647

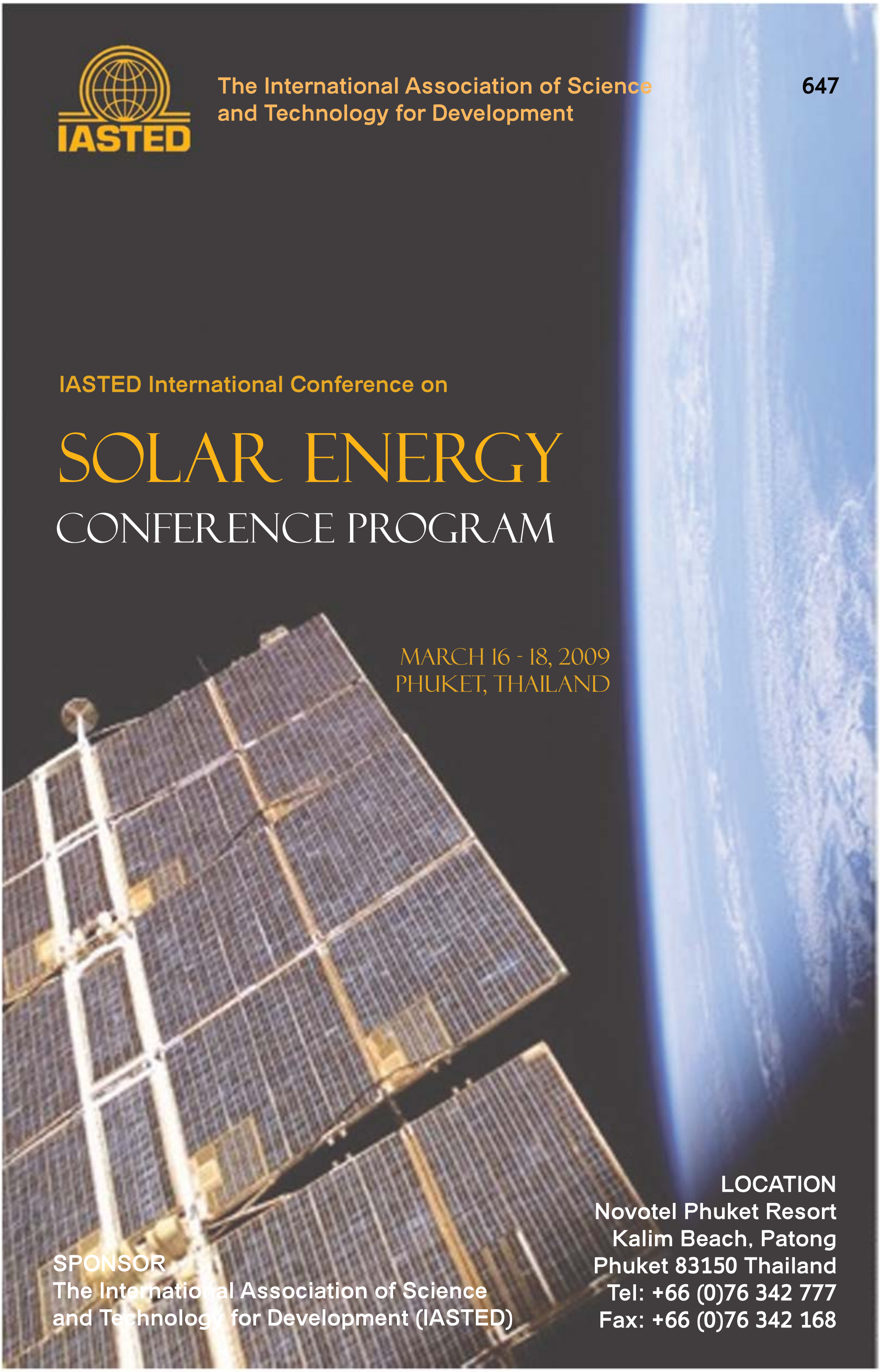
The International Association of Science
and Technology for Development

IASTED International Conference on

# SOLAR ENERGY

## CONFERENCE PROGRAM

MARCH 16 - 18, 2009
PHUKET, THAILAND



SPONSOR
The International Association of Science
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LOCATION
Novotel Phuket Resort
Kalim Beach, Patong
Phuket 83150 Thailand
Tel: +66 (0)76 342 777
Fax: +66 (0)76 342 168

The IASTED International Conference on

# Solar Energy

# ~SOE 2009~

Phuket, Thailand

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The International Association of Science and Technology for Development (IASTED)

## CONFERENCE CHAIR

**Dr. Mohamed Hamza** – IASTED, Canada

## TUTORIAL SESSION

**Professor R.E.I. Schropp –** Utrecht University, Netherlands

## PLEASE NOTE

- Paper presentations are 15 minutes in length with an additional 5 minutes for questions.
- Report to your Session Chair 15 minutes before the session is scheduled to begin.
- Presentations should be loaded onto the presentation laptop in the appropriate room prior to your session.
- End times of sessions vary depending on the number of papers scheduled.

