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An Impact of Artificial Intelligence Control on Photovoltaic/Thermal (PVT) – Ground Source Heat Pump (GSHP) Hybrid System

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Abstract

Hybrid renewable energy utilization in residential and commercial building become an important issue in the world. IEA policy on renewable heat says that expanding the use of modern biomass, geothermal energy, solar energy and ambient energy to produce heat and power could contribute substantially to meet energy security objectives and mitigate climate change. Based on that background, in this study, two different renewable energy systems, which are photovoltaic/thermal (PVT) and ground source heat pump (GSHP) were combined together to produce heating, cooling and electricity simultaneously so-called tri-generation. This hybrid technology has been introduced and analyzed in terms of energy savings compared to the conventional system which uses a boiler and chiller to produce heating, cooling and electricity from the grid. For one house and one office, conventional system consumed 276.7kWh/m2-yr of energy and the combination of three renewable energy systems save the primary energy up to 97.9kWh/m2-yr or 35.4% energy reduction. An impact of Advance control system by using artificial neural network and fuzzy logic control system will be explained and analyze in order to achieve better energy savings. By these two techniques, it showed that for one single residential house, 11%-36% primary energy reduction by using ANN and 11%-23% primary energy reduction by using Fuzzy Logic control could be achieved.

Keywords: *artificial control system, ground source heat pump, photovoltaic/thermal, renewable energy, Trigeneration.*

1. Introduction

The urge of renewable energy utilization in the world become higher and higher as the new policy scenario of energy in the world published. The share of renewables in primary energy use in the New Policies Scenario rises to 18% in 2035, from 13% in 2011. This resulting from the rapidly increasing demand for modern renewables to generate power, produce heat and make transport fuels based on world energy outlook 2013[1]. Power generation from renewables increases by over 7000 TWh from 2011 to 2035, making up almost half of increase in total generation. Renewables become second-largest source of electricity before 2015 and approach coal as the primary source by 2035, with continued growth of hydropower and bioenergy, plus rapid expansion of wind and solar PV as shown in Fig.1.

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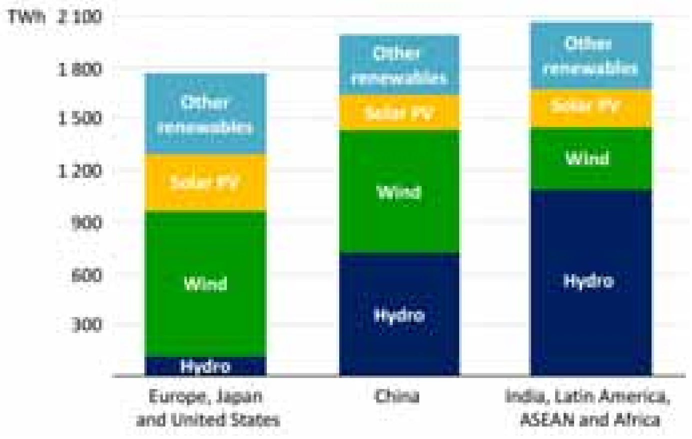

Fig. 1 Growth in electricity production from renewable sources 2011-2035[2]

Based on those background, utilization of renewable energy technologies will be explained not only one source of renewable energy but combination of two renewable energies will be covered and the impact of the advance control system on energy saving. Combination of Photovoltaic/Thermal or known as PVT and Ground Source Heat Pump (GSHP) or Geothermal Heat Pump have been chosen as the system that will be covered in this paper. Photovoltaic/Thermal or PVT is a combination of photovoltaic (PV) and solar thermal components/system which produce both electricity and heat from one integrated component system [3]. Typically, commercially available PV modules are only able to convert 6-18% of the incident radiation falling on them into electricity, with the remainder lost by reflection or as heat [4]. One of the characteristics of photovoltaic is that as the surface temperature of the panel goes up, the efficiency of the system itself decreasing [5]. Ground Source Heat Pump (GSHP) is one of the promising technologies for space heating and cooling applications A GSHP extracts heat energy stored below the ground during the winter for heating applications. As the ground temperature at which heat is absorbed is higher than the ambient temperature, the coefficient of performance of GSHP becomes higher than the system that would operate directly taking heat from the ambient which very low during winter [6]. As what have mentioned before, an impact of advance control system such as Artificial Neural Network and Fuzzy Logic will be analyzed here. Fuzzy logic is a logical system, which is an extension of multivalued logic. However, in a wider sense, fuzzy logic (FL) is almost synonymous with the theory of fuzzy sets, a theory that relates to classes to objects with unsharp boundaries in which membership is a matter of degree. On the other hand, ANN is a type of artificial intelligence that mimics the behavior of human brain and is famous for its robustness due to the use of a generalization technique instead of memorization. By using these two artificial intelligence control, an improvement in energy saving can be achieved. These two intelligence control were chosen because of their capability to deal with lots of dynamic variable of the systems.

