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出國報告（出國類別：其他）

赴日本參加 2014 年宏偉再生能源國際研討會和展覽出國報告

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派赴國家：日本
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摘　要

本次出差係為赴日本參加 2014 年宏偉再生能源國際研討會和展覽，蒐集資料和發表綠色節能技術研發成果論文。本次研討主題包括(1)政策和整合概念(Policy & Integrated Concept)；(2)光伏(Photovoltaic)；(3)太陽熱能應用(Solar Thermal Applications)；(4)創新生物氣候建築(Innovative Bioclimatic Architecture)；(5)風能(Wind Energy)；(6)生質物應用和轉換(Biomass Utilization & Conversion)；(7)氫能和燃料電池(Hydrogen & Fuel Cell)；(8)海洋能(Ocean Energy)；(9)地熱和地源熱泵(Geothermal Energy & Ground-Source Heat Pump)；(10)能源網路和電力電子(Energy Network & Power Electronics)；(11)節約能源和熱泵(Energy Conservation & Heat Pump)；(12)小型水力和其它非傳統能源(Small Hydro & Non-Conventional Energy)。所有主題均與本所的環能研究領域有相關聯。本次會議的演講中，太陽能電池效率面臨的挑戰，太陽能製熱和製冷的貢獻，太陽能熱化學儲熱，太陽能熱化學產氫和太陽能熱化學熱泵的研究內容值得本所參考。

目　　次

一、目　的

2014年宏偉再生能源國際研討會和展覽(Grand Renewable Energy 2014 International Conference and Exhibition)是由日本再生能源委員會(Japan Council for Renewable Energy, JCRE)、國際太陽能協會(International Solar Energy Society, ISES)、新能源和工業技術發展組織(New Energy and Industrial Technology Development Organization, NEDO)、國家前瞻工業科技機構(National Institute of Advanced Industrial Science and Technology, AIST)、日本科技代辦處(Japan Science and Technology Agency, JST)、名古屋工業科學研究院(Nagoya Industrial Science Research Institute, NISRI)、新能源基金會(New Energy Foundation, NEF)、日本太陽能協會(Japan Solar Energy Society, JSES)和日本風能協會(Japan Wind Energy Association, JWEA)聯合主辦，並且超過八十個單位贊助，專題講座是來自德國、法國、義大利、澳洲、美國、丹麥、韓國、日本等各國專家學者。本組受邀於會中發表研發成果論文，並擔任地源熱泵第四會議主席(Ground-Source Heat Pump 4)，實屬榮幸，其研討會相關資料、論文接受函及擔任主席徵詢和通知，論文全文和簡報資料，詳如附錄。本次發表論文題目為『A NOVEL THERMOSYPHON FOR GROUND HEAT EXCHANGER』，論文議程名稱『Area IX: Geothermal Energy & Ground-Source Heat Pump Ground-Source Heat Pump (1)』, 日期：7月31日，時間：14:30 - 15:50。論文主要貢獻，是利用逆流熱虹吸(Reverse Thermosyphon)原理，開發自主性向下傳熱迴路，取代傳統地源熱泵的機械泵驅動土壤換熱迴路(Ground Heat Exchanger)，具有節能、可靠性高、低成本及安裝容易等優點，逆流熱虹吸原型傳熱距離1.5 M，熱阻0.05ºC/W，逆流熱虹吸地源熱泵的耗電是空氣散熱空調的51%。

本次研討主題包括(1)政策和整合概念(Policy & Integrated Concept)；(2)光伏(Photovoltaic)；(3)太陽熱能應用(Solar Thermal Applications)；(4)創新生物氣候建築(Innovative Bioclimatic Architecture)；(5)風能(Wind Energy)；(6)生質物應用和轉換(Biomass Utilization & Conversion)；(7)氫能和燃料電池(Hydrogen & Fuel Cell)；(8)海洋能(Ocean Energy)；(9)地熱和地源熱泵(Geothermal Energy & Ground-Source Heat Pump)；(10)能源網路和電力電子(Energy Network & Power Electronics)；(11)節約能源和熱泵(Energy Conservation & Heat Pump)；(12)小型水力和其它非傳統能源(Small Hydro & Non-Conventional Energy)。所有主題均與本所的環能研究領域有相關聯。

隨著化石燃料大量消耗，不僅拉高油價衝擊經濟發展，並且排放溫室氣體加強了溫室效應，引發氣候變化，因此，能源開發和地球環境保護之課題日益受到重視。為了地球環境的永續發展，本會的主題—再生能源技術的開發是全球重要的課題。

本所電漿在綠色節能環境之開發與應用計畫是發展光伏及節能之元件製程和整合系統、光熱電整合系統和零碳排放整合開發驗證技術。希望藉由參與此研討會及發表論文之機會，與來自世界各地的相關領域傑出的研究者及工業界人士互相交流汲取知識，以獲得更多電漿鍍膜綠色節能技術之資訊及相關發展方向，對本所技術之提升和創新有相當助益。

二、過　程

本次公差共七天，行程安排如表 1 所示。

表 1 公差行程安排

行程				公差地點		工作內容
日	星期	地點		國名	地名	
		出發	抵達			
7/27	日	台北	東京			去程
7/28	一	東京		日本	東京	參加宏偉再生能源國際研討會和展覽
7/29	二	東京		日本	東京	參加宏偉再生能源國際研討會和展覽
7/30	三	東京		日本	東京	參加宏偉再生能源國際研討會和展覽
7/31	四	東京		日本	東京	參加宏偉再生能源國際研討會和展覽
8/1	五	東京		日本	東京	參加宏偉再生能源國際研討會和展覽
8/2	六	東京	台北			返程

本次會議的地點在東京市國際展示場(Tokyo Big Sight)，如圖 1 所示。從成田機場到國際展覽館的路線如下，自成田機場站搭乘 JR Narita Express 到東京站，轉 JR 京濱東北線到大井町站，轉臨海線到國際展示場站，如圖 2 交通路線圖所示。

本次會議的活動包括了特別議程(Special session)、全體議程(Plenary session)、口頭發表(Oral presentation)、壁報發表(Post presentation)、研習會(Workshop)、技術旅遊(Technical tour)、日本光電展覽(PV Japan 2014)、世界再生能源展覽(Renewable energy world exhibition)等，研討會活動行程如圖 3 所示，12 個領域的口頭發表行程如圖 4 所示。

在本次會議的全體議程中，總共邀請了來自 12 個領域的 18 位專家學者舉行專題演講，並且有來自超過 60 個國家超過 800 篇的論文發表。特別議程由 NEDO，AIST 和 JST 等法人機構舉辦。研習會的主題有『如何以再生能源重建災後福島(FUKUSHIMA)』和『客製化零能屋(Zero energy custom house)』。會議和展覽的參訪人數總共 44,210 人，如圖 5 參訪人數統計表所示，總共有 300 多個公司和機構參展。