## INTERNATIONAL PROGRAM COMMITTEE

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**S. H. Jangamshetti** – Basaveshwar Engineering College, India
**S. Jia** – Nanyang Technological University, Singapore
**S. Kaplanis** – Technological Educational Institute Of Patras, Greece

# PROGRAM OVERVIEW

## Monday, March 16, 2009

07:30 - 08:30 Registration
*(Siam Foyer)*

08:30 - 09:00 Welcome Address with WBE Conference
*(Siam A Room)*

09:00 - 10:00 WBE Keynote Presentation - Dr. D.G. Sampson - "Exploiting Mobile and Wireless Technologies in Lifelong Learning"
*(Siam A Room)*

10:00 - 10:30 Coffee Break
*(Siam Foyer)*

13:00 – 14:00 Lunch
*(Coffee House Restaurant)*

16:00 - 16:30 Coffee Break
*(Siam Foyer)*

18:00- Phuket Fantasea Theme Park Optional Tour

## Tuesday, March 17, 2009

08:00 - 10:00 Tutorial Presentation – Professor R.E.I. Schropp – "Solar Cells"
*(Bhuket A+B Room)*

10:00 - 10:30 Coffee Break
*(Siam Foyer)*

10:30 - 11:30 Tutorial Presentation Continued

11:30 - 13:00 ACSE Keynote Speaker – Professor M. H. Williams – "User Control in a Ubiquitous or Pervasive Computing Environment"
*(Siam D Room)*

13:00 - 14:00 Lunch
*(Coffee House Restaurant)*

14:00 - 16:00 Session 1 – Solar Thermal Energy
(*Bhuket A+B Rooms*)

16:00 - 16:30 Coffee Break
*(Siam Foyer)*

16:30 – 17:30 Session 2 – Grid Connection and Energy Conversion
*(Bhuket A+B Room)*

19:30 - Dinner Banquet & Award Ceremony
(*Rabiang Terrace)*

## Wednesday, March 18, 2009

| | |
|---|---|
| 09:00 – 10:30 | Session 3 – Photovoltaic and Nanotechnology<br>*(Bhuket A+B Room)* |
| 10:30 – 11:00 | Coffee Break<br>*(Siam Foyer)* |
| 11:00 – 13:00 | Session 4 – Solar Energy and Applications<br>*(Bhuket A+B Room)* |
| 13:00 - 14:00 | Lunch<br>*(Coffee House Restaurant)* |
| 16:00 - | Evening Sunset Dinner Cruise<br>Optional Tour |

## Thursday, March 19, 2009

| | |
|---|---|
| 08:00 – 18:00 | Full Day Ko Phi Phi Island Tour<br>Optional Tour |

## Monday, March 16, 2009

**07:30 – 08:30 REGISTRATION**
*Location: Siam Foyer*

**08:30 – 09:00 WELCOME ADDRESS (with WBE Conference)**
*Presenter: Prof. V. Uskov (WBE Conference Chair)*
*Location: Siam A Room*

**09:00 – 10:00 WBE KEYNOTE PRESENTATION – "EXPLOITING MOBILE AND WIRELESS TECHNOLOGIES IN LIFELONG LEARNING"**
*Presenter: Dr. D.G. Sampson*
*Location: Siam A Room*

**Abstract:** During the past years, there is a growing interest in the use of mobile technologies and wireless infrastructures in education and training. As a result, mobile learning has attracted the attention of technology-enhanced learning community, mainly as a side effect of the growth of the mobile communications industry. While the educational added-value of m-learning is under investigation, technological efforts are much needed to align m-learning technologies with the current state-of-the-art in learning technologies standards and specifications. In this keynote presentation, the topic of "Exploiting Mobile and Wireless Technologies in Lifelong Learning" will be addressed, presenting a framework for integrating widely adopted international learning technologies specifications (such as the IEEE LOM and IMS Learning Design), so as to be able to include m-learning in large scale Technology-enhanced Lifelong Learning business cases.

**Dr. Demetrios G. Sampson** holds a Diploma in Electrical Engineering (1989) from Demokritus University of Thrace and Ph.D. in Multimedia Communications (1995) from University of Essex, UK.
Dr. Sampson is a Senior Member of IEEE and the elected Chairman of the IEEE Computer Society Technical Committee on Learning Technologies (LTTC).
Dr. Sampson is the Director of the Advanced eServices for the Knowledge Society Research Unit (ASK) at the Informatics and Telematics Institute (ITI) of the Centre of Research and Technology Hellas (CERTH) and an Associate Professor on eLearning at the Department of Digital Systems of the University of Piraeus.
Dr. Sampson's main research interests are in the areas of Technology Enhanced Learning. He is the co-author of *more than 200* publications in scientific

books, journals and conferences with at least 410 known citations.

Dr. Sampson is *Co-Editor-in-Chief* of the Educational Technology and Society Journal, an international journal with Impact Factor 0.469 (2006) on the Thomson Scientific 2006 Journal Citations Report. He is also a *Member of Editorial Board* of (10) International Journals, including the *IEEE Transactions on Learning Technologies* and *Guest Co-Editor* in (14) Special Issues of International Journals.

