

**ARTIFICIAL NEURAL NETWORK (ANN)  
MODELLING FOR PHOTOVOLTAIC THERMAL  
(PVT) COLLECTOR WITH DIFFERENT BASE  
MATERIALS**

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**INDIAN INSTITUTE OF TECHNOLOGY DELHI**

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FOR PHOTOVOLTAIC THERMAL (PVT) COLLECTOR  
WITH DIFFERENT BASE MATERIALS**

*by*

**HOOR FATIMA**

**Centre for Energy Studies**

*Submitted*

*in fulfillment of the requirements of the degree of Doctor of Philosophy*

*to the*



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## Certificate

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This is to certify that the thesis entitled “**Artificial Neural Network (ANN) Modelling for Photovoltaic Thermal (PVT) Collector with Different Base Materials**”, being submitted by Hoor Fatima to the Indian Institute of Technology Delhi, is worthy of consideration for the award of the degree of **‘Doctor of Philosophy’** and is a record of the original bona fide research work carried out by her under our guidance and supervision. The results contained in the thesis have not been submitted in part or full, to any other University or Institute for the award of any degree or diploma.



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**Date:**

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## Abstract

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In the present thesis, the performance of conducting (copper/aluminium) base photovoltaic thermal (PVT) collector have been analyzed on the annual basis. Different base material for a PVT module has been studied in order to find the suitable base for the PVT module. The electrical performance of glass, tedlar (Te), copper/aluminium (Cu/Al) base PV module have been analyzed. Based on the electrical performance, it has been observed that glass base PV modules gives better performance due to low operating temperature. Effect of mass flow rate on the performance copper/aluminium (Cu/Al) base PVT water collector has also been studied. Based on the numerical computation, it has been found that glass and copper/aluminium (Cu/Al) base PVT gives similar performance at mass flow rate of 0.017 kg/sec. The thermal and exergy efficiency of copper/aluminium (Cu/Al) base PVT collector will be 61.05% and 13.35% considering the climatic conditions of New Delhi. The Cu/Al base PVT water collector produced 785.05kWh of thermal energy and 106.67kWh of exergy annually.

The mathematical model based on energy balance equations of the conducting (Cu) base photovoltaic thermal (PVT) water heating system has been developed. An analytical expression for storage water, outlet water from PVT collector and solar cell temperatures has been derived as a function of climatic and design parameters. The developed thermal model has been validated for experimental work carried for the climatic condition of Chennai, India. Further, the instantaneous thermal energy efficiency is also known as a characteristic equation, temperature dependent electrical efficiency, overall thermal and exergy efficiencies have been derived. A fair agreement has been observed between the experimental and theoretical storage water temperature with glazing presenting correlation coefficient ( $r$ ) of 0.999 and mean square error ( $e$ ) of 7.48%. It has also been observed that the maximum overall thermal and exergy efficiency obtained are 33.75% and 14.71% respectively.

The process for water withdrawal from a photovoltaic-thermal compound parabolic concentrator (PVT-CPC) water heating system forms a crucial component in the overall development of an efficient heat management system. In this regard, three different modes of operation of an aluminium based PVT-CPC water heating system are envisaged, which include operating the Al base PVT heating system without any water withdrawal and/or in continuous or intermittent water withdrawal process. Indeed, depending on the process of withdrawal of water from the PVT-CPC, the application may also change and the processes itself may show different levels of the overall gain in thermal and electrical energy. Using a theoretical modelling approach, this study is focused on studying such gains in an Al base PVT-CPC system operated with the arrangements for water withdrawal. In order to have a realistic assessment of the energy and exergy analysis of the system under study, climatic conditions in New Delhi, India are chosen as a reference point for the implementation of the PVT-CPC water withdrawal process. From the overall performance analysis of the PVT systems with the three different water withdrawal processes under study, it is concluded that the continuous water withdrawal process may be best suited for heating large water reservoirs such as in swimming pools. In contrast, the intermittent water withdrawal process is observed to be best suited for smaller scale water heating applications such as in bathing, washing, laundry, cooking and domestic utilities.

Further, the comparative analysis of the two copper (Cu) base PVT and the aluminum (Al) base PVT-CPC collector have been performed using the Artificial Neural Network (ANN) model. The network has been trained using the data from four weather stations Bangalore, Mumbai, and Srinagar and Jodhpur cities and tested for the climatic conditions of New Delhi, India. The performance parameters observed from the ANN model has been compared with the result obtained from the analytical study. The ANN model is based on the feed-forward back propagation algorithm with 2 hidden layers. The Levenberg–Marquardt (LM) with 10 neurons

in the hidden layer, 3 neurons in the input layer and 5 neurons in the output layers is the most suitable algorithm. There is a fair agreement shown between the predicted value of an ANN model and the analytical results. Further, it is observed that it is advantageous to use ANN models over the traditional methods of calculations due to its speed, simplicity and ability to learn from examples.