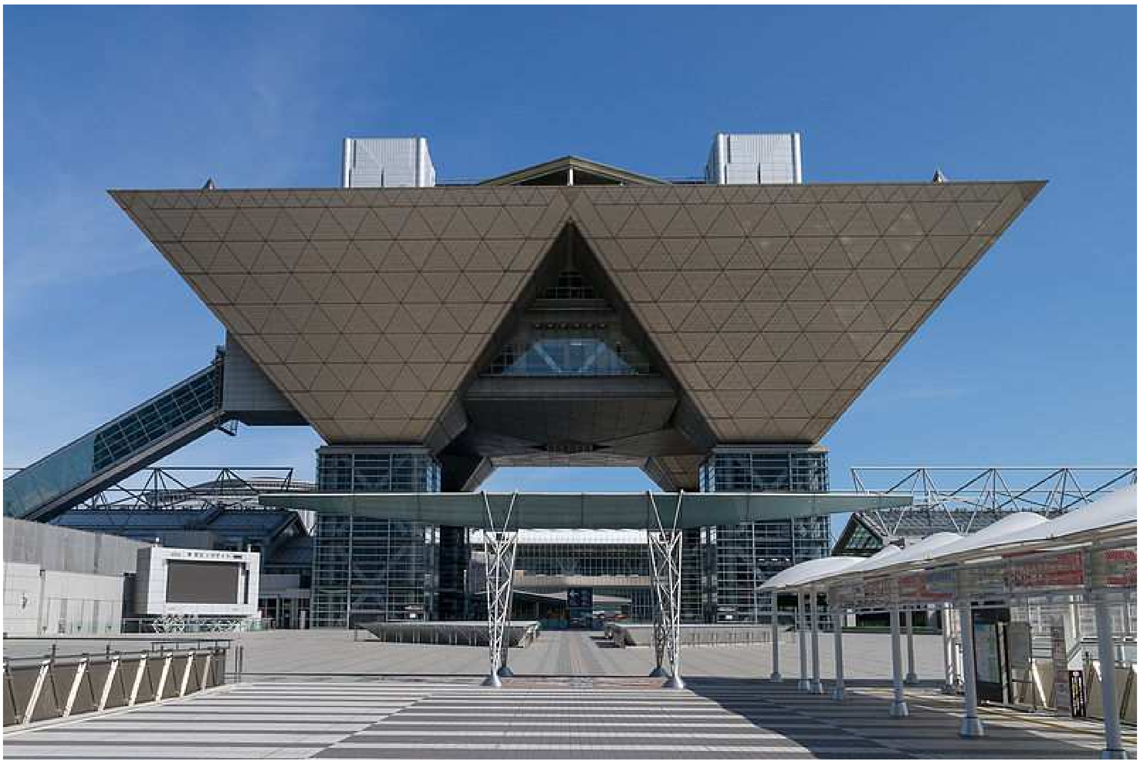


圖 1 東京市國際展覽館

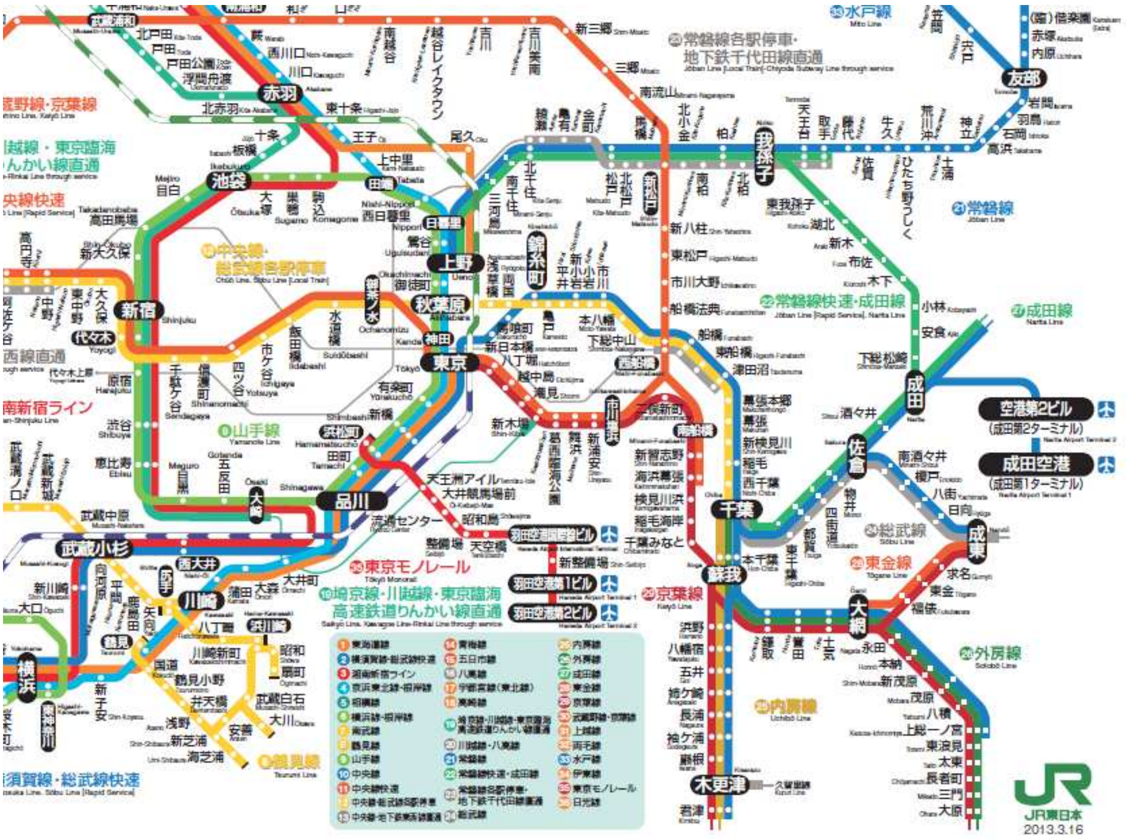


圖 2 東京市交通路線圖

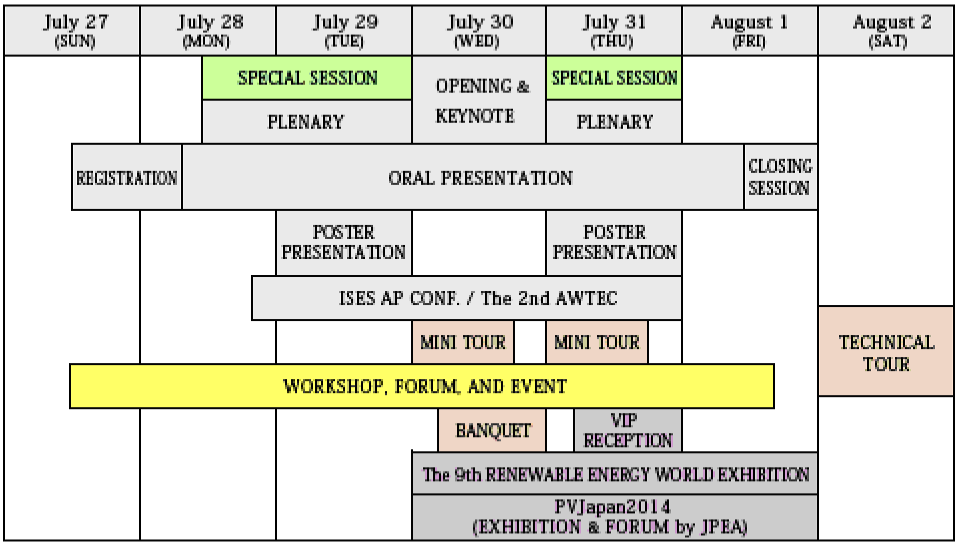


圖 3 會議活動時程表

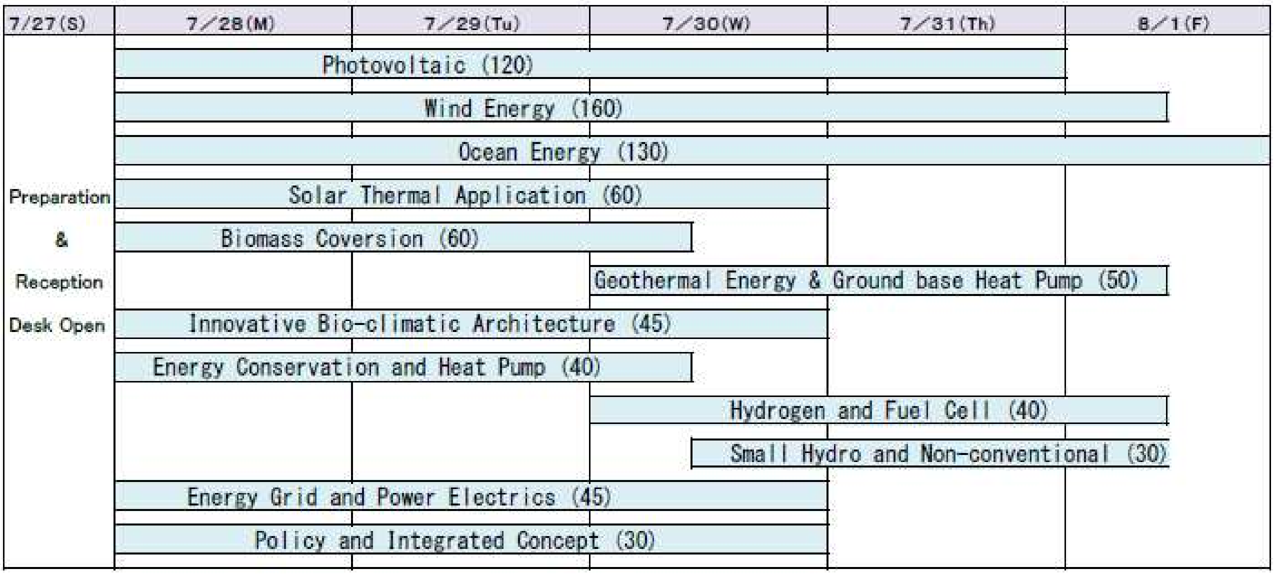


圖 4 會議口頭論文時程表

Date	Weather	Number of visitors
July 30 (Wed)	Fair	13,396
July 31 (Thu)	Fair	13,557
August 1 (Fri)	Fair	15,210
July 28（Mon）- August 1（Fri）	GRAND RENEWABLE ENERGY 2014 INTERNATIONAL CONFERENCE	2,047
Total		44,210

圖 5 參訪人數統計表

三、心　得

(一)Makoto Konagai，東京技術研究院(Tokyo Institute of Technology)，邀請演講題目『The challenge of improving energy conversion efficiency in solar cells』，內容如下：截至 2013 年為止，全世界太陽能電池產量達 37 GW。矽基太陽能電池(Bulk Si solar cell)大面積模組轉換效率亦達 20%。在 2025 年前，矽光電模組轉換效率預期目標將達到 25%。另外，薄膜太陽能電池藉開發新材料和多接面結構技術，提昇轉換效率至 20%。太陽光譜分離技術(Solar spectrum splitting technique)是另一種增加薄膜太陽能電池效率的技術。分離波長在 600 nm，a-Si 在上層而 CIGS 在底層，模擬效率可達 25%，已被實驗證實。藉元件和光學分離器最佳化，分離波長在 614 nm，量測效率已達 23%。再將上層 a-Si 以 InGaP 取代，量測效率已達 26%。矽的能隙(Band gap)是在 1.1 eV，而適合太陽能轉換能隙是在 1.5 eV。矽太陽能電池的轉換效率約 25%，接近理論極限，28~29%。奈米線(Nano-wire)技術可以使目前矽太陽能電池突破物理限制控制矽的能隙，轉換效率預期目標將達到 30%。

(二)Werner Weiss，澳洲永續技術研究院(Institute for Sustainable Technologies in Austria)，邀請演講題目『Contribution of Solar Heating and Cooling to a 100% renewable energy system』，內容如下：2011 年建築部門和工業部門的使用熱能佔世界最終能源消耗的 50%。雖然維持 CO_2 中性(Neutral)逐漸增加生質能和地熱的使用，但仍無法應付加熱和製冷的需要。然而，太陽能加熱技術相對成熟，例如太陽能熱水和游泳池加熱。MW 級的太陽能區域加熱(District heating)和工業應用已達先進展示階段，接近商業化。目前世界最大的太陽能區域加熱系統在丹麥，容量約 25 MW_{th}。智利加夫列拉·米斯特拉爾(Gabriela Mistral)銅礦的太陽熱能系統是連串加熱製程工場的一個環節，此採礦程序容量約 26 MW_{th} (集熱面積 39,300 m^2)，並且於 2013 年被認定是最大的工業加熱應用。在 2012 年前，太陽熱能容量佔 283GWth，相當於集熱面積 $405 \cdot 10^6 m^2$。其中，平板式集熱器佔 26.3%，真空管佔 64.7%，非玻璃水集熱器佔 8.4%，玻璃和非玻璃空氣集熱器佔 0.6%。太陽能加熱和製冷技術有待極力開發，使得價格和效能廣為大眾所接受。IEA 的太陽能加熱和製冷技術發展藍圖的目標，在 2050 年前，每年太陽加熱能源的生產約 16.5 EJ，佔最終加熱能源消耗的 10%，太陽製冷能源的生產約 15 EJ，佔最終製冷能源消耗的 10%。

(三)Matthias Schmidt，German Aerospace Center，口頭報告題目『Operation Modes and Process Integration of a High Temperature Thermochemical Heat Storage System』，內容如下：太陽能聚熱和工業廢熱回收應用的必要條件在於高效率的高溫儲熱。考慮成本和溫度等因數，選擇氫氧化鈣作為儲熱材料，其吸放熱的可逆分解反應式如下：

$$CaO_{(s)} + H_2O_{(g)} \leftrightarrow Ca(OH)_{2(s)} + \triangle H_{reaction}$$

其可逆分解的反應熱為 100 kJ/mol，反應溫度範圍 400~ 600 ºC。為了開發熱化學儲熱系統，研製 25 kg 的 $Ca(OH)_2$ 儲熱測試平台，同時作為 25 kW 吸放熱示範。測試平台的儲熱反應器開啟後，內部如圖 6 所示。儲熱材料放置於寬 20 mm 深 200 mm 的通道內，每個通道安放於耐溫支架，並且彼此分開。本反應器以空氣為熱傳流體從右側連接法蘭流入，接受或傳送反應熱。儲熱反應器與測試平台整合後的外觀如圖 7 所示。然後以 1 bar 水蒸汽分壓的濕空氣與 CaO 進行水合作用(Hydration)，溫度時間曲線如圖 8 所示，曲線高原平衡溫度約 490 ºC。

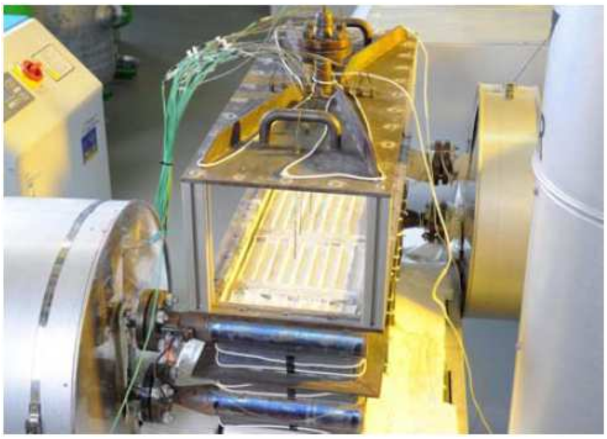


圖 6 儲熱反應器內部

圖 7 測試平台外觀

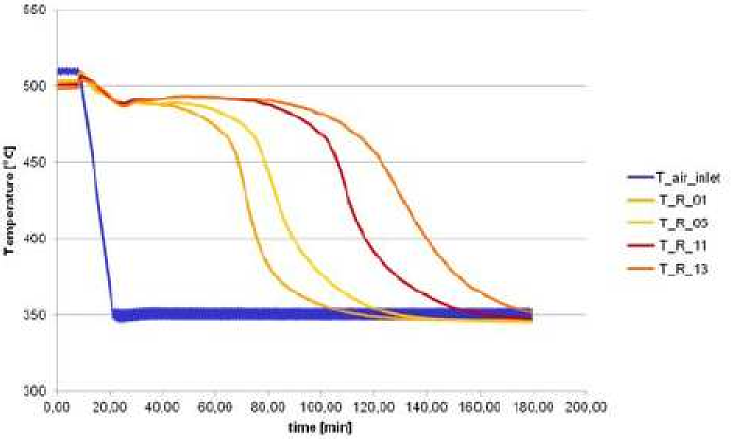


圖 8 水合作用溫度時間曲線

(四) Tatsuya Kodama，Niigata University，口頭報告題目『Performance Tests of a New Beam-Down Solar Concentrating System at Miyazaki for Demonstration of Thermo-Chemical Reactors』，內容如下：兩階段非計量(Nonstoichiometric)氧化鈰(Cerium oxide)熱化學水解(Water spliting)產氫是一種有發展性的太陽能熱化學產氫技術，其吸放熱的可逆分解反應式如下：

$$CeO_2 \rightarrow CeO_{2-\delta} + (\delta/2)O_2 \qquad 1400\text{- }1600\ ^{\circ}C$$

$$CeO_{2-\delta} + \delta H_2O \rightarrow CeO_2 + \delta H_2 \qquad 600\text{- }1000\ ^{\circ}C$$

在第一階段又稱為熱還原(Thermal reduction)階段，金屬氧化物在1400 ºC以上高溫惰性氣體環境下釋放氧分子，然後在第二階段又稱為水分解(Water decomposition)階段，較低溫度狀態下，與水蒸汽反應產生氫。根據此反應程序，Miyazaki大學建造了一座流體化床反應器和100 kW_{th}光束朝下太陽能聚熱系統，其概念設計如圖9所示。中央塔高16 m，直徑4.6 m，外環反射鏡總面積約176 m^2，照片如圖10所示，由Niigata大學和Miyazaki大學共同合作研究。實驗結果：在太陽直接法線輻射強度(DNI)900 W/m^2下，聚熱強度超過500 kW/m^2。

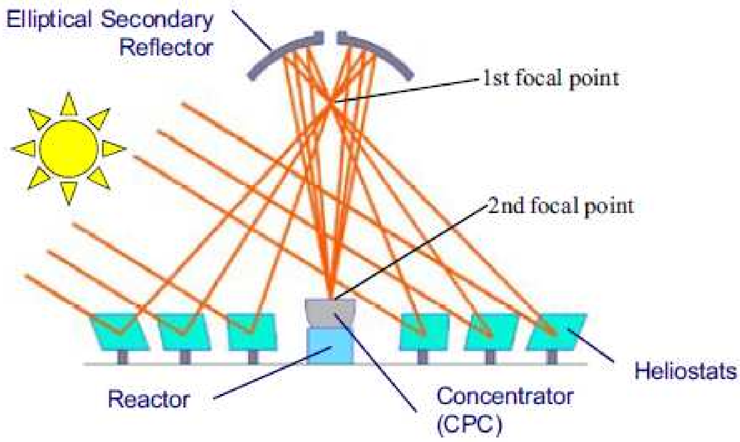


圖9光束朝下太陽能聚熱系統概念設計

圖10 Miyazaki光束朝下太陽能聚熱系統照片

(五)Takayuki Shimazu，Chiba University，口頭報告題目『Experimental and Theoretical Studies on Solar Chemical Heat Pump for Air Conditioning』，內容如下：本研究係為開發太陽能熱化學熱泵，以400 K等級低溫太陽熱能，驅動$CaSO_4 \cdot 1/2H_2O$水合和去水合反應，產生冷氣和熱水。太陽能熱化學熱泵的模型如圖11所示，儲熱實驗的溫度曲線如圖12所示，當反應器溫度超過403 K開始開啟閥門，啟動去水合反應。釋熱實驗的溫度曲線如圖13所示，熱端溫度約363 K，冷端溫度約280 K。釋熱實驗的水合轉換率和釋熱量如圖14所示，水合轉換率在40分鐘內達到95 %，釋熱量約290 MJ/m^3，製冷量約360 MJ/m^3。

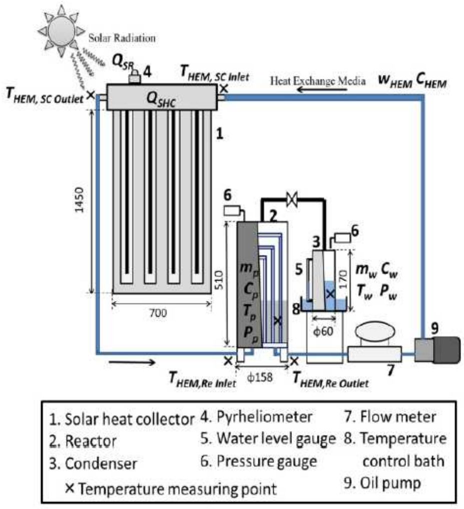


圖11太陽能熱化學熱泵的模型

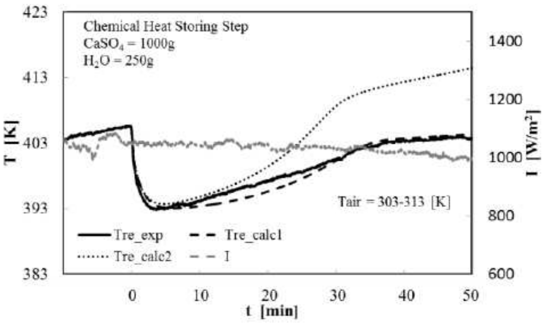


圖12儲熱實驗的溫度曲線

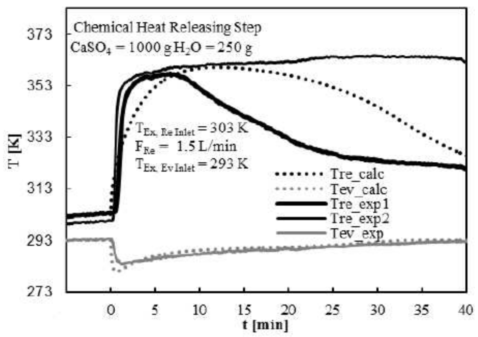


圖13釋熱實驗的溫度曲線

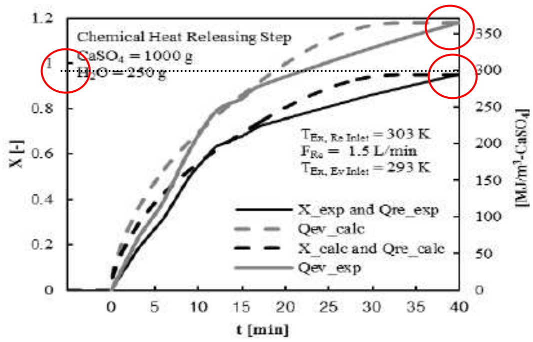


圖14釋熱實驗的水合轉換率和釋熱量

四、建　議　事　項

(一) 2014 年宏偉再生能源國際研討會和展覽(Grand Renewable Energy 2014 International Conference and Exhibition)的內容豐富，涵蓋各種專業領域，但本所僅職一人參加，以致某些領域資料蒐集無法完全，如風能、生質物應用和能源網路等，建議爾後類似大型國際會議本所各組應多派同仁參加。