**10:00 – 10:30 COFFEE BREAK**

*Location: Siam Foyer*

**13:00 – 14:00 – LUNCH**

*Location: Coffee House Restaurant*

**16:00 – 16:30 COFFEE BREAK**

*Location: Siam Foyer*

**18:00 - OPTIONAL TOUR – "PHUKET FANTASEA THEME PARK"**

## Tuesday, March 17, 2009

**08:00 – 10:00 – TUTORIAL PRESENTATION – "SOLAR CELLS"**

*Presenter: Professor R.E.I. Schropp*

*Location Bhuket A+B Room*

After a general background on the position of photovoltaic solar energy within the palette of renewable energies, and an overview of present-day photovoltaics technologies, the emphasis goes to thin films. The various thin film technologies (CIGS, CdTe, dye-sensitized, organic and silicon) will be discussed side by side. Then, by way of a case study, thin film silicon as used in tandem and triple-junction solar cells is reviewed. Multijunction cells, due to their spectrum splitting capability, have true potential for low cost and high conversion efficiency.

Amorphous silicon has a band gap of 1.7-1.8 eV, and thus microcrystalline silicon, with a band gap of 1.1 eV, makes an ideal match to amorphous silicon in tandem cells. Since the first reports on practical microcrystalline cells in 1994, much research effort has been put worldwide into the development of both fundamental knowledge and technological skills that are needed to improve thin film silicon multijunction solar cells. The research challenges are to enhance the network ordering of amorphous semiconductors (leading to protocrystalline networks), mainly for improving the stability, to increase the deposition rate, in particular for microcrystalline silicon; to develop thin doped layers, compatible with the new, fast deposition techniques; to design light-trapping configurations, by utilizing textured surfaces and dielectric mirrors. Examples of progress are given for each one of these four challenges. The world record initial efficiency of 15% for thin film silicon photovoltaic (PV) technology has been obtained for triple-band gap triple-junction cells, using adequate optical enhancement techniques, such as textured back reflectors and intermediate partially reflecting layers. In production, the trend is toward implementation of these multi-junction structures in large area modules. Modules are presently produced batch wise or in-line on glass, or roll-to-roll on stainless steel and other foils, such as polymer plastics.

**Prof. Dr. R.E.I. (Ruud) Schropp** obtained his PhD degree in 1987 from the University of Groningen, The Netherlands, in the field of Thin Film Transistors (TFTs) made of amorphous silicon. After that he worked several years at vacuum equipment manufacturer Glasstech Solar, Inc., in Colorado, USA. Since 1990 he has been employed at Utrecht University (UU), and in Mid-2000, became a full professor in "Physics of Devices". He has over 25 years of experience in the field of thin film semiconductors for displays and solar energy, and now heads the Nanophotonics section of the Faculty of Science at Utrecht University. He also initiated many projects (both national and European) related to thin films and devices, including projects on flexible cells, thin film poly-Si, and nanocrystalline $TiO_2$ dye-sensitized solar cells, composite PPV/$TiO_2$ cells, thin film Si based tandem and triple junction cells (coordinator of international EU project), c-Si heterojunctions, TFTs, and recently for instance, low-temperature thin film silicon cells. Dr. Schropp has been project leader for multiple national SenterNovem funded projects and various STW (Technology Foundation) and Novem (Renewable Energy) projects. He has been visiting professor at NREL, USA, and at 3 different institutes (AIST, JAIST, and TITECH) in Japan. His current research activities are catalytic Hot Wire CVD (silicon and polymer thin films) and advanced VHF CVD for next generation thin films for photovoltaics. He has been an advisor of 23 PhD's, has guided many students inside and outside UU, and authored/co-authored more than 350 papers.

**10:00 – 10:30 COFFEE BREAK**
*Location: Siam Foyer*

**10:30 – 11:30 – TUTURIAL PRESENTATION CONTINUED**

**11:30 – 13:00 ACSE KEYNOTE SPEAKER – "USER CONTROL IN A UBIQUITOUS OR PERVASIVE COMPUTING ENVIRONMENT"**
*Presenter: Prof. M. H. Williams*
*Location: Siam D Room*

Since the original ideas of ubiquitous computing were put forward over twenty years ago, there has been a considerable research effort devoted to trying to realize general ubiquitous or pervasive computing environments. Although different projects have focused on different slants to the research, no system has yet emerged that is generally acceptable. There are several reasons for this:
(1) The issues of performance and scalability have been a major problem so far and until they can be satisfactorily solved, such systems will fail to gain acceptance.
(2) The user must be able to control the decision making within the system and yet not be required to take actions unnecessarily. Thus one needs a balance between system decisions based on knowledge about user context and preferences, and specific user interaction through appropriate interfaces.
(3) The system must provide adequate privacy and security measures to protect the users identity or other sensitive data about the user.
This presentation will discuss these and related problems. It will present some results from experience on several ubiquitous/pervasive system projects, focusing mainly on the question of user control. This includes the recently completed Daidalos project, which was concerned particularly with mobility, and the current Persist project, which is focused on Personal Smart Spaces.