2. System Modeling

Two renewable energy system was chosen as the subject of this study which is the combination of the PVT and GSHP system for the single residential house of 200m2 as its described on Fig. 2 and it's component on Table 1:

Table 1 Main Component of PVT-GSHP system

#	1	2	3	4	5	6	7	8	9	10
Main component	House/ Office	Fan coil unit	Main pump	GSHP	GSHP pump	GS-Tank pump	PVT pump	Solar-tank pump	Hot water tank	Cold water tank
Quantity	n/m	n+m	1	1	1	1	1	1	1	1

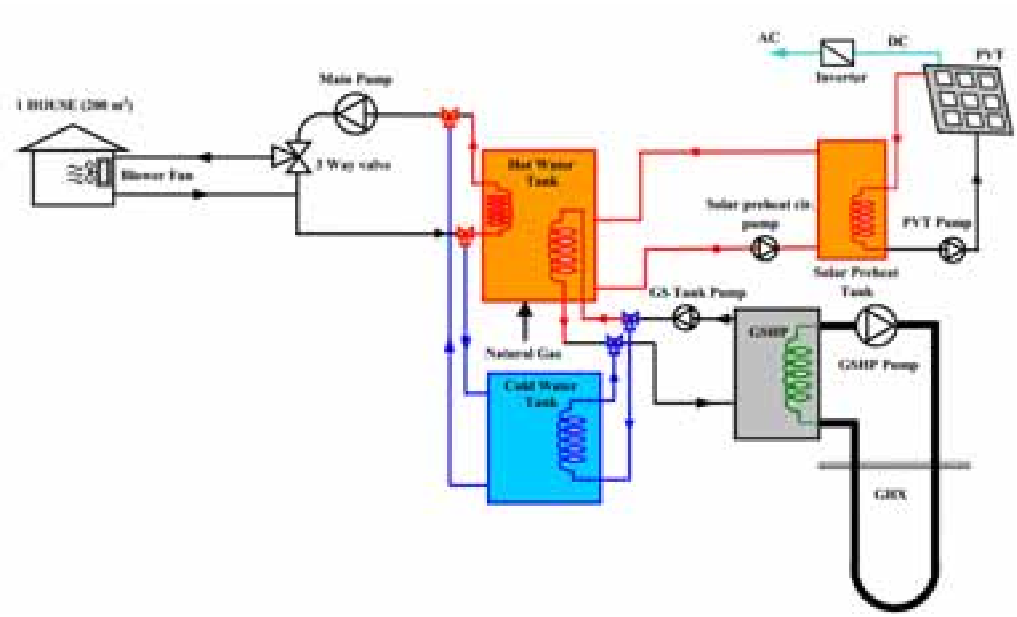

Fig.2 Schematic Diagram of PVT-GSHP system

GHSP system and PVT module that used on the simulation are based on the TRNSYS 17 library. Ground heat exchanger was modelled as a vertical, single U-tube heat exchanger that interacts thermally with the ground. Type 557 ground heat exchanger model was considered to be the state-of-the-art in dynamic simulation of ground heat exchanger and is most commonly used in ground heat exchanger application. It is a water-to water heat pump with 5 ton rated heating capacity and 2.5 ton rated cooling capacity. For the PVT part, TRNSYS17 provides three major model in the library which are Type 50, Type 555 and type 56(mode). All the models are largely theoretical based. These TRNSYS PVT models were reviewed under IEA, Solar Heating and Cooling Program, Task 35. The electrical output for PVT is 295W and the thermal output is 1.5kW

The simulation models were run in Incheon, South Korea weather data over a year to simulate and analyze the energy system's performance while satisfying the building heating and cooling demands. The control and management of microgeneration systems is very important for their optimal operation. Simple On-Off control strategy is often used, but its major disadvantage is not being able to allow part load operation of devices. The efficient operation of the microgeneration systems, especially for single dwellings, has the following attributes: nonlinear behavior uncertainties of electrical and thermal demands; and vagueness of the performance of the microgeneration system. Due to these attributes, an intelligent approach is required. Fuzzy Logic (FL) control approach was chosen because FL linguistic rules can simplify the control of the PVT-GHSP system given its complexity. MATLAB Fuzzy Logic Toolbox was used for the implementation of the FL controller and then integrated to the system models. Also another advance control system called Artificial Neural Network (ANN) will be implemented on this systems. Comparative study was conducted to see the impact of the artificial intelligence control to the possibility energy and cost savings compare to the conventional On-Off strategy.