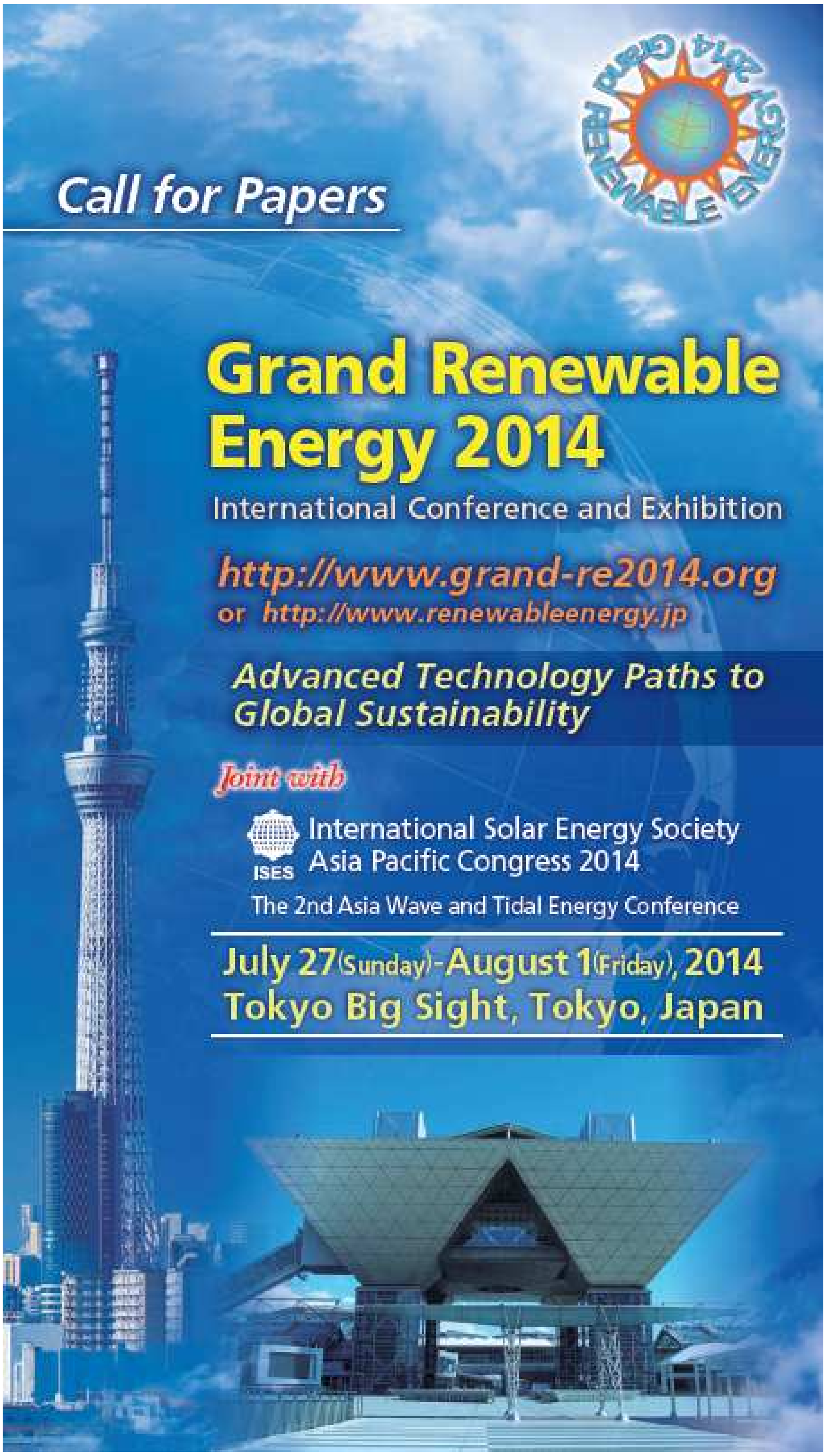
(二) 本次會議的演講中，太陽能電池效率面臨的挑戰，太陽能製熱和製冷的貢獻，太陽能熱化學儲熱，太陽能熱化學產氫和太陽能熱化學熱泵的研究內容值得本所參考。

(三) 本次會議的研習會主題之一『如何以再生能源重建災後福島(FUKUSHIMA)』，日本經過 2011 年福島核災後，展開再生能源重建計畫，在福島災區建立福島再生能源實驗室，實施免費核心技術轉移，輔導受災地區成立新興產業。主要研究項目包括再生能源整合系統，氫能網路，風力發電，熱電模組，超薄(Ultra thin)單晶矽太陽能電池和地熱發電等，不但恢復地方生活機能同時創造就業。台灣經過 88 風災和高雄氣爆後，災區的重建應該向日本仿效。

(四) 在日本光電展覽中，可以發現日本的太陽能電池產業相當進步且完備，其中 Panasonic 發表的 HIT 電池，轉換效率 24.7%是世界第一，太陽能電池輸出保證 20 年，機器功能保證 10 年。並且提出多樣的安裝型式供客戶選擇，依照客戶的需求和建築物現況，進行設計、施工、運轉、申請補助或其它法律行政手續等，完成住宅太陽能光電系統的設置。而其它的公司如 Toshiba，Sharp，Mitsubish 也提供類似完整的保證和服務。本所的太陽光電計畫應注意日本的技術發展，台灣的太陽光電產業完整，商業行為模式應該向日本借鏡。

五、附　錄

研討會資料



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The 2nd Asia Wave and Tidal Energy Conference
July 27(Sunday)-August 1(Friday), 2014
Tokyo Big Sight, Tokyo, Japan

CHAIR PERSONS' MESSAGE

The importance of the renewable energy technology has been growing significantly since the beginning of the 21st century and will continue throughout this century.

Thus, it is our great pleasure to inform you that we are organizing Grand Renewable Energy 2014 (GRE2014) international conference, which follows the two conferences of RE2006 and RE 2010 held in Japan. The Organizing Committee will carry out extensive activities for the success of GRE2014 with our continuous slogan "Advanced Technology Paths to Global Sustainability". Many prominent experts and organizations concerned with renewable energy participate in the committee, in the fields of academia, industry, and government, not only in Japan but also from the various countries of the world.

Expectations have been growing worldwide for renewable energy technologies as a solution for energy and global environment issues; issues projected to become more evident and serious during the 21st century. According to some long-term projections, renewable energy may satisfy half of the world's energy needs by 2050. This would put renewable energy on the same level of importance as conventional energy. Moreover, more aggressive forecasts predict that renewable energy might supply two-thirds of the world's energy by 2100.

We, the specialists involved in the field of renewable energy technologies today, should accept this challenge and respond to these ambitious targets this century. Doing so will influence our direction and quality of life in the future. Knowing that renewable energy is a peaceful energy resource present everywhere on earth should inspire us to further its development and dissemination. At this important time in history, you are invited to contribute to the progress of renewable energy technologies. You can learn about the latest cutting edge technologies at GRE2014. This conference is a joint event organized together with the International Solar Energy Society-Asia Pacific.

The international conference will be held at Tokyo Big Sight from July 27 – August 1, 2014. In parallel, a world exhibition will be open for three days from July 30. Tokyo Big Sight is located within easy access from both Haneda and Narita International Airports.

We, as the organizing committee, welcome all participants, not only those presenting papers but also those just interested in listening and discussing. We assuredly provide all of you with the sharing of innovative information on the latest trends of smart renewable energy development for the 21st century which is linked with global economy growth.

Prof. Kenji YAMAJI
General Chairperson
(The University of Tokyo, RITE)

Prof. Kosuke KUROKAWA
Co-General Chairperson
(Tokyo Tech., JCRE)

Dr. Dave RENNÉ
Co-Chairperson, International Advisory Committee
(NREL, President of ISES)

CONFERENCE ORGANIZATION

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The Grand Renewable Energy 2014 Organizing Committee

Co-Organized by:

- Japan Council for Renewable Energy (JCRE)
- International Solar Energy Society (ISES)
- New Energy and Industrial Technology Development Organization (NEDO)
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- Japan Science and Technology Agency (JST)
- Nagoya Industrial Science Research Institute (NISRI)
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- The Research Association of Hydrogen Supply/Utilization Technology
- Engineering Advancement Association of Japan
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- Japan Geothermal Developers' Council
- Japan Geothermal Association
- Geo-Heat Promotion Association of Japan
- Turbo Machinery Society of Japan
- The Academy of Hydro Power
- The Japan Society of Fluid Mechanics
- The Japan Refrigeration and Air Conditioning Industry Association
- Japan Society of Refrigerating and Air Conditioning Engineers
- Heat Island Institute International
- Photovoltaic Power Generation Technology Research Association
- Research Association for Technological Innovation of Organic Photovoltaic
- Fuel Cell Commercialization Conference of Japan
- Japan Small Wind Turbines Association
- Japan Association of Wind Engineering
- Windpower Promotion Network of Local governments
- Japan Alcohol Association
- The Japan Organics Recycling Association
- Commission Internationale du Genie Rural
- Japanese Business Alliance for Smart Energy Worldwide
- Japan Science Foundation
- Japanese Association of Groundwater Hydrology
- Semiconductor Equipment Association of Japan
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Collaborated with:

- Takahashi Industrial and Economic Research Foundation
- Fuji-Sankei Business I
- Commemorative Organization for the Japan World Exposition '70 (expected)

論文接受函

Dear Dr. Heng Yi Li,

Thank you very much for your email and for the notice.
This is the Abstract Desk for GRE2014.
We noted that you will be the presenter of the abstract no.00099.
Thank you again for joining us and we look forward to welcoming you soon at the conference.

Sincerely yours,

Abstract Desk
Keiko Nishi

Secretariat of the Grand Renewable Energy 2014 c/o Japan Convention Services, Inc.
E-mail: grand-re2014.sec@grand-re2014.org

----------------------- Original Message -----------------------
From: 李恆毅 <hyli@iner.gov.tw>
To: "'grand-re2014.sec@grand-re2014.org'" <grand-re2014.sec@grand-re2014.org>
Date: Mon, 2 Jun 2014 23:12:51 +0000
Subject: RE: Grand Renewable Energy 2014: Information for Your Presentation(00099)

> Dear Sir:
> Thank you for notice. However, there is a mistake. The presenting author of the abstract 00099 is me, Heng Yi Li.
>
> Heng Yi Li
> -----Original Message-----
> From: Secretariat of the Grand Renewable Energy 2014
> [mailto:grand-re2014.sec@grand-re2014.org]
> Sent: Friday, May 30, 2014 4:57 PM
> To: 李恆毅
> Subject: Grand Renewable Energy 2014: Information for Your
> Presentation(00099)
>
> Dear Dr. Heng Yi Li,
>
> On behalf of the Program Committee of the Grand Renewable Energy 2014
> (GRE2014) which will be held from July 27th to August 1st,
> 2014 at Tokyo Big Sight, Tokyo, Japan, it is our great pleasure to
> inform you of your presenting schedule as follows:
>
>
> Abstract Receipt No.: 00099
> Abstract Title: A NOVEL THERMOSYPHON FOR GROUND HEAT EXCHANGER
> Presenting author: Dr. Meng Chang Tsai
>
> Presentation style: Oral Session
> Session category and Name:
> Area IX: Geothermal Energy & Ground-Source Heat Pump
> Ground-Source Heat Pump (1)
>
> Session Time & Date: 14:30 - 15:50 July 31st, 2014 Allotted time for
> your presentation: 20 minutes
>
> For more information to prepare for your presentation, please visit
> our website;
> http://www.grand-re2014.org/eng-conf/instructions/index.html
>
> For hotel accommodations, on-line reservation is also available at;
> http://www.grand-re2014.org/eng-conf/accommo/index.html
>
> Should you have any questions, please feel free to contact the
> conference secretariat.
>
> Respectfully yours,
>
> Prof. Mitsuhiro Udagawa
> (Program Chairperson)
> Grand Renewable Energy 2014
>
> Inquiries:
> Secretariat for Grand Renewable Energy 2014 c/o Japan Convention
> Services, Inc.
> Fax +81-3-5283-5952
> E-mail: grand-re2014.sec@grand-re2014.or

擔任主席徵詢和通知

Dear Dr. Heng-Yi Li,

Thank you very much for your prompt and kind reply.
This is the Abstract Desk for GRE2014.

We would like to express our sincere appreciation for your acceptance to take the role as a chairperson.
We confirm that we received your reply form.

If you have anything until the conference, please feel free to contact us.

We look forward to welcoming you soon.