**Howard Williams** has a PhD in ionospheric physics and a DSc in Computer Science. He has held a chair in Computer Science at Heriot-Watt University in Edinburgh since 1980. For most of this period he has been head of the Database, Information and Knowledge Based Systems research group. Here he has managed a large number of research projects, initially in areas such as deductive, active, parallel and distributed databases, and latterly, in the past decade, in the area of personalization. Here he has been involved in research ranging from the personalized presentation of information returned from databases to the accumulation and application of user preferences to personalize the behavior of ubiquitous or pervasive systems.

**13:00 – 14:00 – LUNCH**
*Location: Coffee House Restaurant*

**14:00 – 16:00 – SESSION 1 – SOLAR THERMAL ENERGY**
*Chair: TBA*
*Location: Bhuket A+B Room*

647-005
Presentation and First Experimental Results of a Solar Air Collector Integrated in a Shutter
*J.-L. Canaletti, G. Notton, and C. Cristofari (France)*

647-007
The Effect of Tube Arrangement on a Flat Plate Solar Water Heater Performance
*E.A. Handoyo and A. Kristianto (Indonesia)*

647-003
An Educational Solar Tracking System
*S.Sh. Soulayman (Syria)*

647-002
Economic Feasibility of Solar Domestic Hot Water Systems in Syria and Armenia
*S.Sh. Soulayman (Syria), N. Ananikyan, and G. Martoyan (Armenia)*

647-036
Some Characteristics of Heat Production by Stationary Parabolic, Cylindrical Solar Concentrator
*M. Bojić, N. Marjanović, I. Miletić, A. Mitić, and V. Stefanović (Serbia)*

**16:00 – 16:30 COFFEE BREAK**
*Location: Siam Foyer*

**16:30 – 17:30 – SESSION 2 – GRID CONNECTION AND ENERGY CONVERSION**
*Chairs: Dr. U. Tipparach (Thailand) & Prof. M.H. Shwehdi (Saudi Arabia)*
*Location: Bhuket A+B Room*

647-014
Input-Output Linearization Control of an LCL Filter Employing a Symmetric Geometry in Grid-Connected Inverter Applications
*D.-H. Ha, K.-J. Lee, R.-Y. Kim, and D.-S. Hyun (Korea)*

647-033
Siting and Sizing of Distributed Generation using Three New Indices
*M.J. Jahromi, M.H. Haque, and K.J. Tseng (Singapore)*

647-031
The Effect of Spherical Hub-Nose Position on Pressure Drop in an Oscillating Water Column System for Wave Energy Conversion
*Z. Taha (Malaysia), Sugiyono (Malaysia, Indonesia), N. Ahmad, R.A.R. Ghazilla, H.J. Yap, T.Y.T. Ya, R. Passarella, I. Hasanuddin, and M. Yunus (Malaysia)*

**19:30 – DINNER BANQUET & AWARD CEREMONY**
*Location: Rabiang Terrace*

## Wednesday, March 18, 2009

**09:00 – 10:30 - SESSION 3 – PHOTOVOLTAIC AND NANOTECHNOLOGY**
*Chairs: Dr. C. Palanisamy (Malaysia) & Dr. J. Waewsak (Thailand)*
*Location: Bhuket A+B Rooms*

647-022
The Effect of Temperature on the Performance of Dye-Sensitized Solar Cells using Nanostructured $TiO_2$
*T. Saipin, P. Wongwanwattana, T. Sompun, S. Pukird, and U. Tipparach (Thailand)*

647-032
Determination of Photovoltaic (PV) Remote Offshore Generation System Performance using Probabilistic Assessment
*M.H. Shwehdi (Saudi Arabia)*

647-024
Enhancing the Performance of Photoelectrolysis Cells for Solar Hydrogen Generation via NANO-$TiO_2$ Photoanodes and Pt-Nanofilm Counter Electrodes
*U. Tipparach, P. Wongwanwattana, T. Sompun, and P. Limsuwan (Thailand)*

647-016
Thermoelectric Properties and Nanostructures of Materials Prepared from Rice Husk Ash
*S. Pukird, U. Tipparach, P. Kasian, and P. Limsuwan (Thailand)*

647-006
Sizing of a PV/$H_2$ Hybrid System to Supply Peak Loads on an Isolated Electrical Grid - A Case Study in Corsica Island (France)
*P. Poggi, C. Cristofari, J.L. Canaletti, C. Darras, and M. Muselli (France)*

**10:30 – 11:00 COFFEE BREAK**
*Location: Siam Foyer*

**11:00 – 13:00 – SESSION 4 - SOLAR ENERGY AND APPLICATIONS**
*Chair: Prof. Soulayman (Syria)*
*Location: Bhuket A+B Room*

647-034
A Solar Vehicle based on Sustainable Design Concept
*Z. Taha, J.M. Sah, R. Passarella, R.A.R. Ghazilla, N. Ahmad, Y.H. Jen, T.T. Khai, Z. Kassim, I. Hasanuddin, and M. Yunus (Malaysia)*