3. METHODOLOGY

Two artificial control system were introduced (Fuzzy Logic and ANN). Fuzzy Logic system that applied on this study consist of two control strategies, FL for GSHP and FL for PVT.

The operation of the heat pump is controlled by two input variables: the storage tank temperature and the temperature difference between the actual room temperature and the thermostat set-point. The output of the fuzzy logic controller is the fractional state of operation of the ground source heat pump with a number ranging from 0 to 1 with 0 turning the device OFF and 1 representing full load operation. On the other side, the operation of PVT system is controlled by 2 input variables: the electrical demand and the temperature difference between panel and the bottom of the tank. The fuzzy logic if-then rules for GSHP and PVT control signal are presented in Table 2 and Table 3 for heating and cooling period respectively. The rules are chosen intuitively based on the research team's experiences.

Table 2 If then rules for GSHP operational state

Hot Water Storage Tank Temp.	dT=Troom-Tset				
	Lg Neg.	Sm Neg.	None	Sm Pos.	Lg Pos.
L	H	H	M	L	L
M	H	M	L	Off	Off
H	M	L	Off	Off	Off
VH	Off	Off	Off	Off	Off
Cold Water Storage Tank Temp.	dT=Troom-Tset				
	Lg Neg.	Sm Neg.	None	Sm Pos.	Lg Pos.
VL	Off	Off	Off	Off	Off
L	Off	Off	Off	L	M
M	Off	Off	L	M	H
H	L	L	M	H	H

Table 3 If then rules for PVT operational state

Electrical Demand	dTtank = Tpanel – Tbottom			
	Vlow	Low	Medium	High
L	Off	L	L	M
M	Off	L	M	H
H	Off	L	M	H

The control strategies using artificial neural network investigated in this study consist with 1 input layer with 11 inputs, 2 hidden layers with 20 neurons each and 1 output layer with 1 output as it described in Table 4. Matlab® Neural Network Toolbox was used to train and test the ANN models. The hyperbolic tangent sigmoid transfer function was used in the hidden layers and the linear transfer function was applied in the output layer because of the two-layer sigmoid/linear network usually can represent any functional relationship between inputs and outputs if the sigmoid later has enough neurons. The simulation was done for both heating and cooling season.

Table 4 ANN layers in PVT-GSHP system

1 Output	T_{room} (+3h)	T_{room} (+4h)	T_{room} (+5h)	T_{room} (+6h)
11 Inputs	Current ambient temperature			
	Ambient temperature 7.5 minutes before			
	Ambient temperature 3 hours later	Ambient temperature 4 hours later	Ambient temperature 5 hours later	Ambient temperature 6 hours later
	Current solar irradiance			
	Solar irradiance 7.5 minutes before			
	Solar irradiance 3 hours later	Solar irradiance 4 hours later	Solar irradiance 5 hours later	Solar irradiance 6 hours later
	Current internal gains			
	Internal gains 7.5 minutes before			
	Internal gains 3 hours later	Internal gains 4 hours later	Internal gains 5 hours later	Internal gains 6 hours later
	Current room temperature			
	Room temperature 7.5 minutes before			

The control algorithms were made based on the output variables on the ANN simulations for heating and cooling. 6 logics for heating and cooling were introduced in this control system as those can be seen in Table 5 and Table 6.