Sincerely yours,
Abstract Desk for GRE2014

Sender: Keiko Nishi

Secretariat of the Grand Renewable Energy 2014 c/o Japan Convention Services, Inc.
E-mail: grand-re2014.sec@grand-re2014.org

----------------------- Original Message -----------------------
From: 李恆毅 <hyli@iner.gov.tw>
To: "'grand-re2014.sec@grand-re2014.org'" <grand-re2014.sec@grand-re2014.org>
Date: Wed, 11 Jun 2014 00:00:27 +0000
Subject: RE: [GRE2014]Session Chair Request:[A9]O/Ground-Source Heat Pump (4)

> Dear Sir:
> I will accept.
> Heng-Yi Li
> -----Original Message-----
> From: Secretariat of the Grand Renewable Energy 2014
> [mailto:grand-re2014.sec@grand-re2014.org]
> Sent: Tuesday, June 10, 2014 10:34 AM
> To: 李恆毅
> Subject: [GRE2014]Session Chair Request:[A9]O/Ground-Source Heat Pump
> (4)
>
> Dear Prof./Dr. Heng-Yi Li,
>
> On behalf of the Program Committee of the Grand Renewable Energy 2014
> (GRE2014) which will be held from July 27th to August 1st, 2014 at
> Tokyo Big Sight, Tokyo, Japan, we are writing this message.
>
> As the conference program is now becoming finalized, we would like to
> cordially request you to take a roll as a chairperson of the following
> session.
>
> Program: Oral Session
> Area: Area IX: Geothermal Energy & Ground-Source Heat Pump
> Ground-Source Heat Pump (4)
> Date and Time: 10:10 - 11:30, 1st August, 2014
>
> Place: Room 610 at Tokyo Big Sight;
> http://www.grand-re2014.org/eng-conf/access/index.html
> *Number of chairpersons planned for this session: 2
>
> We have attached a "Reply Form" to this email.
> We kindly ask you to fill in the "Reply Form" and send us back by 16th
> June, 2014 to grand-re2014.sec@grand-re2014.org We would greatly
> appreciate for your positive consideration.
>
> Upon acceptance, GRE2014 is also asking chairpersons to make online
> registration and payments as participants.
> If you have already registered for the conference as a participant,
> you do not have to register again.
> Online registration is available at the following URL:
> http://www.grand-re2014.org/eng-conf/registration/index.html
>
> If you have any questions or concerns, please do not hesitate to
> contact us.
>
> For more information about the conference, please refer to our web site at:
> http://www.grand-re2014.org/eng-conf/index.html
>

> Thank you very much for your cooperation again and we look forward to
> meeting you in Tokyo.
>
>
> Respectfully yours,
>
> Prof. Mitsuhiro Udagawa
> (Program Chairperson)
> Grand Renewable Energy 2014
>
> Inquiries:
> Secretariat for Grand Renewable Energy 2014 c/o Japan Convention
> Services, Inc.
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論文全文和簡報資料

A NOVEL THERMOSYPHON FOR GROUND HEAT EXCHANGER

Heng-Yi Li, Meng-Chang Tsai, and Chi-Fong Ai
Institute of Nuclear Energy Research

A ground source heat pump (GSHP) is a heating and cooling system that transfers heat to or from the ground. In this paper, a GSHP scheme using the reverse loop thermosyphon (RLT) as the ground heat exchanger is proposed. The RLT could not only transfer heat from a heat source near the top to a heat sink at the bottom but also transfer heat from bottom to top as traditional thermosyphon. The feasibility of the RLT is verified by experiment. By following ground conduction equation and vapor compression model, it can be seen that GSHP with RLT ground heat exchanger has the lowest condenser temperature, so its COP is the highest and electric consumption is the lowest.

Keywords: ground source heat pump, ground heat exchanger, top heat mode, thermosyphon

INTRODUCTION

The Taipei climate is very hot and humid during summer, and little cold in winter [1]. Hence, electrical energy consumption of air conditioning is a serious problem in summer. To save energy, ground source heat pump (GSHP) is a good choice for energy saving air conditioning. A GSHP is a heating and cooling system that transfers heat to or from the ground by using the ground as a thermal energy storage tank. Heat of building is stored in ground in summer for cooling and taken out from ground in winter for heating. In a year, hot days are more than cold days, so energy saving of cooling is more effective than heating. However, GSHP needs the ground heat exchanger (GHE) loop to circulate the heat carrier from ground to the heat pump loop [2]. The GHE loop demands an electrically pump for driving. To improve the heat transfer efficiency from the ground to the heat pump, ground heat exchangers based on the thermosyphon using CO_2 as the working fluid were investigated [3]. Nevertheless, the heat source side of traditional thermosyphon must be lower than the heat sink side to circulate the working fluid naturally. Hence, the CO_2 thermosyphon can be used only for the heat pump extracting heat from the ground, and not for rejecting heat to the ground.

In this study a GSHP scheme using reverse loop thermosyphon (RLT) as a GHE is proposed. The RLT could not only extract heat from the ground, but also reject heat to the ground. The system layouts are described and the feasibility of the RLT is verified by experiment in the following chapters. The performance of GSHP with RLT is calculated and discussed.

SYSTEM AND ANALYSIS

System Description

A GSHP scheme using the RLT as the ground heat exchanger is proposed and operates in two modes. In the summer, the heat pump operates in cooling mode and removes the heat from the building to the ground with RLT as shown Fig. 1. In this mode, the indoor unit functions as a evaporator, the coil heat exchanger functions as a condenser and the ground functions as a heat sink. In the winter, the heat pump operates in heating mode and extracts heat from the ground to the building with RLT as shown Fig. 2. In this mode, the indoor unit functions as a condenser, the coil heat exchanger functions as an evaporator and the ground functions as a heat source. The RLT was proposed by Ipposhi[4]. This design could transfer heat from a heat source near the top to a heat sink at the bottom when power is turned on as shown in Fig. 3. Besides, the RLT could also transfer heat from bottom to top as traditional thermosyphon when power off as shown in Fig. 4. The RLT functions as a GHE whose pipes are inserted in a U-shape into a borehole. The borehole is constructed vertically in the ground. The heat carrier fluid flows down to the bottom of the borehole along one pipe and back upward in another pipe.

Performance Analysis

To analyze the performance of GSHP, the energy interactions between building loads, GHE and heat pump must be considered[5]. The heat transfer in GHE is usually analyzed in two separated regions: the region inside the borehole and the soil region surrounding the borehole.

The borehole inside is filled with the thermal conductive fluid such as water. The heat transfer inside the borehole is determined by the thermal resistance of RLT. It is expressed as follows:

$$R_{th} = \left(T_{vapor} - T_{condenser}\right) / Q_{RLT} \quad (1)$$

where R_{th} is the thermal resistance, T_{vapor} is vapor temperature, $T_{condenser}$ is condenser temperature, and Q_{RLT} is the transfer heat of RLT.

For modeling and simulation of vertical boreholes installed in the ground, Kelvin's line source theory and heat conduction equation are used. The temperature response in the ground due to a constant heat rate is obtained as[6]

$$T_s(r,t) - T_0 = \frac{q'}{4\pi k} \int_{\frac{r^2}{4at}}^{\infty} \frac{e^{-u}}{u} du \quad (2)$$

where $T_s(r, t)$ is the soil temperature around the single borehole, r is radial coordinate (m), t is time (s), T_0 is the initial temperature of soil, q' is heat flow rate per unit length of borehole (W/m), k is thermal conductivity (W/m K), and a is temperature constant.

Considering the single-stage vapour compression cycle, the coefficient of performance (COP) of GSHP for cooling mode is expressed as:

$$COP = \frac{\dot{Q}_e F \cdot \eta_{iso} \cdot \eta_m}{\dot{W}_{comp}} \quad (3)$$

where $\dot{Q}_e$ is the heat input of evaporator, $\dot{W}_{comp}$ is the power input of compressor, F is the factor of safety, η_{iso} is isentropic efficiency of compressor, and η_m is motor efficiency. $\dot{Q}_e$ and $\dot{W}_{comp}$ are obtained from the properties of given refrigerant at cycle specification which includes cooling capacity, evaporator temperature, condenser temperature, pressure loss, and heat loss.

RESULTS AND DISCUSSION

The feasibility of the RLT is verified by experiment, and the measurement temperature points and prototype of two-phase RLT apparatus was shown as figure 3. Eight T type thermocouples were installed as the figure and all temperatures signals were connected to an Omega data logger and continuously logged. The temperature measurement uncertainty was ± 0.1 ºC. To avoid thermal loss, fiberglass foam insulation was used to cover the evaporator, reservoir, and the entire pipe line.

Figure 5 shows the temperature variations over time with 660 W of heat input and 60 % filling ratio of methanol. The heating on mode is kept for 3600 second. It can be seen from the figure during the heating on mode that the temperature high low sequence (Ch1> Ch2> Ch3> Ch4> Ch5> Ch6> Ch7) agrees with the flow direction of Fig. 3. Temperature curves of the evaporator (Ch1 & Ch2) and condenser (Ch4 & Ch6) oscillate. The oscillation amplitude of Ch4 is approximately 1.5 °C, whereas the others are lower than 1 °C. The temperature trend of the condenser outlet (Ch7) is linear in this mode. That is to say the thermal energy store in the water pool of condenser is stable. After the power shut-down, the reservoir becomes the heater of two-phase RLT apparatus. The temperature of Ch5 and Ch7 increase quickly. This is because the saturated vapor flows reversely through Ch5 and Ch7 and demonstrates that the apparatus reverses to natural convection as shown in Fig. 4. In contrast, the Ch4 temperature declines rapidly because the saturated vapor drive pressure is suddenly loss. Temperature Ch7 has the “shaking appearance” in the thermodynamic equilibration process between the evaporator and the reservoir.

Table 1 shows the characteristics of the two-phase RLT with different filling ratios. The thermal resistance of the two-phase RLT was calculated by equation (1) considering that the temperature difference between the vapor and the condenser inlet temperature from 660W heat input. The reverse start time is the time taken for reverse flow overcomes the buoyancy and down to the condenser when power is turned on. This is the delay time between the evaporator heating starts and the condenser inlet temperature (Ch4) begins to rise. It can be seen that the thermal resistance reaches minimum at 60 % filling ratio. Besides, the reverse start time reaches minimum for filling ratio is greater than 53 %.

The proposed GHE loop is consisted of borehole and RLT. The borehole is manufactured in tank shape filled with water inside as shown in Fig. 6. The borehole tank has six fins around the periphery to enforce heat conduction. The manufactured RLT is divided into two parts. The upper part above the lid of borehole tank connects coil heat exchanger and cylinder reservoir with loop as shown in Fig. 7. The lower part under the lid locates inside the tank for heat transfer to the ground as shown in Fig. 8.

For the case of Taipei in summer, it is reasonably assumed that the atmosphere temperature is 32 ºC and 3 m deep soil temperature is 25 ºC. The rejected heat per unit length of borehole is assumed to be 100 W/m. The soil temperature profiles around the borehole tank are calculated with equation (2). Fig. 9 shows the soil temperature around single borehole tank at t=24 hours. It can be seen that the temperature reaches maximum at the borehole and decreases with the distance from the borehole. The overall temperature grows with time and the maximum temperature is still lower than atmosphere temperature after 1 day. Fig. 10 shows the soil temperature around double borehole tanks at t=4 days. It can be seen that the maximum temperature of double boreholes after 4 days is lower than single borehole after 1 day. This is because the heat flux in the soil increases due to double heat transfer surface.

For another case, the average temperature is assumed to be 35 ºC, so the heat pump works in cooling mode. To keep indoor air in 25 ºC the evaporator temperature is set to 15 ºC. The performance comparison of heat pump in cooling mode for three different heat sinks is calculated with equation (3) and shown in Table 2. This work is done by software CoolPack [7] and using R410a as refrigerant. It can be seen that heat pump with RLT ground heat exchanger has the lowest condenser temperature, so its COP is the highest and electric consumption is 51 % of forced air cooling.

CONCLUSION

A GSHP scheme using the RLT as the ground heat exchanger is proposed. The feasibility of the RLT is verified by experiment with 60 % filling ratio of methanol. The soil temperature profiles around the borehole tank are calculated and evaluated. The overall soil temperature grows with time and the maximum temperature is still lower than atmosphere temperature. By following vapor compression model and using R410a as refrigerant, it can be seen that heat pump with RLT ground heat exchanger has the lowest condenser temperature, so its COP is the highest and electric consumption is 51 % of forced air cooling.

References

[1] Historical Weather For 2012 in Taipei City, Taiwan, http://weatherspark.com/history/.

[2] Energy Design Resources, “Ground source heat pumps”, e-News, June 2010.

[3] R. Rieberer, “Naturally circulating probes and collectors for ground coupled heat pumps”, *International Journal of Refrigeration*, **28**, 2005, pp.1308-1315.

[4] S. Ippohshi, “Development of a top heat mode loop thermosyphon”, *Proceedings of the 6th ASME-JSME Thermal Engineering Joint Conference,* 2003, TED-AJ03-578.

[5] A. Michopoulos and N. Kyriakis, “A new energy analysis tool for ground source heat pump systems”, *Energy and Buildings*, **41**, 2009, pp.937-941.

[6] S. K. Fayegh and M. A. Rosen, "Examination of thermal interaction of multiple vertical ground heat exchanger", *Applied Energy*, **97**, 2012, pp.962-969.

[7] Technical University of Denmark, CoolPack version 1.50.

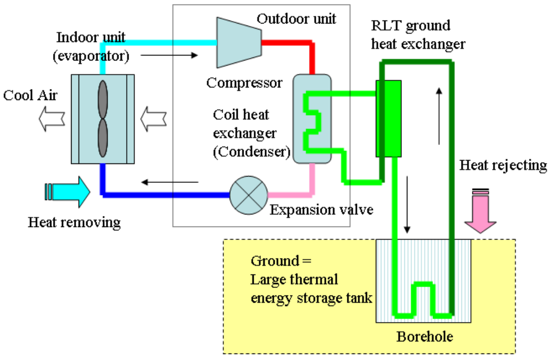

Fig. 1. The GSHP rejects heat to the ground with RLT in the summer.

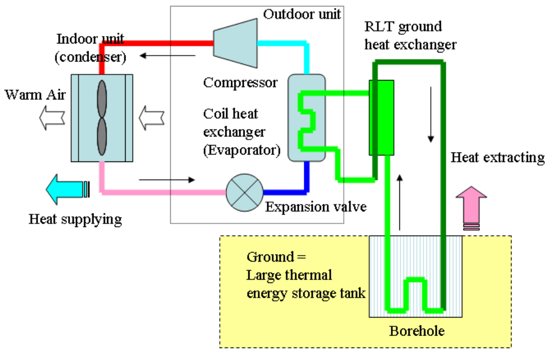

Fig. 2. The GSHP absorbs heat from the ground with RLT in the winter.

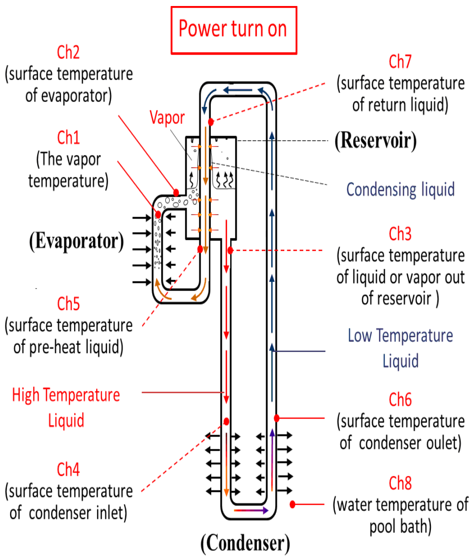

Fig. 3. Measurement points and prototype of two-phase RLT for power on condition.