647-035
Developing of a Telemetry Monitoring System for a Solar Vehicle
*Z. Taha, R. Passarella, J.M. Sah, H.X. Hui, N. Ahmad, R.A.R. Ghazilla, Y.H. Jen, and T.T. Khai*

647-029
Performance of a Forced Convection Solar Drier Integrated with Gravel as Heat Storage Material
*M. Mohanraj (India) and P. Chandrasekar (Malaysia)*

647-037
Maximizing the Energy Storage Performance of Phase Change Thermal Storage Systems
*N.A.M. Amin, F. Bruno, and M. Belusko (Australia)*

647-011
Spatial Distribution and Temporal Variability of Solar Radiant over Southern Thailand
*J. Waewsak and C. Chancham (Thailand)*

**13:00 – 14:00 – LUNCH**
*Location: Coffee House Restaurant*

**16:00 – OPTIONAL TOUR – EVENING SUNSET CRUISE**

## Thursday, March 19, 2009

### 08:00 – OPTIONAL TOUR – FULL DAY KO PHI PHI TOUR

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**IASTED would like to thank you for attending SOE 2009. Your participation helped make this international event a success, and we look forward to seeing you at upcoming IASTED events.**

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# SOE 2009

## *Certificate of Participation*

This is to certify that ***E. Handoyo***
attended the IASTED International Conference on
***Solar Energy***,
held *March 16-18, 2009*, in
*Phuket, Thailand*,
and presented the following paper:

Paper Number: 647-007

Entitled: The Effect of Tube Arrangement on a Flat Plate Solar Water Heater Performance

IASTED

***IASTED Secretariat***

March 18, 2009
***Date***

**Proceedings of the IASTED International Conference**
**Solar Energy (SOE 2009)**
**March 16 - 18, 2009 Phuket, Thailand**

# THE EFFECT OF TUBE ARRANGEMENT ON A FLAT PLATE SOLAR WATER HEATER PERFORMANCE

Ekadewi A. Handoyo and Ade Kristianto
Mechanical Engineering Department – Petra Christian University
Jl. Siwalankerto 121 – 131 Surabaya
Indonesia
ekadewi@petra.ac.id

**ABSTRACT**
The function of the tube of a flat plate solar collector is to circulate the water from the tank to be heated in collector. The three possible arrangements are tube below of, tube between of and tube above of the flat absorber plate. This tube arrangement might cause different heat transfer mode and heat loss from collector. Thus, it might affect the performance of a flat plate solar water heater, i.e. the temperature difference of the water flowing at the inlet and outlet of the collector and its flow rate as well. A research is conducted to find out this effect.

Three models were developed to represent the three tube arrangements. From the experiment conducted on January – February 2008 in Surabaya, Indonesia, it is found that the tubes placed below of the flat plate are suitable for a cloudy and windy surrounding, tubes placed above of the flat plate are suitable for locations that are sunny and still air, and tubes placed between of the flat plate gives the best performance, i.e. the highest temperature of water stored in the tank (means highest flow rate) and the highest temperature difference of water flowing in and out of the collector.

**KEY WORDS**
Tube arrangement, flat plat solar collector, solar water heater.

## 1. Introduction

Indonesia is a tropical country laying in the equator. Therefore, in Indonesia the sun shines almost all the time in the whole year. This blessing shall be used as an alternative source to heat up fluids. The electromagnetic energy emitted by the sun is converted to be thermal energy in a solar collector.

One popular type of solar collector is a flat-plate collector. This collector is used in moderate working temperature. Thus, it is usually used for water heater, room heater and some drying process. It is simpler than a concentrating collector. According to Garg and Prakash [1], a flat-plat solar collector consists of two main parts, i.e. a flat plate absorbing the heat and tubes or passages of the fluids. The plate absorbs most of the heat and transfer to the fluid flowing in passages or tubes. For a solar water heater, water is circulated from the insulated storage tank to the collector via the tubes. The top of the collector is covered with clear glass to trap the incoming electromagnetic waves reflected by the plate absorber. Cross section of a flat plat collector is shown in figure 1.

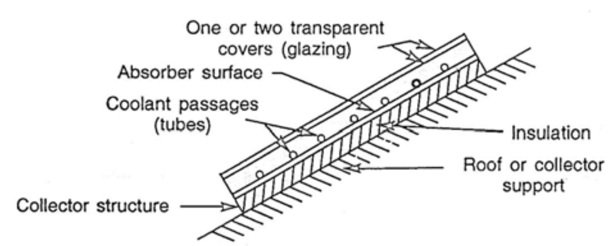



Figure 1. Cross section of a flat plat solar collector
Source: H.P. Garg & J. Prakash, *Solar Energy Fundamental and Applications* (New Delhi: Tata McGraw-Hill Publishing Company Limited, 1997) p. 47.

