Solar Thermal Collectors for Water Heating

太陽能熱水系統的集熱器

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Introduction

Solar energy is a renewable energy which can be used for generating electricity as well as for heating purpose. Although electricity generation by photovoltaic cells has gained its popularity in the past few years as a result of advancement of semiconductor technologies, using solar energy for water heating is still the most common form of solar energy application. This pamphlet aims to provide a brief introduction on solar thermal collectors which capture solar heat for water heating purpose. Solar water heating technologies can be used for low temperature hot water service or industrial process. The latter usually requires higher water temperature (e.g. 80°C - 250°C) and its utilization is currently insignificant worldwide. Thus this pamphlet will focus on solar thermal collector used for low temperature hot water heating purpose.

Basic Principle of Solar Thermal Collector

The heat from the sun is transmitted in the form of infra-red radiation with wavelength approximately between 0.78μm and 2.5μm. The function of a solar thermal collector is to capture the radiation and transfer the thermal energy to a thermal fluid, usually water, for heating use.

Solar thermal collectors, although may be designed with different forms, usually consist of an absorbing surface, thermal fluid piping and a thermally insulated enclosure for housing these components.

The absorbing surface

The intensity of solar energy is usually measured in Watt/m^2 or Mega Joule/m^2. The absorbing surface provides the required surface area to capture the solar energy. Absorbing surface is usually a metal with good thermal conductivity such as copper or aluminium. Sometimes plastic such as polypropylene is used for very low temperature operations. Since radiation heat transfer is heavily affected by the absorption properties of a surface, the coating of the absorbing surface is usually in dark colour. More advanced coating, known as selective coating, which absorbs radiation of a certain range of wavelength is also available in some collectors to increase the effectiveness of the absorbing surface.

Thermal fluid piping

Thermal fluid piping provides a passage to run the thermal fluid through the absorbing surface to extract the heat from the absorbing surface. It is usually a system of thin metallic tube thermally bonded to the absorbing surface for heat transfer. For water heating applications, the thermal fluid is usually water.

Thermal insulated enclosure

The enclosure houses all the components to form the complete solar collector. The enclosure is usually thermally insulated to minimize heat loss to surrounding due to conduction and convection. It is important especially during cold or windy seasons when the temperature difference between the absorbing surface and the surrounding air is large. Solar collectors for high temperature application usually need to have better insulation because temperature difference between the thermal fluid and the surrounding is the main driving force of thermal energy losses.

引言

太陽能是可再生能源，可用來發電及加熱。儘管半導體技術不斷進步，令光伏電池發電在過去數年日漸普及，但利用太陽能把水加熱仍是最普遍的太陽能應用方式。本小冊子旨在簡介用以吸收太陽熱能以便把水加熱的集熱器。太陽能熱水技術可用於供應低溫熱水或作工業用途，但如作工業用途，通常所需的水溫較高（例如攝氏80度至250度），而目前此用途在世界各地並不常見。因此，本小冊子會集中講述如何利用集熱器產生低溫熱水。

集熱器的基本原理

太陽的熱力以紅外輻射的形式傳播，波長大約介乎0.78微米至2.5微米之間。集熱器的功能是吸收紅外輻射，並把熱能傳送到傳熱液體（通常是水）作加熱用途。

集熱器可以有不同的設計，但一般都有吸熱面、傳熱液體喉管及放置這些組件的隔熱外殼。

吸熱面

量度太陽能強度的單位通常是瓦特/平方米或兆焦/平方米。吸熱面是用來吸收太陽能的面層範圍，通常是熱傳導率高的金屬（如銅或鋁），但如所需水溫較低，則或會採用塑料（如聚丙烯）。輻射熱傳導很受吸熱面的吸收特性影響，因此吸熱面的塗層通常是深色的。某些集熱器採用較先進的塗層（如選擇性塗層），集中吸收某一波長範圍內的輻射，以提高吸熱面的效率。

傳熱液體喉管

傳熱液體喉管提供通道，讓傳熱液體流經吸熱面，並從吸熱面吸收熱量。喉管通常是薄金屬管網絡，連接到吸熱面，以傳送熱量。用於把水加熱的集熱器傳熱液體通常是水。

隔熱外殼

外殼容納所有組件，構成整個太陽能集熱器。外殼通常可隔熱，以盡量避免熱量透過傳導及對流散失到四周環境。在寒冷或大風的季節，吸熱面與四周空氣的溫差大，隔熱外殼就尤其重要。傳熱液體與四周環境的溫差是熱量散失的主因，因此如太陽能集熱器需把水加熱到高溫，通常須具備較佳的隔熱能力。

Types of Solar Thermal Collector

The majority of solar thermal collectors for low temperature water heating fall in two types: (1) flat plate solar thermal collector; and (2) evacuated tube solar thermal collector.

