has also emerged on the market. Such heat pump can be regarded as instantaneous water heaters and the hot water storage tank may be eliminated.

熱泵熱水器的類型

1 空氣對水式

空氣對水式熱泵是指那些從空氣中（熱源）提取熱能並輸送至水媒介（熱庫）的熱泵。這類熱泵是相當普遍，因冷氣和熱水都有很廣泛的應用。例如，在廚房這樣熱的環境中安裝空氣對水式熱泵，既可以對場地使用者提供局部冷卻，也可以有效地提供餐飲服務所需的熱水。

熱泵產生的熱水，其溫度取決於製冷劑和熱源的溫度。傳統的熱泵，設計上都只能有效地製造約攝氏40度的熱水。若要有效地製造高達攝氏90度的熱水，則要使用以二氧化碳作為製冷劑的熱泵，這種產品已在一些海外國家的市場上出現。然而，使用二氧化碳熱泵的主要關注點，是其極高的工作壓力（比傳統製冷劑高約4至5倍）。

市場上亦有一類新的熱泵技術，使用的是傳統製冷劑（即只有正常的製冷劑壓力），但卻能生產適量較高溫度的熱水。該類熱泵可當作為即熱式熱水器，也可以省卻儲水箱。

2 Water-to-Water

Water-to-water heat pump can be employed to generate hot water for venues with central air-conditioning. The cool water output can be deployed via heat exchanger to the chilled water return circuit of the central air-conditioning plant to save plant energy. The heat pump COP, however, may not be at optimum as heat is extracted from the chilled water of the central A/C plant which is a cool medium.

TYPES OF REFRIGERANTS

As heat pump is basically working on the vapour compression cycle, refrigerants that are used in refrigeration machines could also be applicable to heat pumps. Users/designers may choose suitable refrigerant for heat pumps according to the latest regulatory requirements related to environmental protection.

MAINTENANCE

Maintenance requirements for heat pumps are quite similar to those for air conditioners.

Potential Applications and Energy Savings

The overall efficiency of heat pump system will be higher if we can make use of both the heating and cooling energy output of the machine.

SIMULTANEOUS DEMAND FOR BOTH HEATING AND COOLING

The followings are some typical applications where both heating and cooling energy demands exist:

2 水對水式

水對水式熱泵可於有中央空調的場地，用來製造熱水，並將所製造的冷水，透過熱交換器接駁到中央空調系統的冷水回路，從而節省中央空調系統的耗電。但熱泵要從低溫的中央空調冷水中抽取熱能，其效能系數未必會是最優化的。

製冷劑的類型

由於熱泵的運作也是建基於氣體壓縮循環，一般用於冷藏設備的製冷劑，都可適用於熱泵。使用/ 設計者可以按當前環保法規的要求，選擇合適的製冷劑。

維修

熱泵的維修與一般空調的維修要求十分相似。

應用和節能潛質

若能將熱泵所產生的熱能和冷能盡用，則熱泵系統的整體效率便會更高。

同時有供暖和冷凍的需求

以下是一些典型的應用例子，當中存在著供暖和冷凍的需求：

A. Gymnasium - hot water for showers and air-conditioning for activity areas

B. Sauna - hot water for sauna and air-conditioning for reception counters

C. Swimming Pool - heating for pool water and cooling or dehumidification for ancillary areas

D. Hair Salon - hot water for shampoo and air-conditioning for salon

E. Club House of Housing Estate – hot water provision for various activities and air-conditioning for indoor areas

F. Catering - hot water for catering services and air-conditioning for dining, servicing areas or kitchen

G. Hospital - hot water for pre-heating in steam generation, for bathing patients, cleansing and cooling supplementing central air-conditioning

H. Foot Massage - hot water for massage and cooling for venue

DEMAND FOR HEATING ONLY

The followings are some typical heating applications where heat pumps can be used:

A. Boilers - Heat pumps can be used to generate the hot water direct or serve for pre-heating efficiently the make up water feeding a boiler system for hot water or steam generation.

B. Laundry - Laundry plants consume large amount of hot water and heat pumps can meet the demands efficiently.

Heat pumps are energy efficient machines for water heating applications. For further information, please contact the Energy Efficiency Office of the Electrical and Mechanical Services Department.