The temperature difference of the fluid flowing in and out of the collector shows the rate of heat radiation absorbed by the fluid as it flows across the collector. The flow rate of the fluid across the collector is hard to be measured. Yet, it is possible to measure the time needed to heat up the fluid in the storage tank. The longer the time needed, the smaller the flow rate of the fluid across the collector. These two are the collector's performance.

To design a flat-plate solar collector, some parameters need to be determined are its dimension, the tube spacing, the tube diameter, the thickness of the absorber plate, the insulation, the angle of collector to horizontal, the glass cover and the tube arrangement.

According to Duffie and Beckman [2], the general tube arrangements for a flat plate collector with a flat cover are as shown in figure 2. The difference of these arrangements is in expressing the collector efficiency factor, F'.

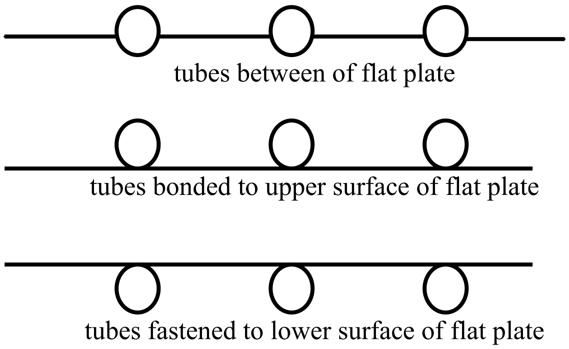



Figure 2. Tube arrangement and the plate absorber

The collector efficiency factors for each arrangement are:

$$F' = \frac{1}{\frac{WU_L}{\pi D h_{f,i}} + \frac{W}{D + (W-D)F}} \qquad \text{for figure 2.a}$$

$$F' = \frac{1}{\frac{WU_L}{\pi D h_{f,i}} + \frac{1}{\frac{D}{W} + \frac{1}{\frac{WU_L}{C_{bond}} + \frac{W}{(W-D)F}}}} \qquad \text{for figure 2.b}$$

$$F' = \frac{1}{\frac{WU_L}{\pi D h_{f,i}} + \frac{WU_L}{C_{bond}} + \frac{W}{D + (W-D)F}} \qquad \text{for figure 2.c}$$

where W is the tube spacing, $U_L$ is overall loss coefficient, D is tube diameter, $h_{f,i}$ is heat transfer coefficient inside the tubes, $C_{bond}$ is the bond conductance which depends on the bond thermal conductivity, and F is the fin efficiency.

When the bond conductance is very large, as usually assumed especially when copper are used for the tubes and plate, then the F' will have the same expression for the three arrangements. Thus, a research to find the effect of the arrangement is necessary.

The hypothesis for the research as followed: The tubes arranged above of the plate or between of the plate, as in figure 2.a and 2.b, will receive heat radiation directly from the sun. While the tube arranged below of the plate, as in figure 2.c get heat conduction transferred from the plate. The heat absorbed by the working fluid in tubes placed between of and above of the plate is much more than in tubes placed below of the plate. On the other hand, the tubes below of the plate emit less heat loss caused by convection to the surrounding. It is important and interesting to find out whether the larger absorbed area or the heat loss to surrounding that is more dominant for a flat-plate solar water heater.

Thus, the purpose of the research is to find out the effect of the tube arrangement to the temperature difference of the water flowing at the inlet and outlet of the collector and its flow rate as well. This result will be useful to improve a flat-plat solar water heater design.

Some previous works in Indonesia are adopted in this research. Kiem San [3] affirmed that the best result was when he used the 0.5-mm plate with 103-mm tube distance.

Purnawarman [4] declared that the best glass cover was 3-mm clear glass used with 2-cm space between the glass and the plate. The glass cover is used to shield the absorber plate and tubes from the surroundings and to trap the radiation reflected by the plate to create the greenhouse effect inside the collector.

The angle and orientation of the solar collector installed in certain location affect the collector performance. From his research, Mintorogo [5] said that in Surabaya which is located at $7^{o}17'$-21' South Latitude, the collector will receive the highest average solar radiation when the collector is installed with angels tilted 30 degrees and orientation to the north.

## 2. Research Methodology

The research was started with designing three model collectors for heating water using the previous works. The models are made of same material and dimension with three tube arrangements as shown in figure 2. The difference was only on the tube arrangement. Having three models, the experiment could be conducted simultaneously.

### 2.1 Design of the model collector

From the previous works, the model was designed as in figure 3 with following condition:

- The collector box is made of 2-cm wood.
- The insulation used in the bottom of collector is 4-mm Styrofoam and on the outside of the storage tank is 25-mm glass wool covered with aluminum foil.
- The glass cover on the top of the collector is made of 3-mm clear glass and placed 2 cm above the plate.
- The water to be heated is stored in a 1.5-litre plastic tank.
- The tubes are made of copper pipe which diameter is 0.5 inches.
- The absorber plate is made of 0.5-mm copper plate with tubes spacing is 103 mm.

The collector's plan of view is shown in figure 4.
Then, the three models were built as seen in figure 5.