Table 5 ANN based control for heating period

		System components controlled by the ANNs based controller	Input variables used by the ANNs based controller	Condition to be satisfied	Output of ANN controller in case of the previous condition is satisfied
Heating period	ANN_LOGIC H1	Blower Fan, Main Pump	T_{room}(+3h), T_{room}(+4h), T_{room}(+5h), T_{room}(+6h)	At least 2 of T_{room}(+3h), T_{room}(+4h), T_{room}(+5h), T_{room}(+6h) greater than 21.5 °C	Blower Fan & Main Pump: OFF
	ANN_LOGIC H2	Blower Fan, Main Pump		At least 1 of T_{room}(+3h), T_{room}(+4h), T_{room}(+5h), T_{room}(+6h) greater than 21.5 °C	
	ANN_LOGIC H3	Blower Fan, Main Pump, GSHP, GSHP Pump, GS Tank Pump, Auxiliary heater	T_{room}(+3h), T_{room}(+4h), T_{room}(+5h), T_{room}(+6h), Hot Water Tank Temperature at levels 2 & 5		Blower Fan & Main Pump: OFF; GSHP & GSHP Pump & GS Tank Pump: ON if T2≤45 °C, OFF if T5≥50 °C; Auxiliary heater: ON if T2≤40 °C, OFF if T5≥45 °C
	ANN_LOGIC H4		T_{room}(+3h), T_{room}(+4h), T_{room}(+5h), T_{room}(+6h)		Blower Fan & Main Pump: OFF; GSHP & GSHP Pump & GS Tank Pump: OFF; Auxiliary heater: OFF
	ANN_LOGIC H5	Blower Fan, Main Pump, GSHP			Blower Fan & Main Pump: OFF; GSHP: operation at lower heating capacity (2 ton)
	ANN_LOGIC H6	GSHP			GSHP: operation at lower heating capacity (2 ton)

Table 6 ANN based control for cooling period

		System components controlled by the ANNs based controller	Input variables used by the ANNs based controller	Condition to be satisfied	Output of ANN controller in case of the previous condition is satisfied
Cooling period	ANN_LOGIC C1	Blower Fan, Main Pump	T_{room}(+3h), T_{room}(+4h), T_{room}(+5h), T_{room}(+6h)	At least 2 of T_{room}(+3h), T_{room}(+4h), T_{room}(+5h), T_{room}(+6h) lower than 20.5 °C	Blower Fan & Main Pump: OFF
	ANN_LOGIC C2	Blower Fan, Main Pump		At least 1 of T_{room}(+3h), T_{room}(+4h), T_{room}(+5h), T_{room}(+6h) lower than 20.5 °C	
	ANN_LOGIC C3	Blower Fan, Main Pump, GSHP, GSHP Pump, GS Tank Pump	T_{room}(+3h), T_{room}(+4h), T_{room}(+5h), T_{room}(+6h), Cold Water Tank Temperature at levels 2 & 9		Blower Fan & Main Pump: OFF; GSHP & GSHP Pump & GS Tank Pump: ON if T2≥15 °C, OFF if T9≤12 °C
	ANN_LOGIC C4		T_{room}(+3h), T_{room}(+4h), T_{room}(+5h), T_{room}(+6h)		Blower Fan & Main Pump: OFF; GSHP & GSHP Pump & GS Tank Pump: OFF;
	ANN_LOGIC C5	Blower Fan, Main Pump, GSHP			Blower Fan & Main Pump: OFF; GSHP: operation at lower cooling capacity (1.5 ton)
	ANN_LOGIC C6	GSHP			GSHP: operation at lower cooling capacity (1.5 ton)

On-off control strategy of GSHP is controlled by an aquastat in hot water and cold-water tank for both heating and cooling season. PVT panels that are controlled by on-off strategy, use the temperature difference between tank top and hot water storage tank bottom as the control variable. Table 7 and Table 8 describe the control strategy of on-off control system:

Table 7 On-off control strategy for GSHP

GSHP		Aux. heater	
ON	OFF	ON	OFF
T2(HT[b]) ≤ 50 °C T9(CT[b]) ≥ 12 °C	T8[a] (HT[b]) ≥ 55 °C T9[a] (CT[b]) ≤ 8 °C	T2(HT[b]) ≤ 45 °C	T8(HT[b]) ≥ 55 °C

[a] T2, T8, T9 are the temperature sensors in tank node 2, 8 and 9 respectively. Each storage tank is divided into 10 isothermal nodes, 1 at the tank top and 10 at the tank bottom.
[b] HT: hot water storage tank; CT: cold water storage tank (when GSHP in cooling mode operation).

Table 8 On-off control strategy for PVT

PVT circulation pump		Solar preheat tank circulation pump	
ON	OFF	ON	OFF
$\Delta T^a \geq 10$°C	$\Delta T^a \leq 3$°C	$\Delta T^b \geq 7$°C	$\Delta T^b \leq 2$°C

[a] ΔT is the temperature difference between the PVT panel and solar preheat tank bottom.
[b] ΔT is the temperature difference between the solar preheat tank top and hot water storage tank bottom.