## सार

वर्तमान थीसिस में, वार्षिक आधार पर कंडक्टर (कॉपर / एल्यूमीनियम) बेस फोटोवोल्टिक थर्मल (PVT) कलेक्टर के प्रदर्शन का विश्लेषण किया गया है। पीवीटी मॉड्यूल के लिए उपयुक्त आधार खोजने के लिए एक पीवीटी मॉड्यूल के लिए विभिन्न आधार सामग्री का अध्ययन किया गया है। ग्लास, टेलर (Te), कॉपर / एल्युमिनियम (Cu / Al) बेस PV मॉड्यूल के विद्युत प्रदर्शन का विश्लेषण किया गया है। विद्युत प्रदर्शन के आधार पर, यह देखा गया है कि ग्लास बेस पीवी मॉड्यूल कम ऑपरेटिंग तापमान के कारण बेहतर प्रदर्शन देता है। प्रदर्शन तांबा / एल्यूमीनियम (Cu / Al) बेस PVT वाटर कलेक्टर पर द्रव्यमान प्रवाह दर के प्रभाव का भी अध्ययन किया गया है। संख्यात्मक अभिकलन के आधार पर, यह पाया गया है कि ग्लास और तांबा / एल्यूमीनियम (Cu / Al) बेस PVT 0.017 किग्रा / सेकंड के द्रव्यमान प्रवाह दर पर समान प्रदर्शन देता है। तांबा / एल्यूमीनियम (Cu / Al) बेस PVT कलेक्टर की तापीय और बाहरी दक्षता नई दिल्ली की जलवायु परिस्थितियों को देखते हुए 61.05% और 13.35% होगी। Cu / Al बेस PVT वाटर कलेक्टर ने 785.05kWh की तापीय ऊर्जा और 106.67kWh प्रतिवर्ष का उत्पादन किया।

गणितीय ऊर्जा का संचालन (घन) आधार फोटोवोल्टिक थर्मल (PVT) जल तापन प्रणाली के ऊर्जा संतुलन समीकरणों पर आधारित है। भंडारण पानी के लिए एक विश्लेषणात्मक अभिव्यक्ति, पीवीटी कलेक्टर और सौर सेल तापमान से आउटलेट पानी को जलवायु और डिजाइन मापदंडों के एक समारोह के रूप में व्युत्पन्न किया गया है। विकसित थर्मल मॉडल को चेन्नई, भारत की जलवायु स्थिति के लिए किए गए प्रयोगात्मक कार्यों के लिए मान्य किया गया है। इसके अलावा, तात्कालिक थर्मल ऊर्जा दक्षता को एक विशेषता समीकरण के रूप में भी जाना जाता है, तापमान पर निर्भर विद्युत दक्षता, समग्र थर्मल और एगजॉस्ट एफिशिएंसी व्युत्पन्न की गई है। प्रयोगात्मक और सैद्धांतिक भंडारण पानी के तापमान के बीच 0.999 के ग्लेज़िंग प्रस्तुत सहसंबंध गुणांक (आर) और 7.48% का मतलब वर्ग त्रुटि (ई) के साथ एक उचित समझौता देखा गया है। यह भी देखा गया है कि प्राप्त अधिकतम समग्र तापीय और पादरी दक्षता क्रमशः 33.75% और 14.71% है।

फोटोवोल्टिक-थर्मल कंपाउंड परवलयिक सांद्रता (PVT-CPC) जल तापन प्रणाली से पानी की निकासी की प्रक्रिया एक कुशल ताप प्रबंधन प्रणाली के समग्र विकास में एक महत्वपूर्ण घटक है। इस संबंध में, एल्यूमीनियम आधारित पीवीटी-सीपीसी जल तापन प्रणाली के तीन अलग-अलग तरीकों की परिकल्पना की गई है, जिसमें अल बेस पीवीटी ताप प्रणाली का संचालन बिना किसी जल निकासी और / या निरंतर या रुक-रुक कर जल निकासी प्रक्रिया में शामिल है। दरअसल, पीवीटी-सीपीसी से पानी की निकासी की प्रक्रिया पर निर्भर करता है।

आवेदन भी बदल सकता है और प्रक्रियाएं थर्मल और विद्युत ऊर्जा में समग्र लाभ के विभिन्न स्तरों को दिखा सकती हैं। सैद्धांतिक मॉडलिंग दृष्टिकोण का उपयोग करते हुए, यह अध्ययन पानी के निकासी की व्यवस्था के साथ संचालित एक अल बेस PVT-CPC प्रणाली में इस तरह के

लाभ का अध्ययन करने पर केंद्रित है। नई दिल्ली में अध्ययन के तहत प्रणाली की ऊर्जा और बाहरी विश्लेषण का यथार्थवादी आकलन करने के लिए, भारत को पीवीटी-सीपीसी जल निकासी प्रक्रिया के कार्यान्वयन के लिए एक संदर्भ बिंदु के रूप में चुना जाता है। अध्ययन के तहत तीन अलग-अलग पानी निकासी प्रक्रियाओं के साथ पीवीटी सिस्टम के समग्र प्रदर्शन विश्लेषण से, यह निष्कर्ष निकाला गया है कि बड़े पानी के जलाशयों जैसे कि स्विमिंग पूल में हीटिंग के लिए निरंतर पानी निकासी की प्रक्रिया सबसे उपयुक्त हो सकती है। इसके विपरीत, छोटे पानी के ताप अनुप्रयोगों जैसे स्नान, धुलाई, कपड़े धोने, खाना पकाने और घरेलू उपयोगिताओं के लिए आंतरायिक जल निकासी प्रक्रिया को सबसे उपयुक्त माना जाता है।