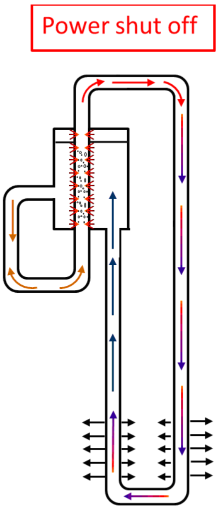

Fig. 4. Prototype of two-phase RLT for power off condition.

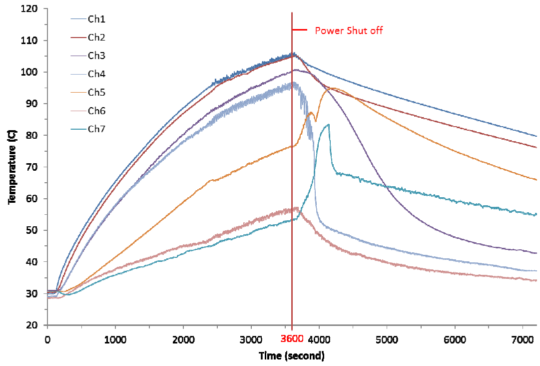

Fig. 5. Temperature variations over time with 660 W of heat input and 60% filling ratio.

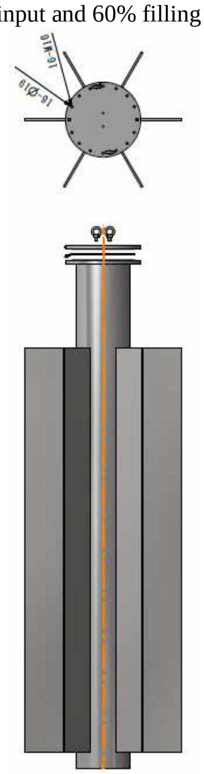

Fig. 6. The shape of borehole tank.

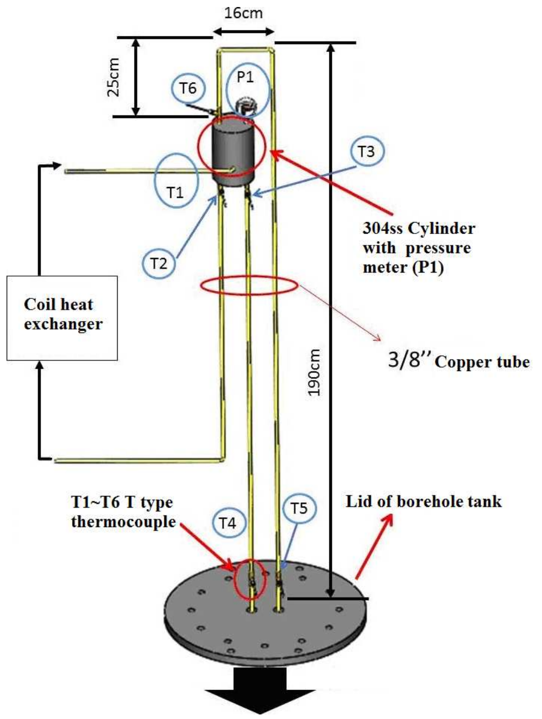

Fig. 7. Reverse thermosyphon loop above the lid of borehole tank.

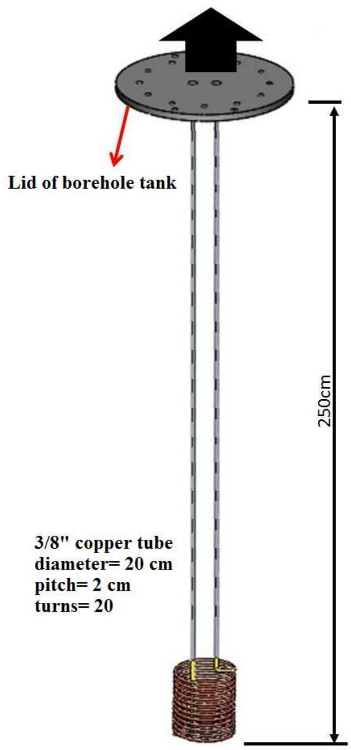

Fig. 8. Reverse thermosyphon loop inside borehole tank.

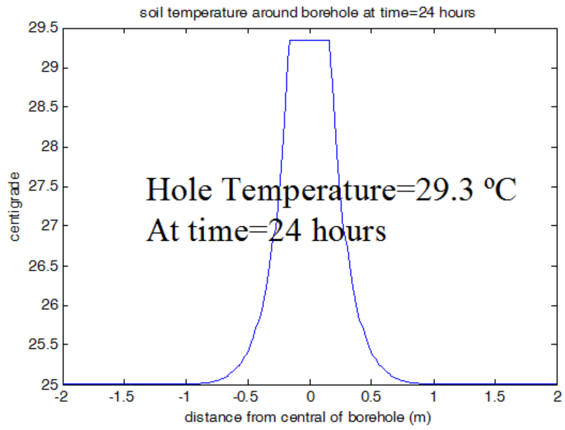

Fig. 9. Analytical solution for soil temperature around single borehole tank.

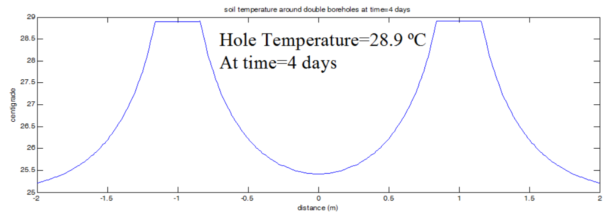

Fig. 10. Analytical solution for soil temperature around double borehole tanks.

Table 1. The characteristic of two-phase RLT for different filling ratio

Filling ratio (%)	Vapor Temperature (°C)	Condenser Inlet Temp. (°C)	Thermal Resistance (°C/W)	Reverse Start Time (second)
47	149	76	0.11	700
50	146	78	0.10	700
53	114	79	0.05	400
57	109	80	0.05	250
60	106	77	0.04	250
63	109	76	0.05	250

Table 2. Performance comparison of heat pump in cooling mode for different heat sinks.

Heat sink	Condenser Temp (ºC)	COP	Elec. Consu.
Forced air cooling	50	4.117	1.00
Cooling water tower	40	6.293	0.65
RLT ground heat ex.	35	8.114	0.51

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Abstract Title: A NOVEL THERMOSYPHON FOR GROUND HEAT EXCHANGER
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Heng-Yi Li, Meng-Chang Tsai, and Chi-Fong Ai
Presenting author: Dr. Heng-Yi Li
Institute of Nuclear Energy Research
2014/7/31

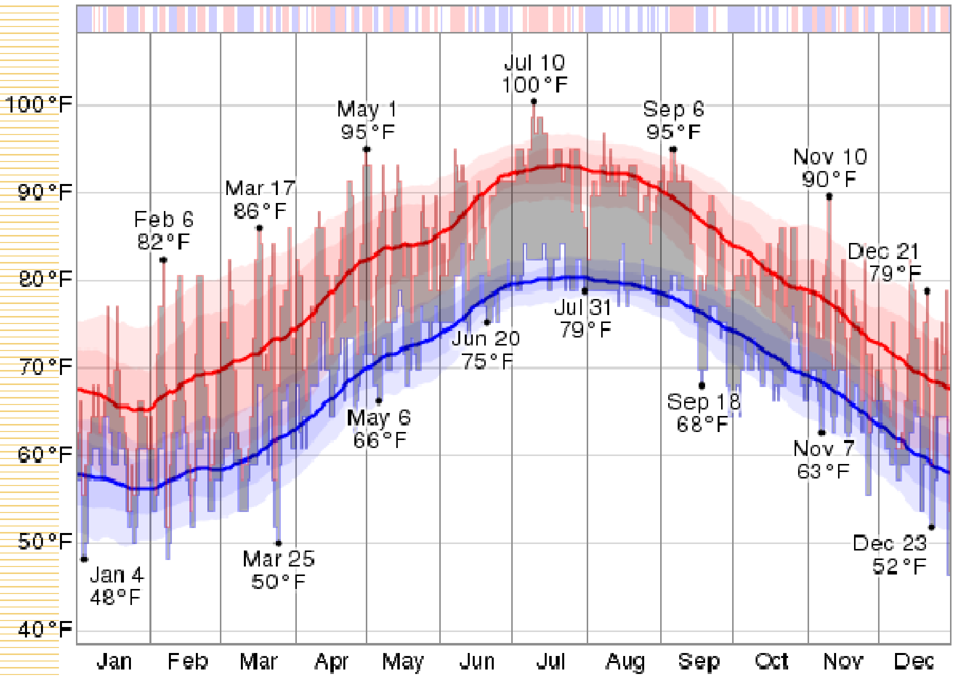
核研 行政院原子能委員會核能研究所

Outline

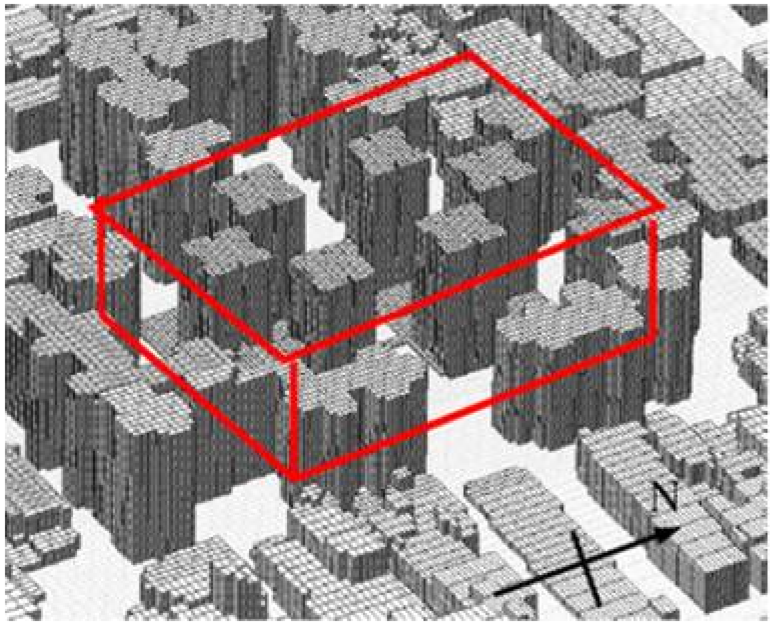
- Introduction
- System and Analysis
- Results and Discussion
- Conclusion

Introduction

The Taipei climate is very hot and humid during summer, and little cold in winter.
The hottest day of 2012 was July 10 with a high temperature of 100 ºF (37.8 ºC), and the hottest month was July with an average daily high temperature of 94˚F (34.4 ºC).
Hence, electrical energy consumption of air conditioning is a serious problem in summer.
The high-temperature urban areas are known as urban heat islands (UHIs). UHIs worsen the efficiency of air conditioner and increase electrical energy consumption.



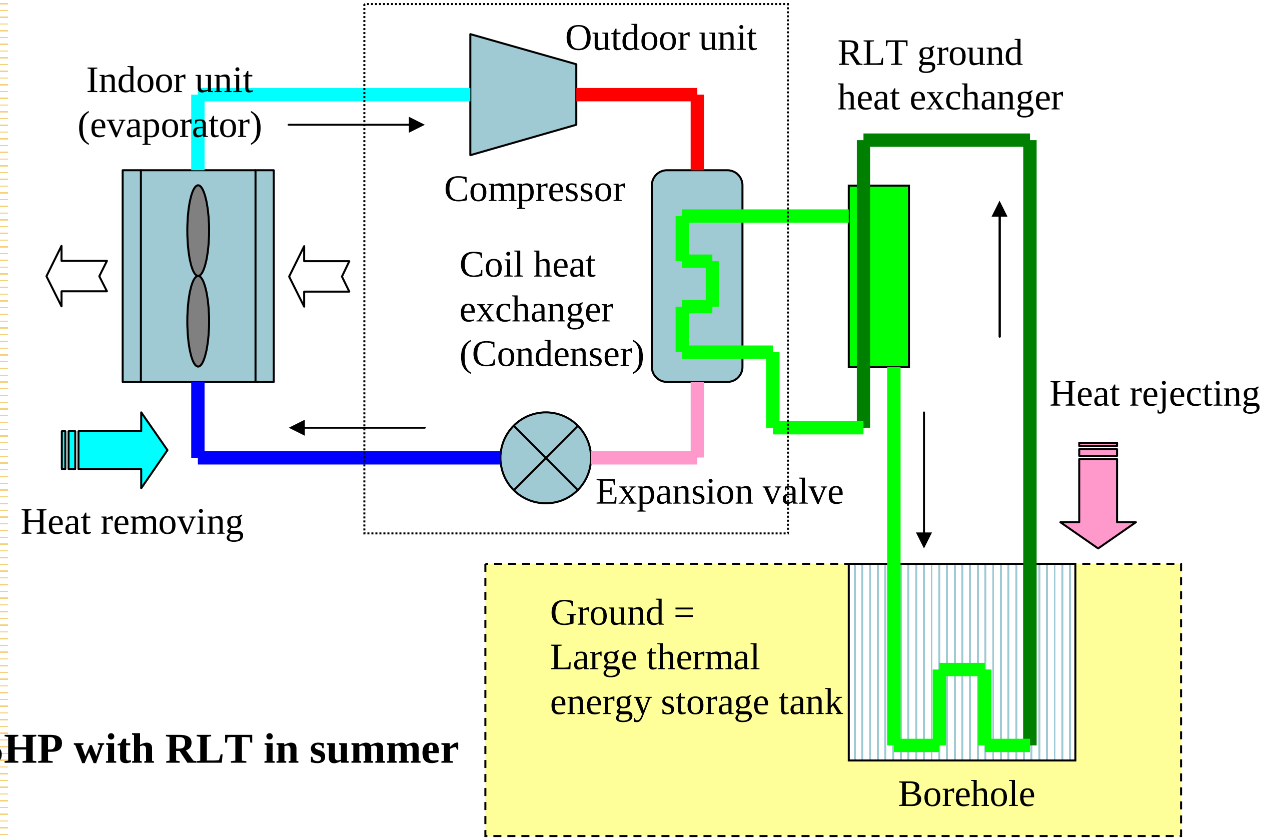
Taipei temperature in 2012



Urban heat islands in Taipei

System and Analysis

- In this study a ground source heat pump (GSHP) scheme using reverse loop thermosyphon (RLT) as a GHE is proposed.
- In the summer, the heat pump operates in cooling mode and removes the heat from the building to the ground with RLT.