4. RESULT AND DISCUSSION

The impact of artificial intelligence, fuzzy logic control and ANN control system on PVT-GSHP are explained below:

The result of the usage of fuzzy logic compared to the on-off control system for PVT-GSHP can be seen in Fig.7 and Fig. 8:

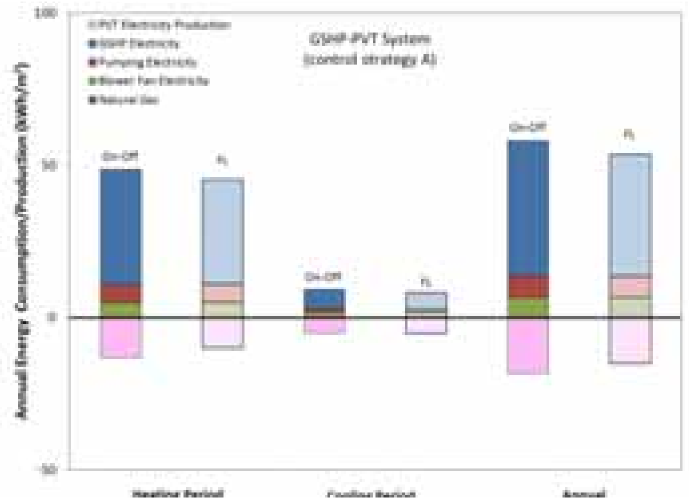

Fig. 7 (A) GSHP and PVT system with FL control

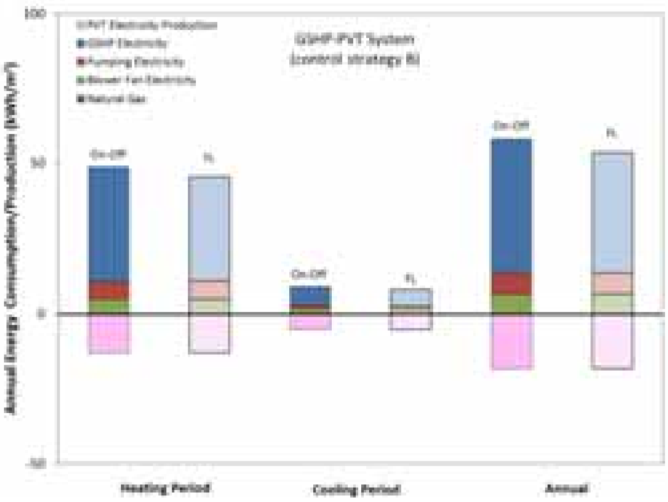

Fig. 8 (B) GSHP with FL control and PVT system with On-off control

The result shown in Fig. 7 and Fig. 8, indicate that the GSHP and blower fan electricity consumption are approximately the same and the pumping energy is slightly higher for the system with control strategy B. The main difference resulted from the two control for the PVT system resulted in higher electricity production, since all PVT panels are circulated with glycol fluid which reduces panel surface temperature and subsequently increases electric efficiency (production). Conversely, in the case of PVT system is controlled with FL strategy (strategy A), a fraction of total installed PVT panels is circulated with fluid to provide thermal energy depending on solar pre-heat tank temperature and electric demand. This causes the panel surface temperature and subsequently increases for PVT panels without circulation fluid and consequently reduces electric efficiency and overall electricity production.

In Artificial Neural Network Part, TRNSYS software is used for the system models development and the MATLAB® Neural Networks Toolbox is used for the implementation of the ANN controllers. The result shows that control logic H4, H5, C4 and C5 shows the best energy saving compared to the on-off control system among all the other control logic strategies. Fig. 9 shows the result of ANN control on PVT-GSHP system.