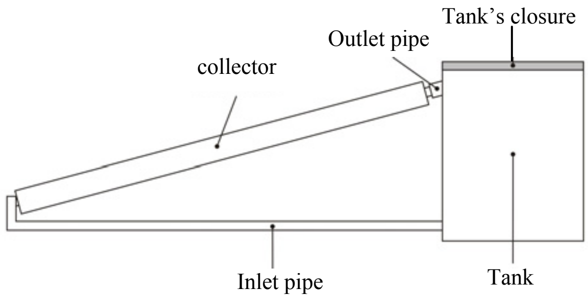


Figure 3. The model of collector

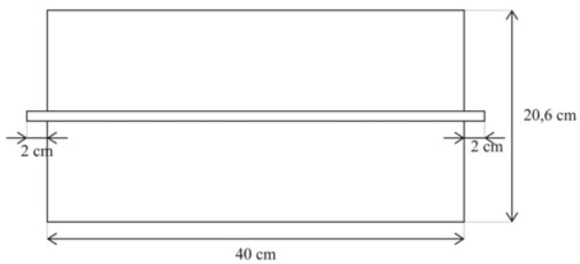


Figure 4. Plan of view the model collector

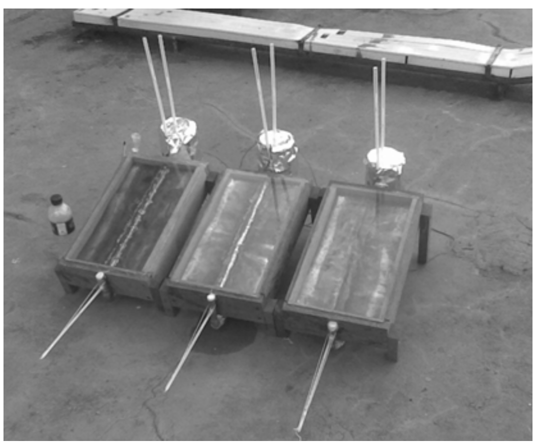


Figure 5. The photograph of three models.

## 2.2 The experiment

The experiments were conducted on 31 January, 25 February, 27 February, and 28 February, 2008 at Petra Christian University campus on Surabaya, Indonesia. For the three models as in figure 5, the data taken every 30 minutes were:

- The temperature of ambient air and its wind velocity,
- The temperature of the absorber plate,
- The temperature of water at the inlet and outlet pipes,
- The temperature of water in the storage tank.

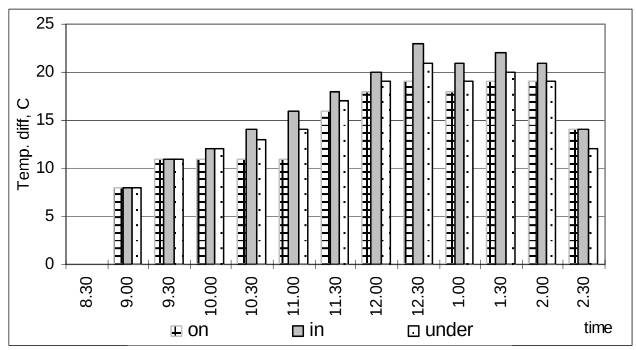
The data is written in the table. Actually, the table includes all three tube arrangements. Since the column in this paper is too narrow, the table 1 only shows for tube placed 'on' the flat plate.

Table 1
Data for tube placed 'on' above of flat plate

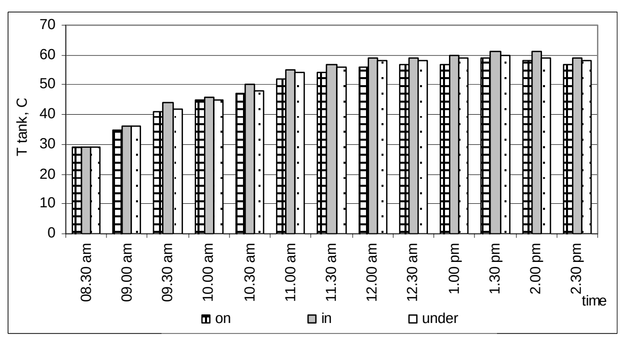
| time | Tube 'on' plate ($^0$C) | | | | $T_\infty$ $^0$C | Wind velocity ( m/s) | Weather |
|---|---|---|---|---|---|---|---|
| | Tank | In | Out | Plate | | | |
| 8.30 | | | | | | | Clear/cloudy |
| 9.00 | | | | | | | |
| … | | | | | | | |
| 14.30 | | | | | | | |

## 3. The result and analysis

The temperature difference of water at inlet and outlet of collector resulted from experiment done on 31 January 2008 is shown in figure 6.a and the temperature of water in the storage tank is shown in figure 6.b. The ambient temperature when the experiment was conducted was 29$^o$C in the morning and changed to reach 34$^o$C in 12.30 and decreased to 31$^o$C at 2.30 pm. The wind's velocity was between 0.3 m/s – 2.1 m/s. On the day of the experiment, the wind blew harder in the morning.