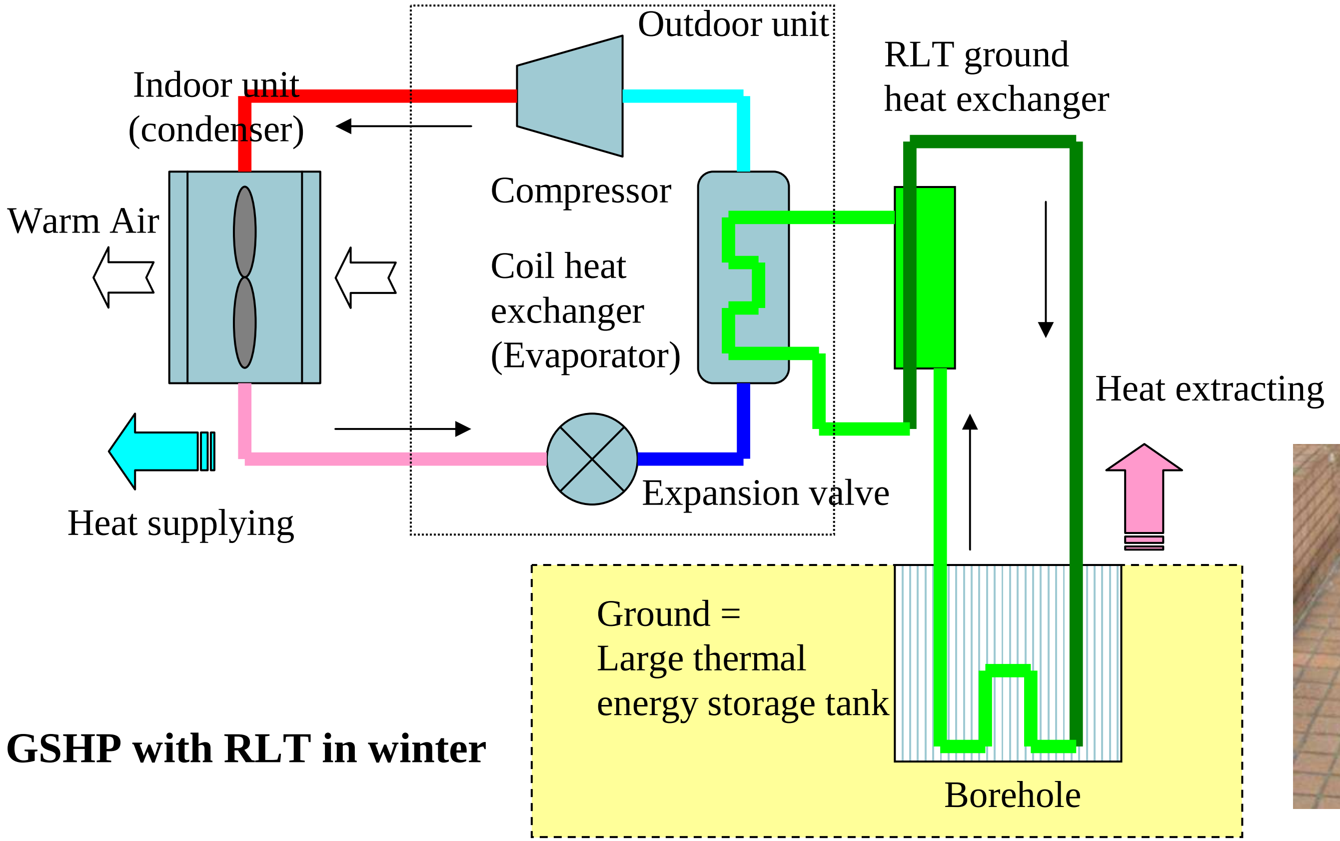


GSHP with RLT in summer

Drainage ditch

System and Analysis

- In the winter, the heat pump operates in heating mode and extracts heat from the ground to the building with RLT.

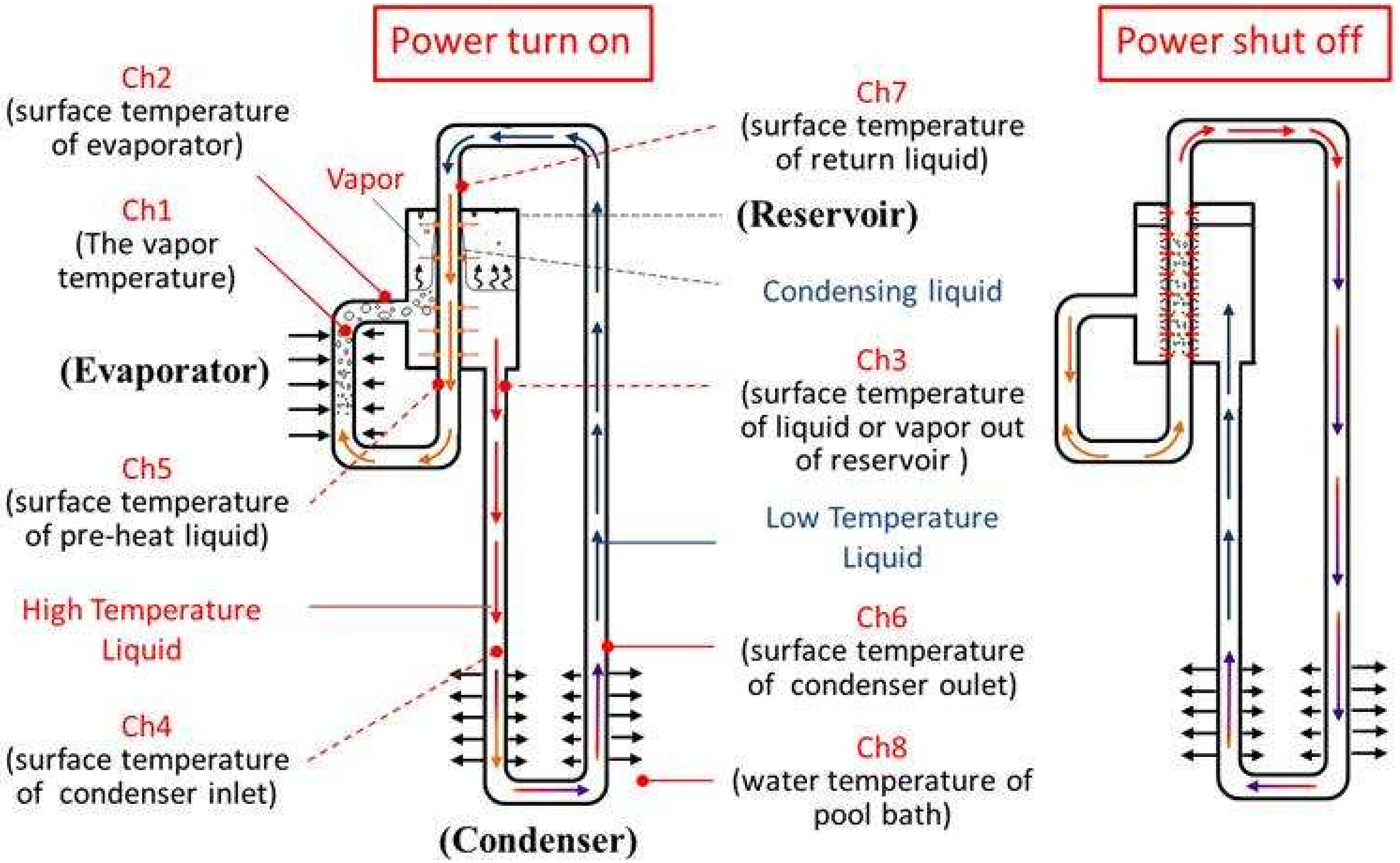


GSHP with RLT in winter

Drainage ditch

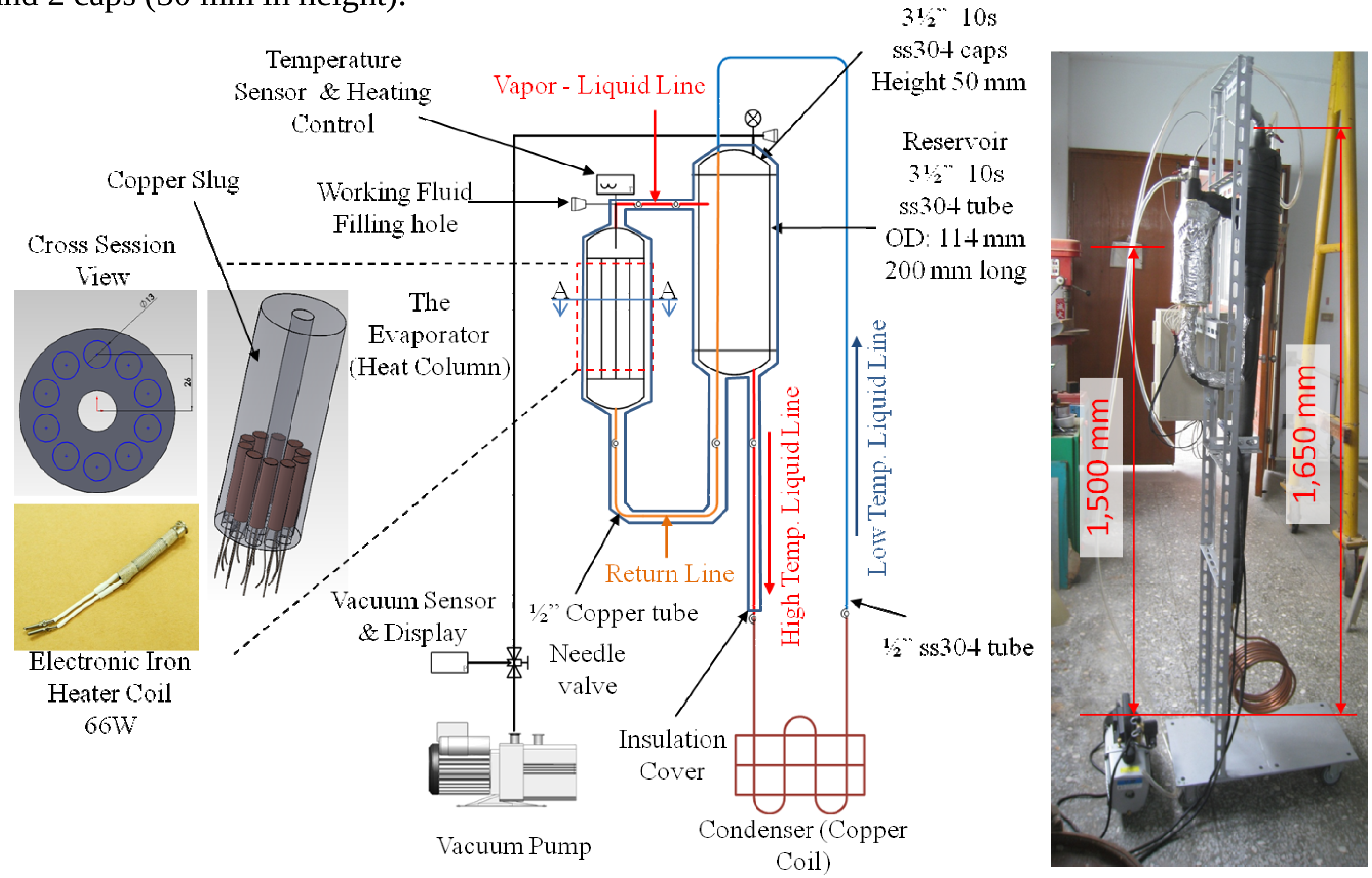
System and Analysis

- This design could transfer heat from a heat source near the top to a heat sink at the bottom when power is turned on.
- Besides, the RLT could also transfer heat from bottom to top as traditional thermosyphon when power off.



Results and Discussion

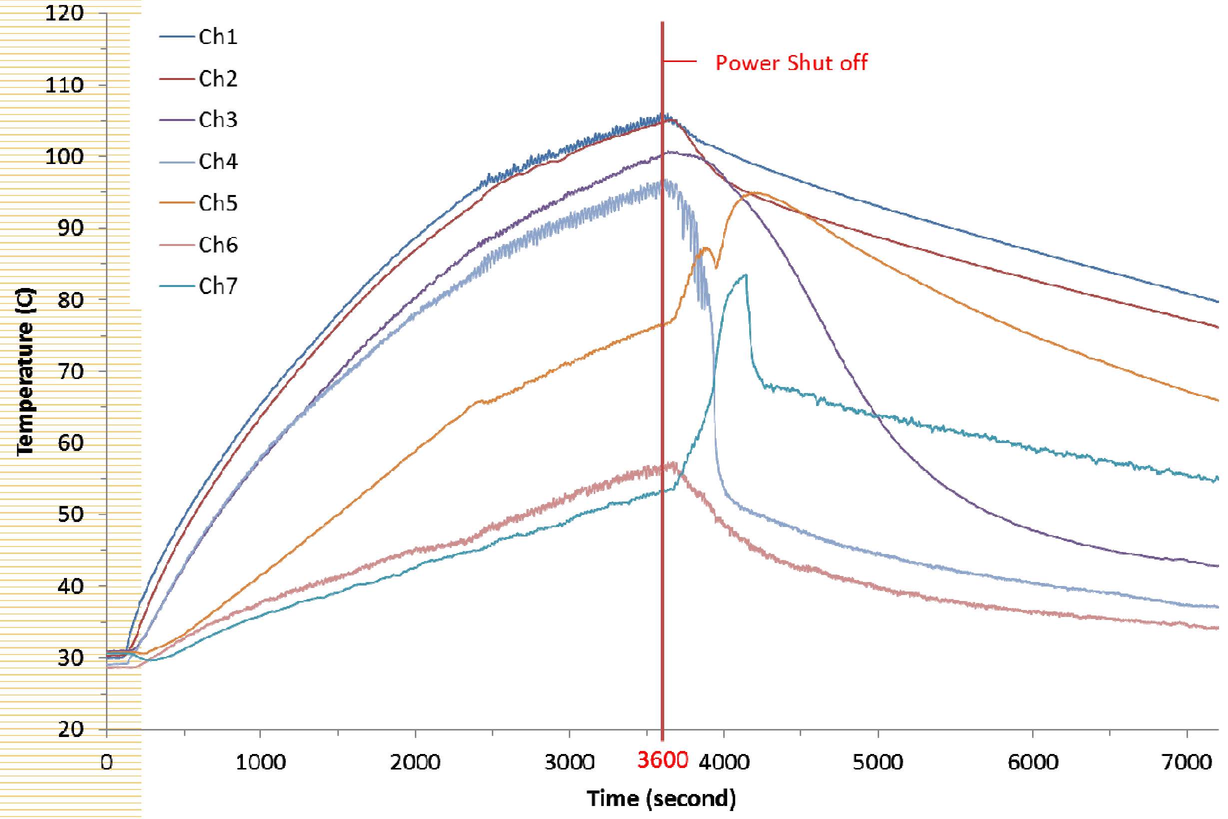
- The RLT comprised an evaporator, a condenser, a preheat reservoir, and pipes connecting each of the components. The evaporator comprised a 72 mm diameter copper slug in which 10 electrical ohmic heaters were installed. The condenser comprised 620 mm long ½〃 copper coil and a temperature controlled bath for heat exchange and storage respectively. The reservoir comprised a 3½〃 stainless steel tube with a height of 200 mm and 2 caps (50 mm in height).