Flat plate solar thermal collector

Flat plate solar thermal collector has been the traditional design for solar thermal collectors for decades. It has an overall collector dimension nearly the same as that of the absorbing surface area. The enclosure is thermally insulated with the front side left un-insulated for exposure to solar radiation. The un-insulated front side can be either glazed or unglazed. Collector with a glazing in the front can reduce thermal heat loss to the surrounding. However, the glazing will incur transmission loss to the solar radiation. The thermal fluid is running through the piping bonded to the absorbing surface to extract the thermal energy.

The whole of the solar water heating system can be constructed by series and/or parallel connecting modules of the flat plate solar thermal collectors.

太陽能集熱器的類型

用來把水加熱至低溫熱水的太陽能集熱器通常分為兩類：(1)平板型太陽能集熱器；及(2)真空管太陽能集熱器。

平板型太陽能集熱器

平板型太陽能集熱器數十年來都是太陽能集熱器的傳統設計，集熱器尺寸差不多等於吸熱面的面積。外殼內置隔熱材料，前面讓太陽輻射照射。外殼前面不隔熱，可安裝或不安裝玻璃，但前面安裝玻璃的集熱器可減少熱量散失，但太陽輻射經過玻璃時亦會有損失。傳熱液體流經連接到吸熱面的管道，以吸收熱能。

整個太陽能熱水系統可由以串聯及/或並聯方式連結的平板型太陽能集熱器模組組成。

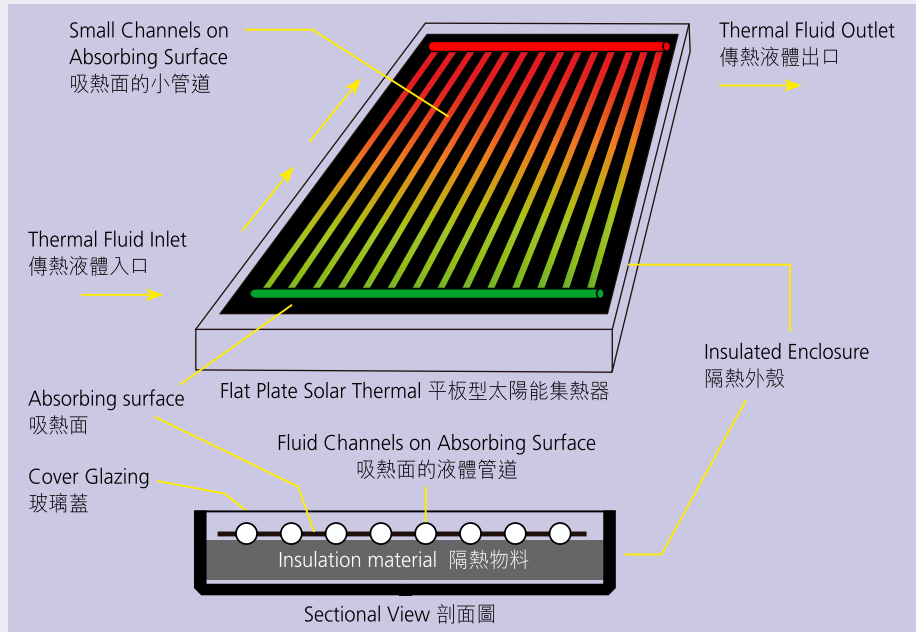
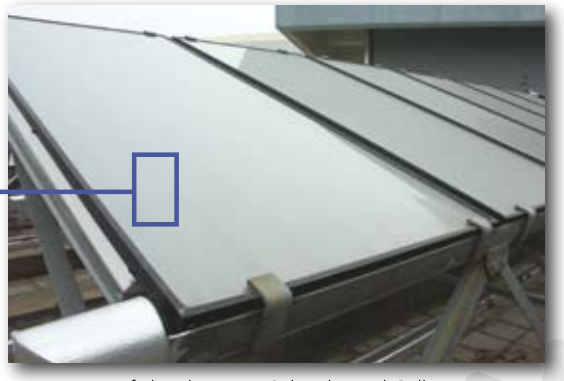


Fig. 1b - The Construction and Components of The Collector 圖1b - 集熱器的構造及組件

Fig. 1a - Flat Plate Solar Thermal Collector
圖1a - 平板型太陽能集熱器

The small channels on the absorbing surface can be seen at a close look at the surface
可在近距離見到吸熱面的小管道



Appearance of Flat Plate Type Solar Thermal Collector
平板型太陽能集熱器外貌

Advantages of Flat plate solar thermal collector

The main advantage of flat plate solar thermal collectors is their low equipment cost. Under the current market, the cost of a flat plate solar thermal collector is about 1/3 to 1/2 that of an evacuated tube solar thermal collector. In low temperature applications, since the temperature gradient between the thermal fluid and the surrounding is small, the efficiency may surpass that of evacuated tube solar collectors. However, this competitive edge diminishes rapidly as the temperature differential increases or under windy or cold weather.