इसके अलावा, आर्टिफिशियल न्यूरल नेटवर्क (ANN) मॉडल का उपयोग करके दो कॉपर (Cu) बेस PVT और एल्युमीनियम (Al) बेस PVT-CPC कलेक्टर का तुलनात्मक विश्लेषण किया गया है। नेटवर्क को चार मौसम स्टेशनों बेंगलूर, मुंबई और श्रीनगर और जोधपुर शहरों से डेटा का उपयोग करके प्रशिक्षित किया गया है और नई दिल्ली, भारत की जलवायु परिस्थितियों के लिए परीक्षण किया गया है। ANN मॉडल से देखे गए प्रदर्शन मापदंडों की तुलना विश्लेषणात्मक अध्ययन से प्राप्त परिणाम से की गई है। एएनएन मॉडल 2 छिपे हुए परतों के साथ फीड-फॉरवर्ड बैक प्रोपोगेशन एल्गोरिदम पर आधारित है। छिपी हुई परत में 10 न्यूरॉन्स के साथ लेवेनबर्ग-माक्वर्ट (एलएम), इनपुट परत में 3 न्यूरॉन्स और आउटपुट परतों में 5 न्यूरॉन्स सबसे उपयुक्त एल्गोरिदम है। एक ANN मॉडल के अनुमानित मूल्य और विश्लेषणात्मक परिणामों के बीच एक उचित समझौता दिखाया गया है। इसके अलावा, यह देखा गया है कि इसकी गति, सरलता और उदाहरणों से सीखने की क्षमता के कारण गणना के पारंपरिक तरीकों पर ANN मॉडल का उपयोग करना फायदेमंद है।

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## Nomenclatures

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$A$	Area, m <sup>2</sup>
$b$	Width, m
$C_f$	Specific heat of air, J/kg K
$dt$	Elemental time, s
$dx$	Elemental length, m
$\dot{E}x$	Exergy, kWh
$F_R$	Heat removal factor
$h_i$	Heat transfer coefficient from solar cell to flowing air, W/m <sup>2</sup> K
$h_o$	Heat transfer coefficient from solar cell to ambient through glass cover, W/m <sup>2</sup> K
$I_t$	Incident solar intensity, W/m <sup>2</sup>
$I_b$	Beam solar intensity, W/m <sup>2</sup>
$I_d$	Diffuse solar intensity, W/m <sup>2</sup>
$K$	Thermal conductivity, W/m K
$L$	Length, m
$\dot{m}_f$	Mass flow rate of fluid, kg/s
$M_w$	Mass of fluid, kg
$\dot{Q}_u$	Useful heat, W
$t$	Time, s
$T$	Temperature, K
$\bar{T}$	Average temperature, K
$U_{b,fa}$	Overall heat loss coefficient from flowing fluid to ambient, W/m <sup>2</sup> °C

- $U_L$  Overall heat transfer coefficient for the system,  $W/m^2\text{ }^\circ\text{C}$
- $U_{t,c,a}$  Overall heat transfer coefficient from solar cell to ambient through glass cover,  $W/m^2\text{ }^\circ\text{C}$
- $U_{b,cpg}$  Overall heat transfer coefficient from bottom of the solar cell to absorbing plate through glass cover,  $W/m^2\text{ }^\circ\text{C}$
- $U_{b,cpt}$  Overall heat transfer coefficient from bottom of the solar cell to absorbing plate through tedlar,  $W/m^2\text{ }^\circ\text{C}$
- $U_{b,cp}$  Overall heat transfer coefficient from bottom of the solar cell to conducting (copper/aluminum) plate,  $W/m^2\text{ }^\circ\text{C}$
- $v$  velocity of air, m/s

### ***Subscripts***

- $a$  ambient
- $b$  base
- $c$  solar cell
- co copper
- al aluminium
- t tedlar
- I insulation
- g glass
- $eff$  effective
- $f$  fluid (air)
- $f_i$  inlet fluid
- $f_o$  outgoing fluid
- $g$  glass
- $ins$  insulation

$L$  length

$m$  module

$Te$  tedlar

***Greek letters***

$\alpha$  Absorptivity

$\beta$  Packing factor

$\beta_o$  Temperature coefficient of efficiency,  $K^{-1}$

$\eta_c$  Temperature dependent solar cell efficiency

$\eta_o$  Efficiency at standard test condition ( $I(t) = 1000 \text{ W/m}^2$ ,  $T_a = 25 \text{ }^\circ\text{C}$ )

$\tau$  Transmissivity

$\epsilon$  emissivity

$\rho$  Density,  $\text{kg/m}^3$

**Abbreviation**

ANN Artificial Neural Network

PVT Photovoltaic thermal

tCO<sub>2</sub>e Tons of CO<sub>2</sub> equivalent