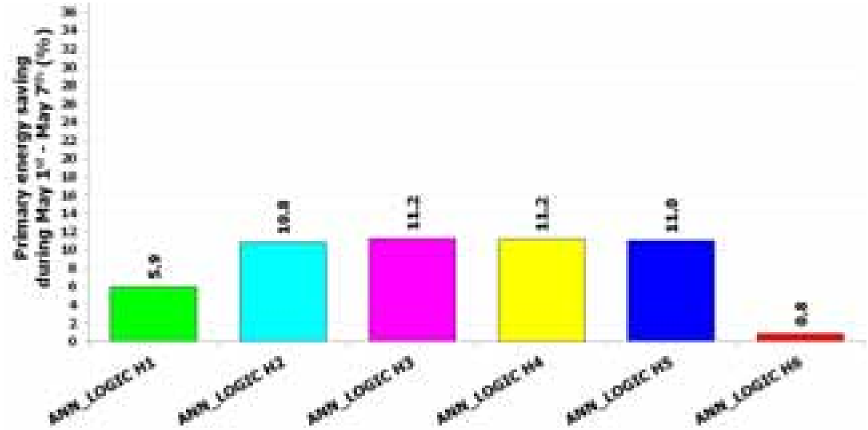

Fig. 9 Primary energy saving on ANN control during heating season

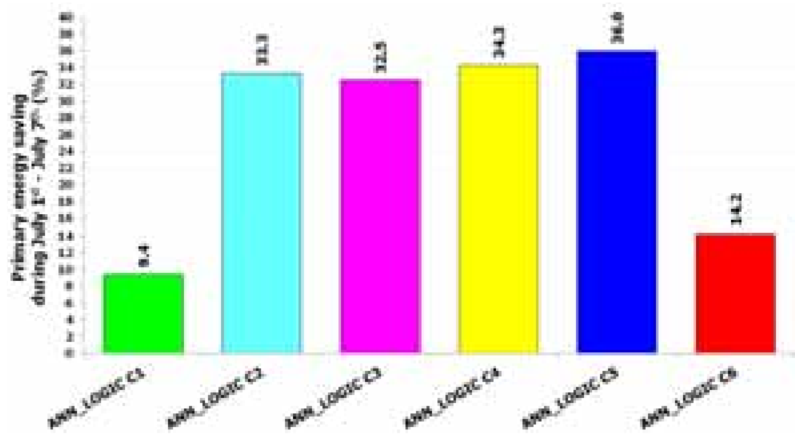

Fig. 10 Primary energy saving on ANN control during cooling season

The result show that the GSHP-PVT system with the ANN based strategies has low primary energy consumption if compared to the On-Off logic in particular, the strategies ANN_LOGIC H4 and ANN_LOGIC H5 result in approximately 11% total primary energy saving while ANN_LOGIC C4 and ANN_LOGIC C5 allow to reduce the primary energy consumption approximately 35% during a week.

5. Conclusion

In this study, as the main objectives, PVT-GSHP was developed, analyzed and optimized by using Fuzzy Logic control system, artificial neural network and on-off control system for application in residential buildings with 200m2 size. Energy consumption by utilize GSHP and PVT system analysis had been done on the previous research and showed a significant energy reduction. By using artificial intelligence control (fuzzy logic, artificial neural network and on-off control), system was calculated using TRNSYS 17 and MATLAB software and these are the conclusions:

- With the application of the FL control strategy and Artificial Neural Network instead of conventional On-Off control, the GSHP and GSHP-PVT systems are able to show a promising result in reduction of energy consumption in residential building with 200m2 size compared to the building (residential)

- Energy reduction of PVT-GSHP system while using fuzzy logic controller is quite significant for FL(A) is 15.8% and FL (B) with 18.3%. FL(B) strategy has the better energy reduction because of all the PVT works which reduce the surface panel temperature and increase the efficiency of the system.
- With the utilization of ANN control to the system, system could save energy up to 11% during heating period (May 1st – May 7th) and 36% during the cooling period (July 1st – July 7th)

It is expected that in future study, cost analysis also will be performed in the future research to see the effect of the system cost, fuel cost, control cost and also payback period of the system. Comparison with the another advance control systems also will be done to see the effect of Fuzzy Logic and ANN control compared to another control system such as PID controller. Also with the application of advanced control strategies and system optimization, a microgeneration system will be able to achieve further energy and cost savings.

6. ACKNOWLEDGEMENT

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7. REFERENCES

[1] IEA (International Energy Agency), 2013, World Energy Outlook 2013-Renewable energy outlook, OECD/IEA, Paris

[2] Van der Hoeven, Maria, 2013, World Energy Outlook 2013, London

[3] T.T. Chow, 2010, A Review on photovoltaic/thermal hybrid solar technology, Applied Energy, 87,365-379

[4] T.N. Anderson et al.,2009, Performance of a building integrated photovoltaic/thermal(BIPVT) solar collector, Solar Energy, 83,445-455

[5] L.R. Katherine, 2010, Photovoltaic Cell Efficiency at Elevated Temperatures, Massachusetts Institute of Technology, USA

[6] T Sivasakthivel, K Murugesan, PK. Sahoo, 2014, Optimization of ground heat exchanger parameters of ground source heat pump for space heating applications, Energy, 78,573-586

[7] Minister of Natural Resources Canada, 2001-2005, Clean Energy Project Analysis: RETScreen Engineering & Cases Textbook Ground-Source Heat Pump Project Analysis Chapter, Minister of Natural Resources, Canada