Evacuated tube solar thermal collector

Evacuated tube solar collectors are tubular in shape and make use of vacuum for thermal insulation. The vacuum forms good thermal insulation to minimize

平板型太陽能集熱器的優點

平板型太陽能集熱器的主要優點是設備成本低。按目前的市況，平板型太陽能集熱器的成本是真空管太陽能集熱器的三分之一至二分之一。如所需水溫較低，因傳熱液體與四周環境的溫差小，其效率有機會超越真空管太陽能集熱器。不過這優勢會隨溫差擴大或在大風或寒冷天氣下迅速消減。

真空管太陽能集熱器

真空管太陽能集熱器呈管型，利用真空來隔熱。真空的隔熱效

heat loss to the surrounding due to conduction and convection while the clear glass surface allows good transmission of solar radiation. Each module of solar thermal collector panel is made up of 20 - 30 numbers of tubes thermally coupled to a header pipe.

There are a number of varieties in the design of evacuated tube solar thermal collectors. The followings are two examples:

1. Evacuated heat pipe solar thermal collector

   In the evacuated heat pipe design, the solar heat is conveyed by a heat pipe between the absorbing surface and the heat exchanging point (the condenser). The whole set of heat pipe and the absorbing surface are completely sealed inside a vacuum tube. The condenser is located at the top end of the evacuated tube which is thermally coupled with the water common header. The heat pipe is completely sealed so that the thermal fluid inside the heat pipe is separated from the thermal fluid of the heating system.

   The heat pipe transfers thermal energy by a vaporizing/condensing cycle of thermal fluid inside the heat pipe. The solar thermal energy vaporizes the thermal fluid inside the heat pipe to vapour phase which rises to the top of the heat pipe due to buoyancy where the condenser is fitted. The vapour then condenses back into liquid phase after the thermal energy is transferred to the system's thermal fluid.

   Good quality evacuated heat pipe solar thermal collector has efficiency comparable with flat plate collector at low temperature range (e.g. at about 40°C) and significantly out-perform flat plate collector at moderate to higher temperature range (e.g. at 60 - 80°C).

果良好，可盡量避免熱能透過傳導及對流散失到四周環境，而清澈的玻璃面則可有效傳送太陽輻射。每個集熱器模組由二三十支管組成，這些管把熱能傳送給總喉管。

真空管太陽能集熱器有多種設計，以下是兩個例子：

1. 熱管式真空管太陽能集熱器

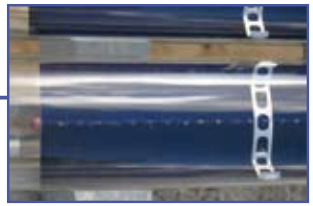
   按熱管式真空管的設計，熱能由吸熱面經熱管傳送到熱交換點（冷凝器）。整套熱管及吸熱面全部置於真空管內，而冷凝器位於真空管頂端，把熱能傳送給總喉管。熱管完全密封，令管內的傳熱液體與加熱系統的傳熱液體隔離。

   熱管利用管內傳熱液體的蒸發 / 凝結循環傳遞熱能。太陽熱能令熱管內的傳熱液體蒸發成氣體，蒸氣因浮力而上升到裝有冷凝器的熱管頂部。把熱能傳送到系統的傳熱液體後，蒸氣會凝結，然後變回液體。

   優質熱管式真空管太陽能集熱器在低溫（例如熱水溫度大約攝氏40度）的效率可媲美平板型太陽能集熱器，在中至高溫（例如熱水溫度大約攝氏60至80度）則明顯較平板型太陽能集熱器優勝。

Fig. 2a - Evacuated Heat Pipe Solar Thermal Collector 圖2a - 熱管式真空管太陽能集熱器

Appearance of Evacuated Heat Pipe Solar Thermal Collector
熱管式真空管太陽能集熱器外貌



The absorbing surface can be clearly seen at a closer look of the evacuated tube
在近距離見到真空管的吸熱面