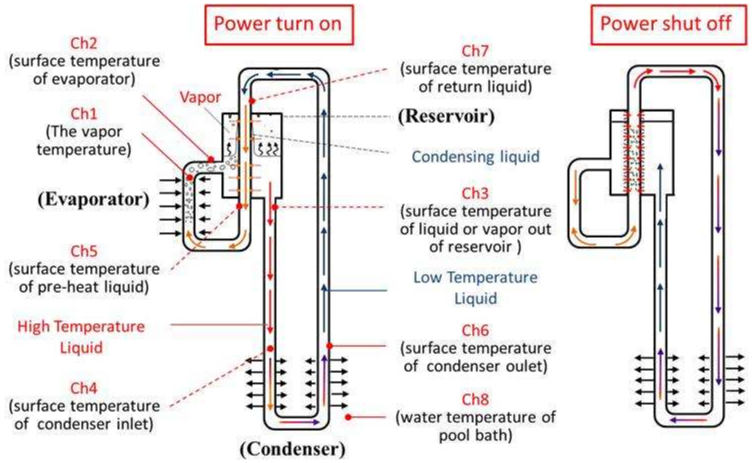


The schematic of the two-phase RLT design and its device photo.

Results and Discussion

- The heating on mode is kept for 3600 second. It can be seen from the figure during the heating on mode that the temperature high low sequence (Ch1> Ch2> Ch3> Ch4> Ch5> Ch6> Ch7) agrees with the flow direction.





The temperature variations over time with 660 W of heat input and 60 % filling ratio of methanol.

Results and Discussion

$$R_{th} = \left(T_{vapor} - T_{condenser}\right)/Q_{RLT}$$

Filling ratio (%)	Vapor Temperature (˚C)	Condenser Inlet Temp. (˚C)	Thermal Resistance (˚C/W)	Reverse Start Time (second)
47	149	76	0.11	700
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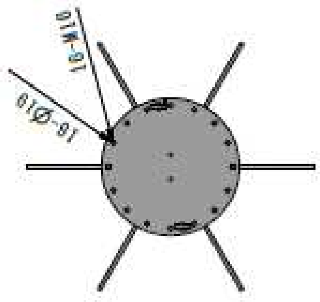
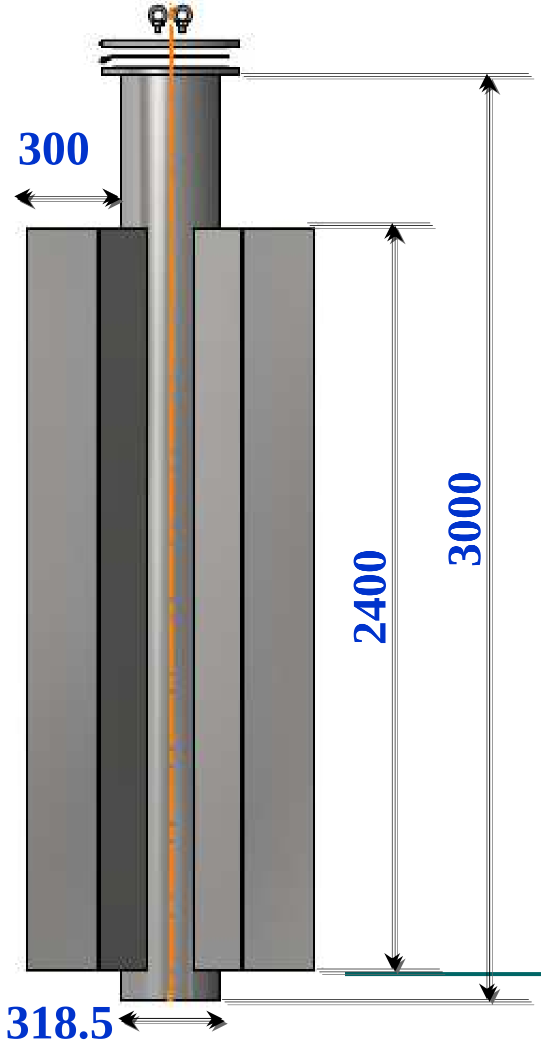
Results and Discussion

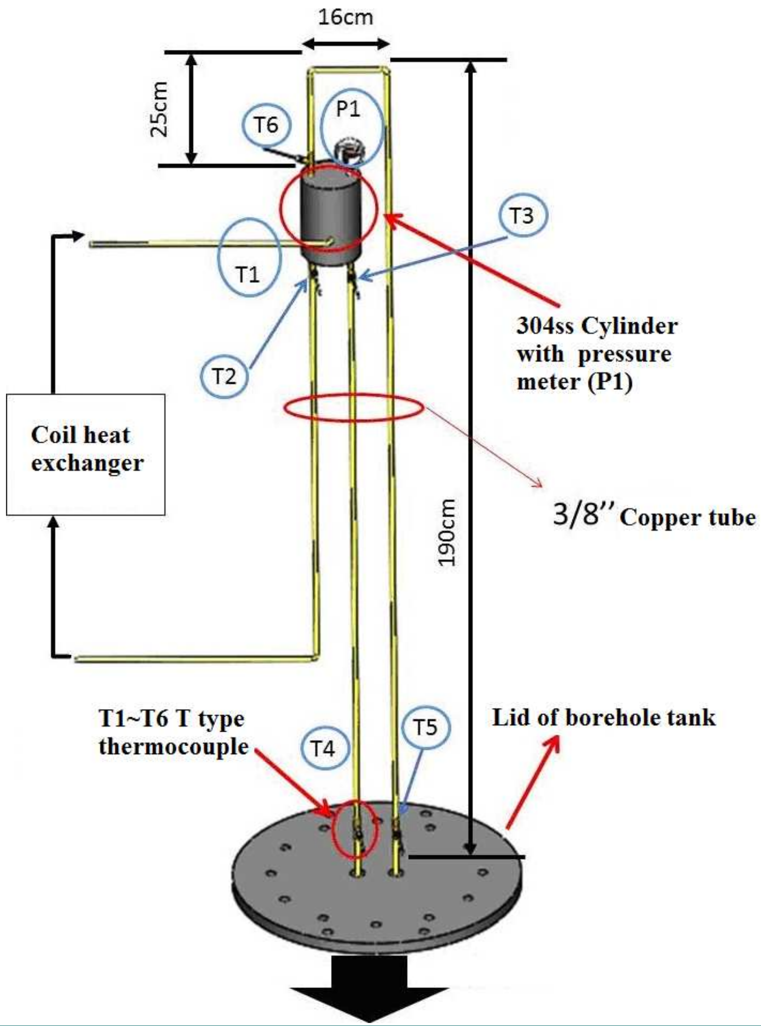
- Borehole tank

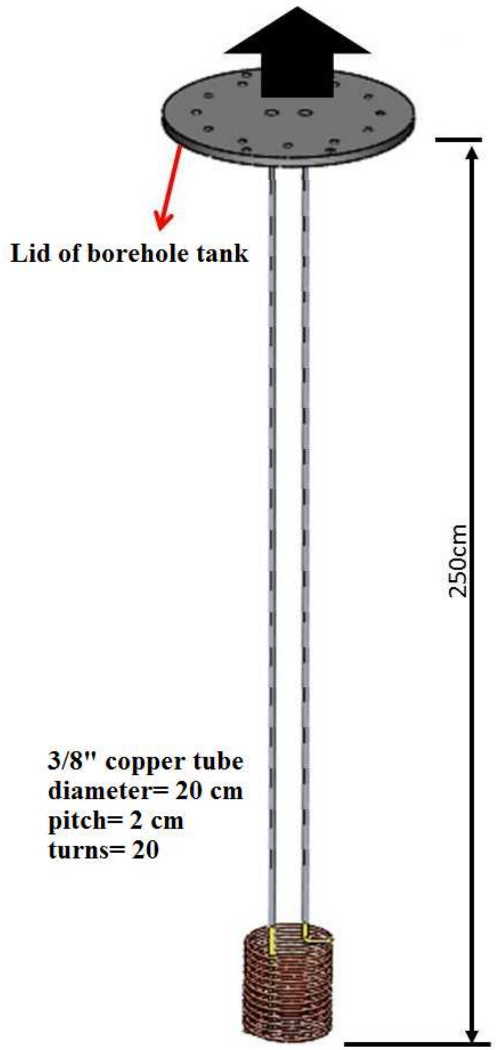




Results and Discussion

- Reverse thermosyphon loop above the lid of borehole tank
- Reverse thermosyphon loop inside borehole tank

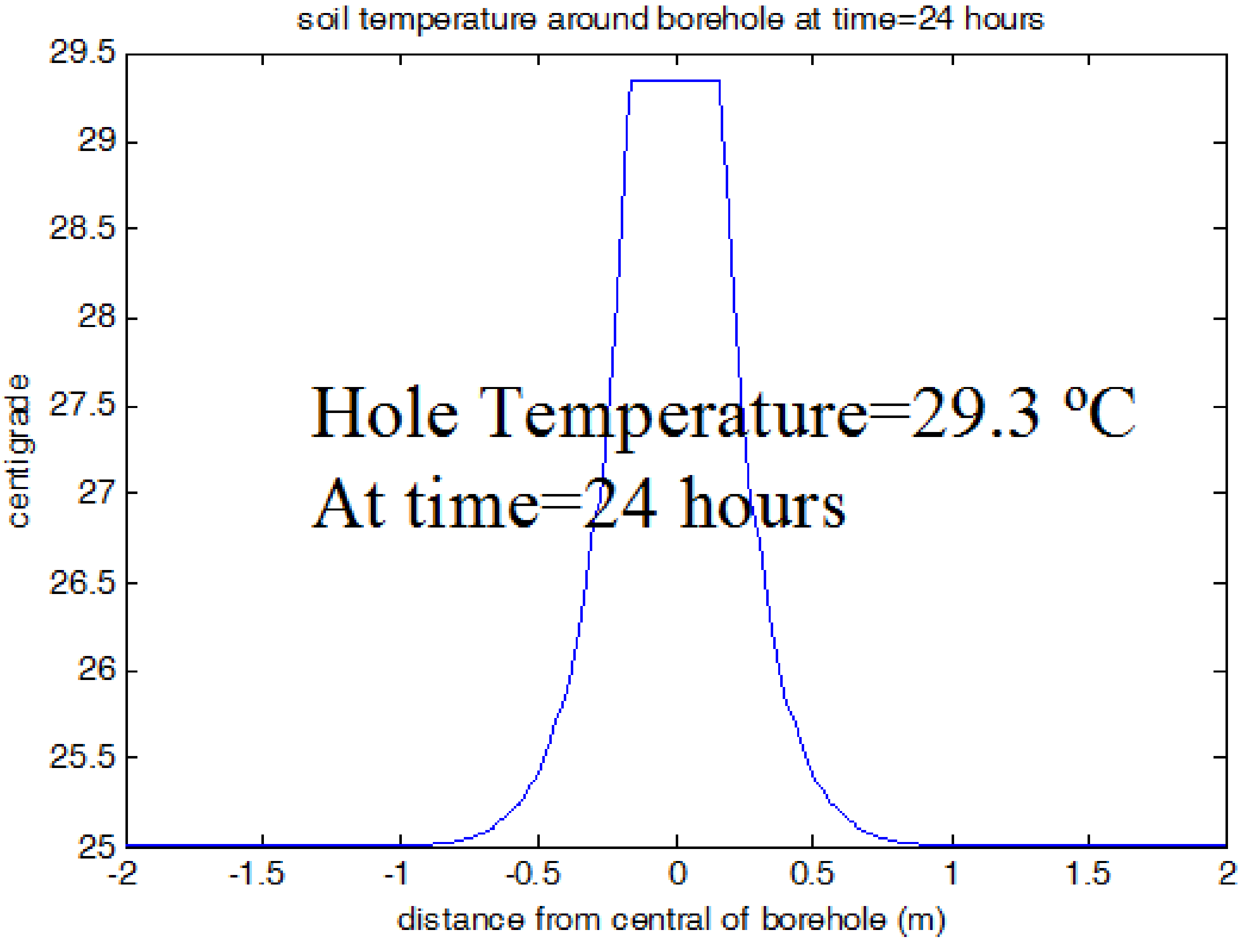




Results and Discussion

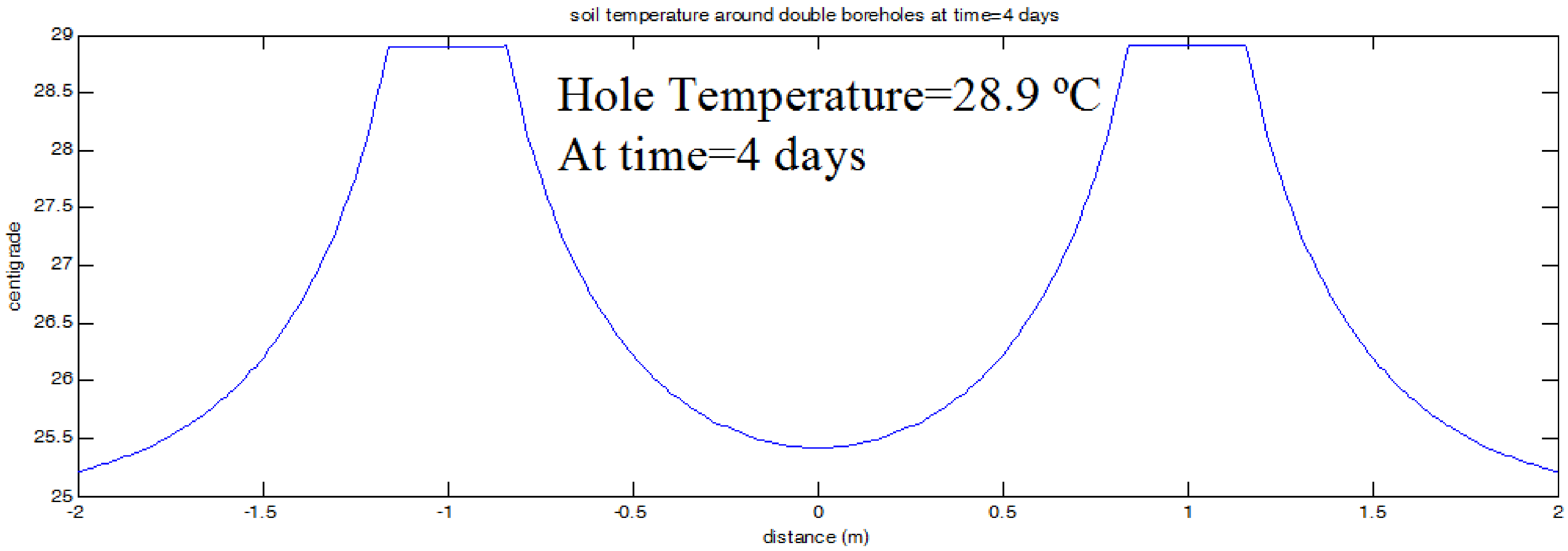
- The soil temperature around single borehole tank at t=24 hours.
- General form of heat conduction equation in cylindrical coordinates.