The temperature difference of water at inlet and outlet of collector



The temperature of water in the tank

Figure 6. The result of experiment done on 31 January 2008

The experiments done on the other dates showed the same phenomenon as happened on 31 January 2008. So, the result shown in figure 6 could represent the result on other days.

In a few words, the results are:

- The highest temperature difference of water flowing in and out of the collector is found in tubes placed between of the plate as shown in figure 2.a.
- The highest temperature of water in the storage tank is found in collector which tubes placed between of the plate as well.

From figure 6.a, it was found that the temperature difference of the water as it flows in and out of the collector at 8.30am was zero and it increased until reach a maximum value but then decreased. The experiment was stopped at 2.30 pm because the sky was getting to be cloudy. In Indonesia, January – February is wet season. The temperature difference at 12.30 pm could reach 23C$^o$ for collector with tubes placed 'in' (= between of) the plate while the other tube arrangements only reach 19C$^o$ and 21C$^o$ for 'on' (= above of) the plate and 'under' (= below of) the plate, respectively. Thus, tubes placed between of the plate gave a better temperature difference.

From figure 6.b, it was found that for all arrangements the temperature of water stored in the tank reached 50$^o$C at 11am. Thus, the collector heated 1.5-litre water in 2.5 hours though it was cloudy. From the chart, it is obvious that the tubes placed 'in' the plate made water stored in the tank get higher temperature than the other tube's arrangements.

Tubes placed between of the plate, as in figure 2.a, gave higher temperature difference of water flowing in it and higher temperature of water stored in the tank than the other arrangement. Why could this happen? The explanations are as followed.

Water flowing inside the tubes placed 'under' the plate, as shown in figure 2.c got heat transferred only by conduction from the plate which behaves as fin. Thus, the heat received by the water in this arrangement was less than the other arrangements. Yet, the tube below of the plate made water gives least heat loss to surrounding. This could be seen from chart in figure 6.a. The temperature difference of water flowing in tubes 'under' the plate was higher than tubes 'on' (= above of) the plate in the morning when the wind blew harder (means more heat loss to surrounding) and the sky was cloudy (means less solar radiant received). So, when solar radiation was low and the wind blows fast, tubes placed below of the plate gives better temperature difference than tubes placed above of the plate.

The water flowing inside the tubes placed 'on' and 'in' the plate receives heat more by conduction through the plate, by radiation from the sun, and by convection of the air trapped inside the collector. Thus, collectors which tubes placed above of and between of the plate get more heat. There is a temperature difference between the surrounding and the collector, including the water in the tube. This temperature difference drives heat loss from collector to the surrounding, even though glass cover is put on the top to restrict the heat loss. The tubes placed 'on' the plate are bare tubes compared to the ones 'under' the plate that are enclosed with insulation. So, when the surrounding is colder or cloudy and the wind blow harder, the tubes placed 'on' the plate gives the lowest temperature difference. Yet, the tubes placed 'in' the plate emit moderate heat loss and get more heat.

The temperature difference of water affects its circulation from the collector to the storage tank. Water flows from the tank to the collector by gravity and moves up to the tank by free convection. In free convection, fluid motion is due to buoyancy force which depends on the fluid density gradient. The higher the temperature difference, the higher the density gradient and the easier for water to move up back to the tank. Thus, it means the higher the flow rate. The flow rate of water flowing in the collector could not be measured in this experiment. Yet, the temperature of the water in the tank could be a parameter showing the flow rate of the water. When the temperature of the water in the tank rises faster and higher, it indicates that the water flow rate in collector is high.

## 4. Conclusion

From the experiments conducted on three flat plate solar water heater models, the conclusions are:

- Tubes placed below of the flat plate are suitable for a cloudy and windy surrounding.
- Tubes placed above of the flat plate are suitable for locations that are sunny and still air.
- Tubes placed between of the flat plate gives the best performance, i.e. the highest temperature of water stored in the tank (means highest flow rate) and the highest temperature difference of water flowing in and out of the collector. This arrangement is suitable for any weather.

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## References

[1] H. P. Garg, and J. Prakash, *Solar energy: Fundamental and applications* (New Delhi: Tata McGraw-Hill Publishing Company Limited, 1997).

[2] John A. Duffie, and William A. Beckman, *Solar engineering of thermal process* (2$^{nd}$ Ed) (New York: John Willey & sons, Inc., 1991).

[3] Yoe Kiem San, Pengaruh tebal plat dan jarak antar pipa terhadap performansi kolektor surya plat datar, *Jurnal Teknik Mesin*, *3(2),* October 2001, 5-12.

[4] Heru Purnawarman, *Pengaruh jumlah kaca dan jarak kaca terhadap temperatur plat solar kolektor*. (TA No: 01.54.43). Universitas Kristen Petra, Surabaya, 2001).
[5] Danny S. Mintorogo, Surabaya's solar radiation preferences to design: building façade, solar hot water heater, and photovoltaic. Sub Theme 2: Sustainability in Architecture & Technology, *Proc. 8th SENVAR & 2ND MALAY Architecture Conference*, Surabaya, Indonesia, 2007, 2.118-2.123.