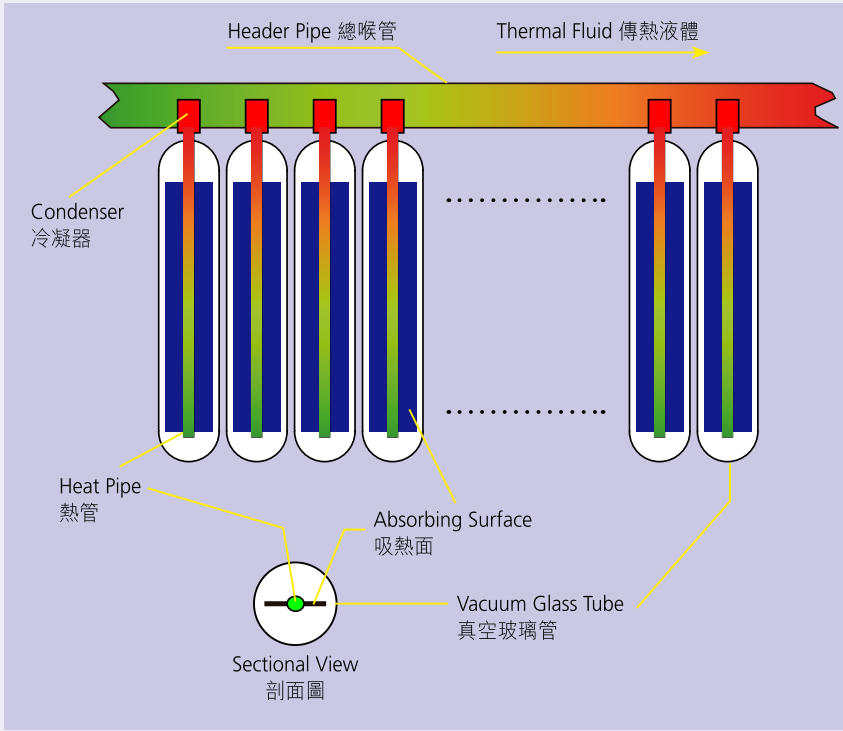


Fig. 2b - The Construction and Components of The Collector 圖2b - 集熱器的構造及組件

2. Evacuated jacket solar thermal collector

An alternative to the evacuated heat pipe design is the evacuated jacket design. The appearance of evacuated jacket is looking very similar to the evacuated heat pipe collector. Thus it is very easy to take evacuated jacket collector for evacuated heat pipe collector by mistake.

The construction of the collector is a vacuum jacket formed by two concentric glass tubes sealed with a vacuum space in between. The absorbing surface and heat pipe for the thermal fluid are inserted inside the cavity of the inner glass tube. The jacket forms a thermal insulation to reduce heat loss due to conduction and convection. In order to enhance the absorption of solar radiation, the outside surface of the inner glass tube is usually coated with a layer of selective coating.

The market price range of evacuated jacket collectors lies in between flat plate collector and evacuated heat pipe collector. The cost of evacuated jacket solar thermal collector is about 20% - 30% higher than flat plate collector. However, its efficiency is about 20-25% lower than the evacuated heat pipe collector. In low temperature applications (e.g. for applications with temperature range at about 40°C), the drop in efficiency will further diminish its competitive edge because the efficiency of a good quality flat plate collector may out-perform the evacuated jacket solar thermal collector.

2. 真空套管太陽能集熱器

真空套管設計是另一款真空管設計。真空套管的外貌與熱管式真空管非常相似，因此大家很容易把真空套管誤認作熱管式真空管。

集熱器由兩支同心玻璃管構成，把玻璃管之間的空間密封兼抽真空，成為真空外套。吸熱面及傳熱液體流經的熱管位於內玻璃管內，外套成為隔熱層，減少因傳導及對流造成的熱量散失。為增加吸收太陽輻射的效率，內玻璃管的外表面通常有一層選擇性塗層。

真空套管太陽能集熱器的市價在平板型太陽能集熱器及熱管式真空管太陽能集熱器之間，其成本較平板型太陽能集熱器高20%至30%，但效率較熱管式真空管太陽能集熱器低20%至25%。優質平板型太陽能集熱器的效率可高於真空套管太陽能集熱器，因此真空套管太陽能集熱器如只須把水加熱至低溫熱水（例如大約攝氏40度），其較低的效率會再削弱其競爭力。