$$\frac{\partial^2 T}{\partial r^2}+\frac{1}{r}\frac{\partial T}{\partial r}+\frac{1}{r^2}\frac{\partial^2 T}{\partial \varphi^2}+\frac{\partial^2 T}{\partial z^2}+\frac{\dot{q}_{gen}}{k}=\frac{1}{\alpha}\frac{\partial T}{\partial t} \qquad T_s(r,t)-T_0=\frac{q'}{4\pi k}\int_{\frac{r^2}{4at}}^{\infty}\frac{e^{-u}}{u}du$$



Results and Discussion

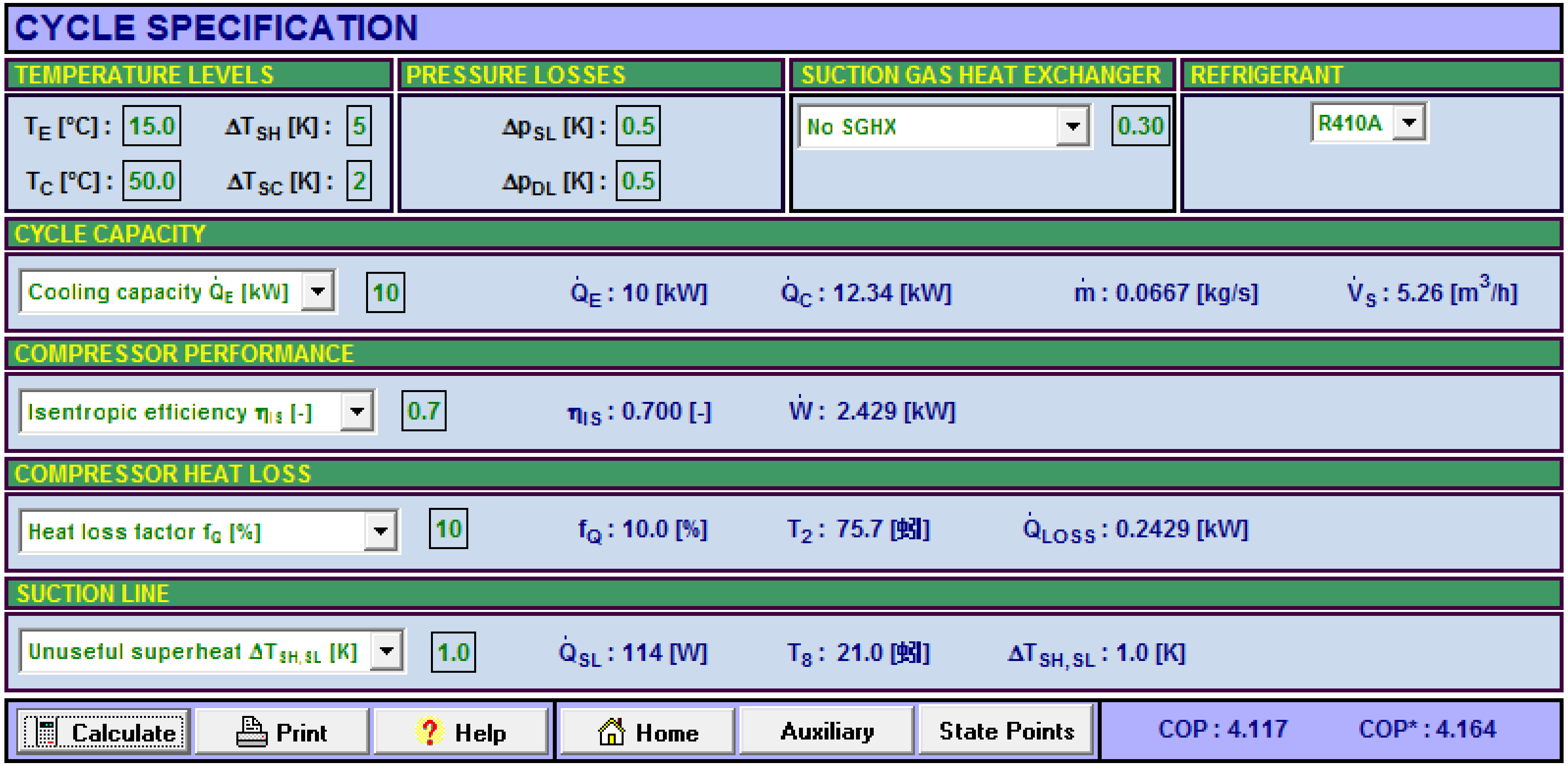
- The soil temperature around double borehole tanks at t=4 days.



Results and Discussion

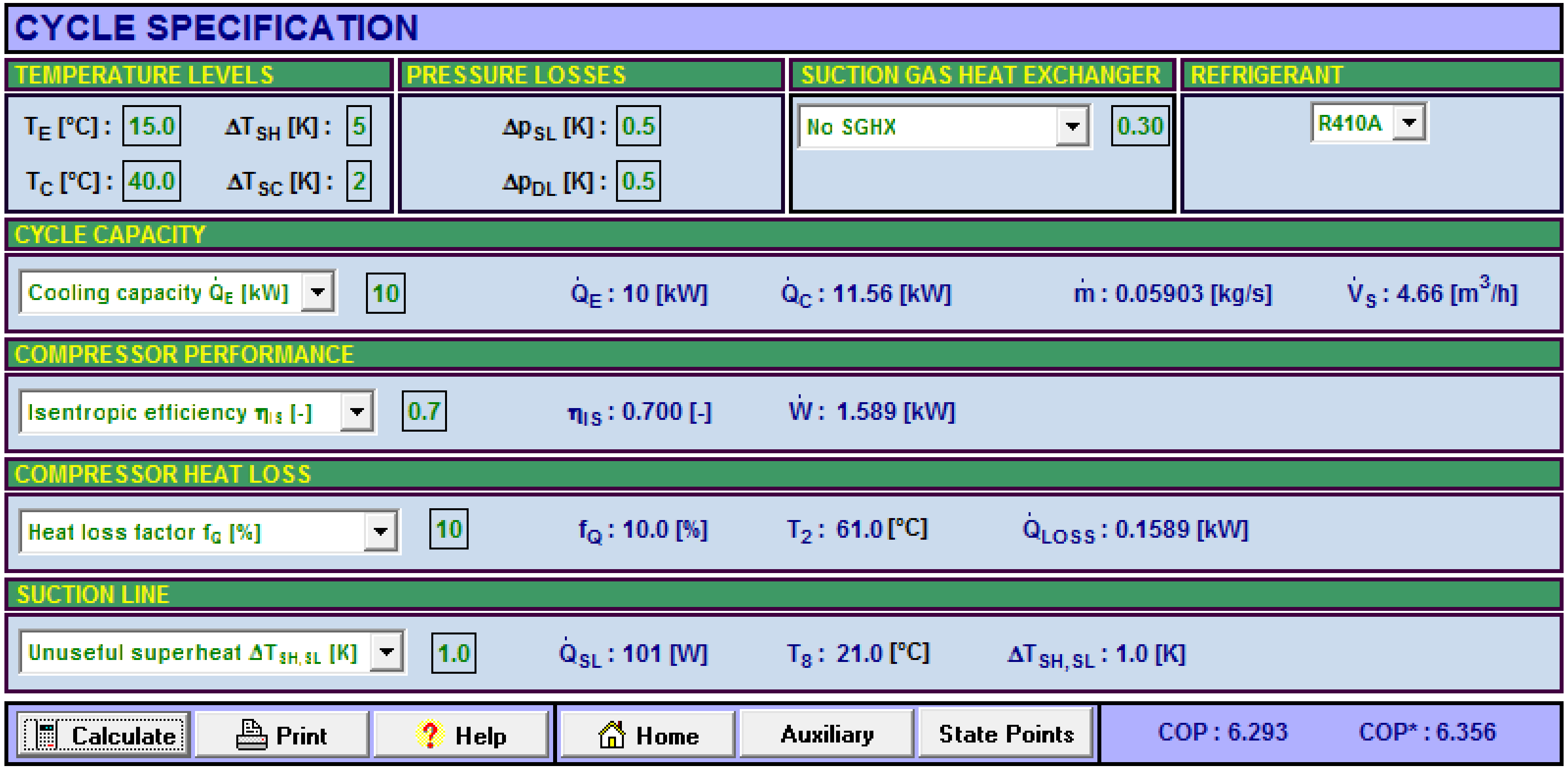
- Performance comparison of heat pump in cooling mode for different heat sinks.
- Forced air cooling.

$$COP = \frac{\dot{Q}_e F \cdot \eta_{iso} \cdot \eta_m}{\dot{W}_{comp}}$$



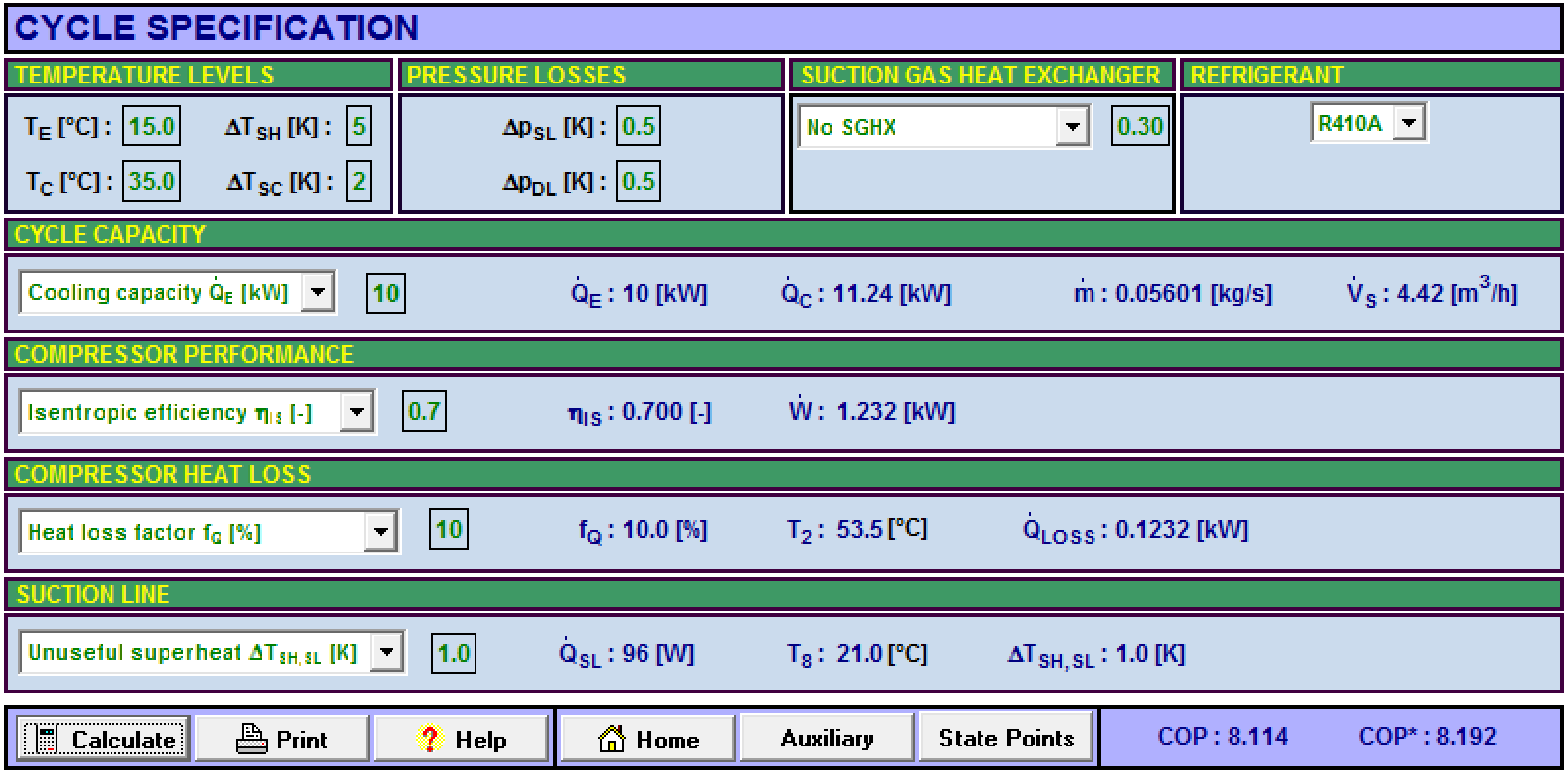
Results and Discussion

- Performance comparison of heat pump in cooling mode for different heat sinks.
- Cooling water tower



Results and Discussion

- Performance comparison of heat pump in cooling mode for different heat sinks.
- RLT ground heat exchanger



Results and Discussion

Heat sink	Condenser Temp (°C)	COP	Elec. Consu.
Forced air cooling	50	4.117	1.00
Cooling water tower	40	6.293	0.65
RLT ground heat ex.	35	8.114	0.51

Conclusion

- A GSHP scheme using the RLT as the ground heat exchanger is proposed.
- The feasibility of the RLT is verified by experiment with 60 % filling ratio of methanol.
- The soil temperature profiles around the borehole tank are calculated and evaluated. The overall soil temperature grows with time and the maximum temperature is still lower than atmosphere temperature.
- By following vapor compression model and using R410a as refrigerant, it can be seen that heat pump with RLT ground heat exchanger has the lowest condenser temperature, so its COP is the highest and electric consumption is 51 % of forced air cooling.