A. 體育館-作淋浴熱水，供活動區空調

B. 桑拿-作桑拿熱水，供接待處空調

C. 游泳池-為池水加熱，為泳池附屬範圍降溫或除濕

D. 髮廊-作洗髮熱水，供場內空調

E. 屋苑的會所-供各種活動用的熱水，供室內地方空調

F. 餐飲-作餐飲服務用的熱水，供餐廳、服務處或廚房空調

G. 醫院-為蒸氣產生器提供給水預熱、供病人洗澡或清潔，補充中央空調

H. 足部按摩-作按摩熱水，為場地供冷

只有供暖需求

以下是一些熱泵供暖的典型應用例子：

A. 鍋爐-熱泵可直接用於製造熱水，或為熱水或蒸氣鍋爐的補給水有效率地預熱。

B. 洗衣房-洗衣設備消耗大量熱水而熱泵能有效率地滿足這方面的需求。

熱泵是具能源效益的熱水設備。如需進一步資料，請聯絡機電工程署的能源效益事務處。

Case Study

HOT WATER SHOWERS

Showers are provided to the staff of three shifts in a venue. Six gas boilers of 275L were replaced with two water-to-water heat pumps of 30kW heating power and two additional storage tanks of 1000L each. The annual hot water consumption was around 700m^3. $COP_{Heating}$ of around 2.2 to 2.8 was recorded. The cooling energy was used in the changing room. The simple payback period for the retrofit was around 5.2 years. The total amount of energy saved from town gas and in central air-conditioning plant as a result of heat pump installation was around 290,000kWh annually.

個案研究

熱水淋浴

一場所中有淋浴間提供給其三班輪值員工使用。個案中將六台275升容量的燃氣鍋爐改為兩台有30千瓦加熱功率的水對水式熱泵，另外加裝兩個各1000升的儲水箱。每年熱水耗水量約為700立方米。供暖效能系數錄得介乎2.2至2.8。冷能則供應更衣室作空調。該改裝項目的簡單投資回本期約為5.2年。熱泵安裝後，從煤氣和中央空調裝置節省的總能源，每年約為29萬千瓦時。

(One heat pump with a 1000L water tank
熱泵及其1000升容量的儲水箱)

HYDROTHERAPY POOL

Water of the indoor pool was required to be kept at 34±1˚C round the clock. Four existing 18kW instantaneous electric heaters were replaced with a water-to-water heat pump of 30kW heating power and cooling was used to pre-cool the fresh air intake of the A/C plant. The heat pump achieved an average daily

水療池

一個室內的水療池，水溫要經常維持在攝氏34±1度。改裝項目將4個現有的18千瓦即熱式電熱水器替換為1台有30千瓦加熱功率的水對水式熱泵，而同時產生的冷水就用來預冷空調系統的鮮風。熱泵的平均

$COP_{Heating}$ of 4.25 and the annual energy savings was around 165,000 kWh. The simple payback period for the retrofit was around 3.8 years.

按日供暖效能系數達4.25，而每年節省能源約16.5萬千瓦時。該改裝項目的簡單投資回本期約為3.8年。

(Hydrotherapy pool 水療池)

LAUNDRY

A new high temperature heat pump was installed in an industrial laundry to preheat part of the make-up to the existing diesel-fuelled boiler system. The cooling energy is used to provide cooling to a small office. Hot water as high as around 60°C was generated in one pass. The average $COP_{Heating}$ and $COP_{Heating+Cooling}$ achieved were 2.6 and 3.2 respectively. The highest daily $COP_{Heating}$ recorded was 4.0. Electricity of around 30000 kWh was consumed to save around 5500L diesel annually. Simple payback period was around 8.6 years.

洗衣場

一個工業洗衣場裝有用柴油作為燃料的鍋爐系統，改造項目加裝了一台新高溫熱泵，將鍋爐系統的部分給水預熱。冷能則用來提供空調給一個小辦公室。熱水一次過加熱到約攝氏60度。平均的供暖效能系數和供暖冷凍總效能系數分別為2.6和3.2。而最高錄得的按日供暖效能系數為4.0。一年的電力消耗約3萬千瓦時，而柴油的消耗則節省約5500升。簡單投資回本期約為8.6年。

HAIR SALON

For a typical application, assuming annual consumption of 40°C hot water for shampoo is 1000 m^3 (around 50 to 100 shampoos per day). Use of a high temperature heat pump instead of electric boiler could save over 14000 kWh of electricity annually. The incremental cost could be payback in around 1.8 years. Moreover, cooling energy generated could also be used to supplement the air-conditioning in the salon.

髮廊

典型的髮廊，假設每年消耗1000立方米的攝氏40度熱水於洗髮上（即每天洗髮約50至100次）。利用高溫熱泵去取代電熱水爐，每年可以節省超過1.4萬千瓦時。增加的額外安裝費用可在約1.8年後回本。髮廊更可享用熱泵提供的冷能，減低空調的消耗。

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