Fig. 3a - Evacuated Jacket Solar Thermal Collector
圖3a - 真空套管太陽能集熱器

Appearance of Evacuated Jacket Solar Thermal Collector
真空套管太陽能集熱器外貌

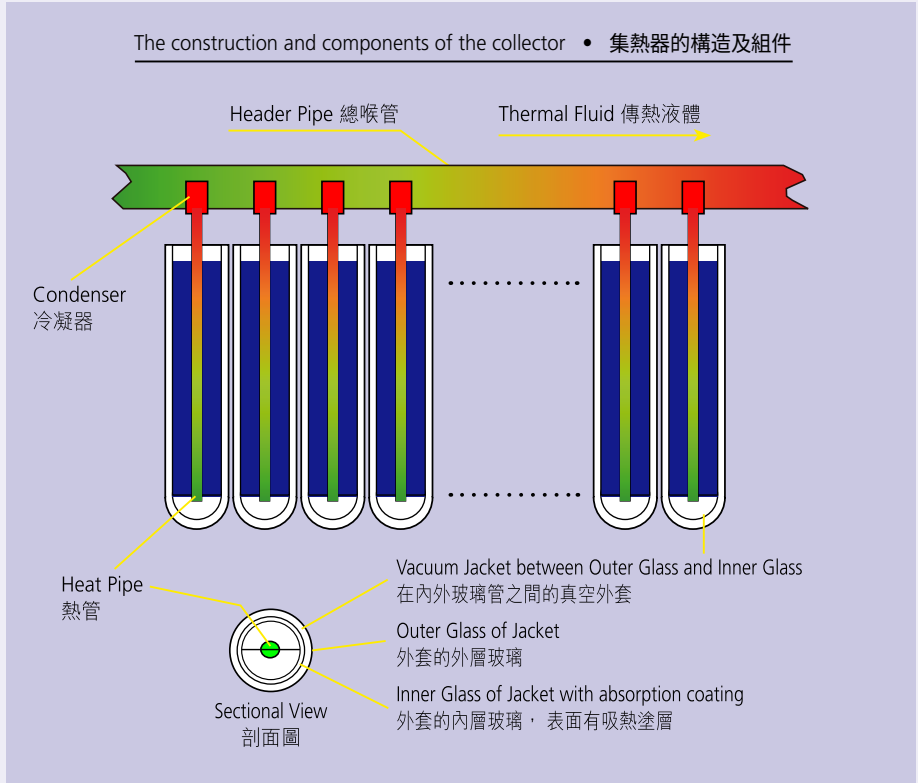


Fig. 3b - The Construction and Components of The Collector 圖3b - 集熱器的構造及組件

Advantages of evacuated tube solar thermal collector

Evacuated tube solar thermal collectors are more expensive than flat plate solar thermal collectors. However, they are more efficient for applications with higher temperature difference between the thermal fluid and the ambient air. Additionally, the structural support for the panel can be lighter because the gaps between glass tubes reduce the uplift forces significantly in gusty weather.

Other advantages lie in the maintenance issue because the thermal fluid is not running through the whole panel area. This reduces the chance of pipe blockage or leakage. Furthermore, failure of one vacuum tube only entails limited deterioration to the panel's performance and the malfunctioned vacuum tubes can be replaced individually instead of replacement of the whole panel as in the case of flat plate collectors.

真空管太陽能集熱器的優點

真空管太陽能集熱器較平板型太陽能集熱器昂貴，但如需要高溫熱水，即傳熱液體與四周空氣溫差較大，則真空管太陽能集熱器較有效率。此外，玻璃管之間的空隙減少大風造成的上舉力，因此集熱器的支架可較輕巧。

在維修方面，亦有其優點。由於傳熱液體不流經整片集熱器，喉管阻塞或洩漏機會得以減少。此外，一支損壞的真空管只令集熱器的表現下降少許，失靈的真空管可個別更換，而平板型太陽能集熱器在同樣情況下就要更換整塊集熱器。

The following table summarizes the relative merits and demerits of the two main types of solar thermal collector:

下表摘錄兩種主要太陽能集熱器的優點及缺點：

	Pros 優點	Cons 缺點
Flat-plate Collectors 平板型太陽能集熱器	• Capable to deliver moderate temperature hot water (e.g. hot water service, space heating, indoor pool heating, process heating etc.). 能夠供應中等溫度的熱水(例如供應熱水、空間供暖、加熱室內游泳池池水、工藝加熱等)。 • Lower cost when compared with evacuated tube collectors. 成本較真空管太陽能集熱器低。	• Heavier collector weight 集熱器較笨重。 • Larger wind load under windy condition. 在大風環境較當風。 • More susceptible to pipe blockage and leakage. 管道較容易阻塞及洩漏。 • More complications in maintenance issue. 維修方面較複雜。
Evacuated Tube collectors 真空管太陽能集熱器	• Lower heat loss to surrounding 較少熱能散失到四周環境。 • Capable to deliver moderate to high temperature (60°C - 80°C) water (domestic hot water, space heating, process heating, etc.) 能夠供應中等溫度至較高溫度(攝氏60至80度)的熱水(家用熱水、空間供暖、工藝加熱等) • Lighter support structure requirement 需要的支架較輕便。 • Simplicity in maintenance. 維修簡單。	• Higher capital cost compared with flat plate collector. 與平板型太陽能集熱器比較，建設費用較高。

Table 1 - Relative merits and demerits of the two main types of solar thermal collector.
表1 - 兩種主要太陽能集熱器的優點及缺點

Thermal Energy Output of Collectors

The thermal energy output that can be obtained from the solar thermal collectors depends on the available solar resources of the site, the efficiency of the solar thermal collectors and the operating temperature differential between the fluid running through the collector and the ambient temperature. As an indication, the approximate value of theoretical thermal energy output with the operating condition of low to moderate temperature (operating range around 20 - 60°C of water temperature) solar water heating application under local climate condition is shown in the table below:

集熱器的熱能輸出量

太陽能集熱器可輸出多少熱能，視乎有關地點有多少陽光、集熱器的效率，以及集熱器操作時流經集熱器的液體與四周環境的溫差。下表顯示按本港氣候情況，太陽能熱水系統在提供低至中水溫的情況下（攝氏20至60度）的大約理論熱能輸出量。

	Evacuated Tube Collector 真空管太陽能集熱器	Flat Plate Collector 平板型太陽能集熱器
Theoretical Annual Energy Output per Gross Collector Area 集熱器的理論每年熱能輸出量	2,600 - 3,800 MJ/m^2 每平方米2,600至3,800兆焦	2,100 - 3,400 MJ/m^2 每平方米2,100至3,400兆焦

Table 2 - Approximate Theoretical Thermal Output of Two Types of Collectors Based on Application Conditions of Local Weather Conditions
表2 - 根據本港天氣情況推算兩種太陽能集熱器的大約理論熱能輸出量

Installation Considerations

When installing solar thermal collectors, there are certain considerations that can help to assure better performance.

Location of Installation

Location for installation of solar thermal collectors should have abundant solar resource for capture by the collectors. Surfaces facing south direction and clear from shading of surrounding objects such as trees or buildings etc. are more preferable for solar thermal collector installations.

安裝時須考慮的事項

安裝太陽能集熱器時，須考慮以下事項，以確保集熱器有較佳的表現。

安裝位置

太陽能集熱器的安裝位置應有充足陽光，讓集熱器收集。太陽能集熱器的吸熱面最好向南，並遠離四周物體（如樹木、建築物等）造成的陰影。

Tilting Angle

Analysis has shown that a tilting angle equal to the latitude of the geographic location produces the best year round energy yield from the collector. Therefore in Hong Kong, installing collectors tilting at an angle 22°15′ to the horizontal captures the highest year round solar energy. However, it does not mean that other tilting angles are not suitable. If the solar thermal energy demand is on seasonal base (e.g. the system is only used to assist winter heating), the tilting angle can be adjusted to capture the maximum solar energy for the season. For example, one can install solar thermal collector at a tilting angle larger than 22°15′ to capture more solar thermal energy during the winter season. On the other hand, it is found that evacuated tube solar thermal collector is more flexible in tilting angles.

Flow Balance

In systems that consist of an array of solar thermal collectors connected in parallel, it is easy to overlook the importance of maintaining a balanced flow through each solar collector. This will ensure sufficient flow in the collector and avoid extreme local high temperature build up as a result of flow deficiency. Extreme high temperature in solar thermal collectors may lead to local boiling and steam generating which will further block up the piping and choke the flow. Additionally, large temperature swing will shorten the life span of materials such as pipe joints.

Suitable piping layout such as using a "reverse return" or installing balancing devices at suitable locations can help ensuring suitable flow through each collector in the array.

傾斜角度

經分析後，我們發現如集熱器的傾斜角度等於當地緯度，全年收集所得的太陽能便會最多，因此在香港安裝與地平線成22度15分夾角的集熱器全年可收集到最多太陽能。不過，這並不表示其他傾斜角度不適合。如對太陽能的需求隨季節變化（例如有關系統只用來在冬季供暖），可調校傾斜角度，以便在某一季節收集最多太陽能。例如人們可以安裝傾斜角度大於22度15分的太陽能集熱器，以便在冬季吸收更多太陽能。另一方面，有文獻顯示真空管太陽能集熱器的傾斜角度可較為靈活。

平衡傳熱液體流量

對於由以並聯方式連接的太陽能集熱器組成的系統，人們往往忽略保持平衡每個集熱器的傳熱液體流量的重要性。平衡流量可確保集熱器有足夠傳熱液體流經，避免因流量不足而導致局部溫度過高。太陽能集熱器溫度過高可導致局部沸騰，產生蒸汽，進一步堵塞管道，阻礙流動。此外，溫度大幅波動會縮短物料（例如管道接口）壽命。

適當的管道布置（如利用「反向回流」或在適當地方安裝平衡裝置）有助確保集熱器內每個真空管都有一定流量。

Row Separation

For installation with a large number of solar collectors connected in multiple rows, the row should have sufficient separation in order not to cast shadows to the rows behind.

Figure 4 below shows the end view of two rows of collector with collector height *a* and row separation *b*. In order to avoid significant reduction in amount of energy that can be captured by the row behind, it is suggested to have the *a* to *b* ratio be kept at about 0.6 for solar collector mounting at a tilting angle about 22°15′. If area available for installing the panels is limited, such ratio should still be kept as far as possible so as not to exceed 0.8.

列距離

如有關裝置設有大量太陽能集熱器，並連接成多列，列與列之間須有一定距離，以免對後面的列投下陰影。

下文圖4顯示兩列集熱器的剖面圖，集熱器的高度是*a*，列距離是*b*。為避免大幅減少後列收集到的能量，若太陽能集熱器的傾斜角度大約是22度15分，*a*與*b*的比率應保持在大約0.6。如可安裝集熱器的地方有限，亦應盡量保持這比率，使其不超過0.8。

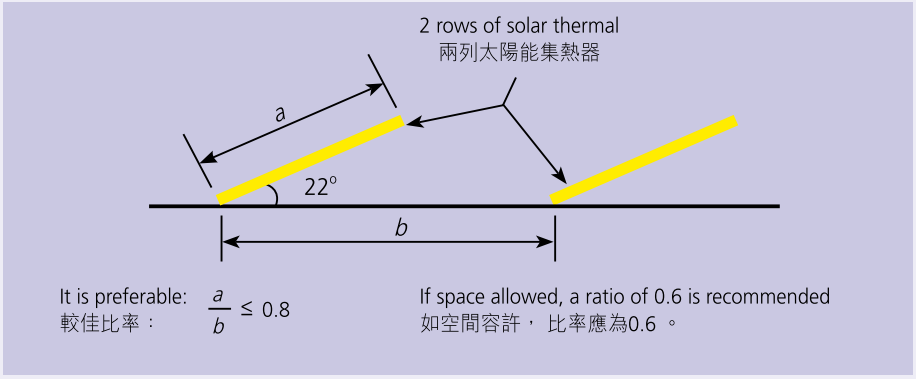


Fig. 4 - Row separation, *b*, should be sufficient to avoid shadows cast onto the row behind.
圖4 - 列距離*b*應足以避免前列對後列投下陰影。

Maintenance Considerations

Solar thermal collector itself requires minimal maintenance. Regular surface cleansing and pipe descaling can upkeep the efficiency of the collectors. On the contrary, more maintenance efforts should be directed to the fluid circulation system to ensure there is no flow deficiency (e.g. due to scale formation in fluid channel, air entering the pipe work, or local boiling) and leakage in collector panels. Flat plate collector is more susceptible to water leakage and oxidation of the absorbing surface due to exposure to outdoor weather. Even though there is usually a cover glazing, there may be water ingression into the collector enclosure to aggravate the surface oxidation. Evacuated tube collector on the other hand, should regularly be checked for loss of vacuum due to breaking of tube seals.

維修方面須考慮的事項

太陽能集熱器的維修較簡單，定時清潔表面及去除管道的水垢便可保持其效率。維修工作應着眼於液體循環系統，以確保集熱器沒有傳熱液體流量不足（例如在液體管道內形成水垢、空氣進入管道或局部沸騰）及滲漏的問題。平板型太陽能集熱器較容易有漏水及吸熱面因在室外日曬雨淋而氧化的問題。集熱器表面通常有玻璃，但水也會滲入集熱器內部，加劇表面氧化。另一方面，應定期檢查真空管太陽能集熱器，看看有沒有真空管破裂，不再真空。

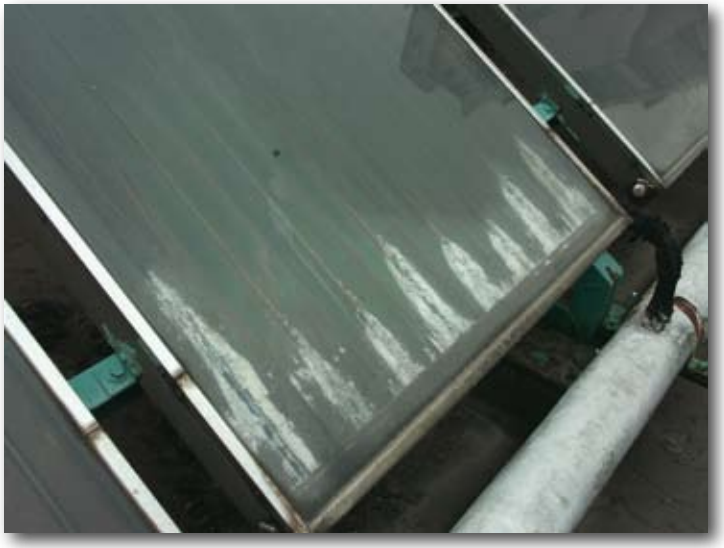


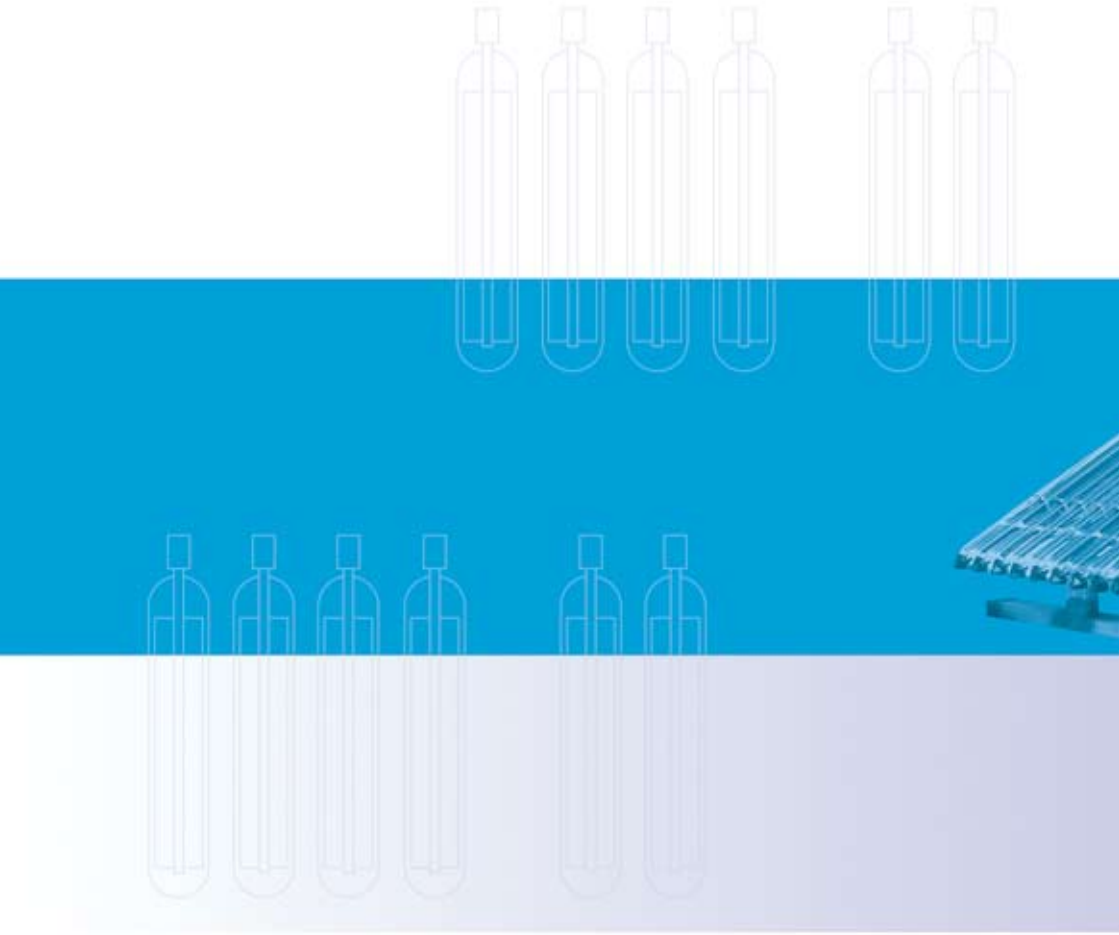
Fig. 5 - Flat Plate Solar Thermal Collector is more susceptible to water leakage and oxidation of absorbing surface
圖5 - 平板型太陽能集熱器較容易有漏水及吸熱面氧化的問題。

If the fluid of the whole solar heating system has to be drained off for overhaul for a considerable period of time, it is suggested to cover up the solar collectors to avoid high temperature build up on the absorbing surface which may accelerate material aging and pipe joints leakage. It is also advisable to avoid stagnant flow when the collector is exposed to direct sunlight for the same reason.

For more information about solar thermal collector, please contact the Energy Efficiency Office of the Electrical and Mechanical Services Department.

如要排清整個太陽能熱水系統的液體，以便長時間進行大修，應覆蓋集熱器，以免吸熱面持續處於高溫，令物料加速老化及管道接口漏水。基於同一原因，亦應避免集熱器在水不流動時有陽光直射。

如欲索取更多有關太陽能集熱器的資料，請聯絡機電工程署能源效益事務處。



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