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Geothermal Energy Potentials and Technologies in Thailand

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Abstract

This paper presents a concept for using the geothermal energy in Thailand. The geophysical properties and the suitable technologies are considered; moreover the prototypes of the suitable technology have been constructed and tested the system performances. The potential of 97 hot springs in Thailand are classified into three groups as high, moderate and low potential. Organic rankine cycle is selected for 12 high potential hot springs to generate electricity 3,909 kWe. Absorption chiller and 8 moderate potential hot springs could be produced the total cooling capacity 304 kW and the payback period is 22 months. Central drying room and 8 moderate potential hot springs could be used in the heating process at 406 kW and the payback period is 15 months. Drying room integrated with vapor compression heat pump is represented for boosting 26 low potential hot springs. The upgrading heat around 2,002 kW could be used for drying the agricultural products 200 Ton/d which the payback period is 29 months. It could be found that the geothermal energy potential in Thailand could be developed from 46 hot springs to be used for heat and power at around 6.6 MW.

Keywords: Geothermal energy; Organic rankine cycle; Heat pump system; Drying room; Absorption chiller.

Introduction

Geothermal energy is one type of renewable energy which the Thailand government sets a geothermal policy to increase the power generation to be 1 MW in 2021. Department of Mineral Resources of Thailand [1] reports 112 hot springs in Thailand. In 2008, Chiang Mai University (CMU) [2] also reported 97 potential of hot springs in Thailand and classified them into three groups as high, moderate and low potential which is shown in Figure 1. For high potential hot spring, the surface water temperature is higher than 80°C. Moderate potential hot spring refers the surface water temperature between 60-80°C and low potential hot springs represents the surface water temperature is lower than 60°C. Thus, the aim of this research is to study the appropriate technologies for using geothermal energy in Thailand.

For technology to generate electricity, the various literatures are presented such as Chaiyat and Chaichana [3] reported using high temperature hot spring at higher than 90°C to generate the electricity by using a binary system and a thermoelectric module. Combs et al. [4] studied the small geothermal power plant in America and Japan at capacity around 100-1,000 kW. The technologies of the slim hole and binary-cycle technology were selected to use for the off-grid area. And, the environment affect from the geothermal power plant was lower than the fossil power plant which was similarly Brophy [5], Kose [6] and Dagdas [7]. For the simulation studies, the selection of suitable working fluids for the organic rankine cycle (ORC) system was the hot issue which had many reports to study this topic such as Hettiarachchi et al. [8], Schuster et al. [9], Guo [10], Sauret et al. [11], Liu et al. [12], Edrisi et al. [13], Li et al. [14], and Rodriguez et al. [15]. It was found that the suitable working fluid of those results were different because the system conditions of each study were different. But the most suitable working fluid of those studies introduced R-134a and R-245fa. In generating electricity process, the ORC system was compared with a Kalina cycle in term of efficiency. Guzovic et al. [16] studied the geothermal energy to power plant in Croatia. The high temperature hot spring at 175°C was supplied to binary system which of organic rankine cycle and kalina cycle. The simulated results shown the ORC cycle had a higher thermal efficiency and energy efficiency compared with the kalina cycle. Moreover, a low potential geothermal at hot water temperature around 61-80°C in China had studied by Aneke [17]. R-134a ORC system was chosen to produce electricity and the system efficiency was around 8.8%.

For the cooling technology, an absorption chiller is presented by various literatures. Kanoglu and Cengel [18] reported economic evaluation of geothermal power generation, heating, and cooling. It found that geothermal heating and geothermal absorption cooling were revenue higher than geothermal power generation about 3.1 times and 2.9 times, respectively. Kececiler et al. [19] simulated the absorption refrigeration cycle by using hot spring in Sivas, Turkey as heat source. The simulation results also shown that hot spring in Sivas did not be used efficiently in electricity generation. Kairouani and Nehdi [20] presented a novel combined refrigeration system which was absorption system cascaded with conventional compression system. The modified system increased the efficiency around 37-54% which was similarly the research of Ayala et al. [21], Seara et al. [22] and Kairouani and Nehdi [23].

For technique for drying process, Chaiyat and Chaichana [24] presented 2 types of drying processes which are a central drying room and a geothermal heat pump for drying room. The central drying room used hot spring to direct supplied into the drying room. For geothermal heat pump, a R-290 vapor compression heat pump for upgrading hot spring temperature around 40-50°C to be hot water around 70°C for using in the drying room. Heat pump dryer was found to be an effective equipment with low energy consumption as reported by Singharajwarapan and Chaiyat [25] which used low potential hot spring at temperature around 50°C to generate hot water temperature around 70°C for the drying room. Pendyala et al. [26], Chou et al. [27],

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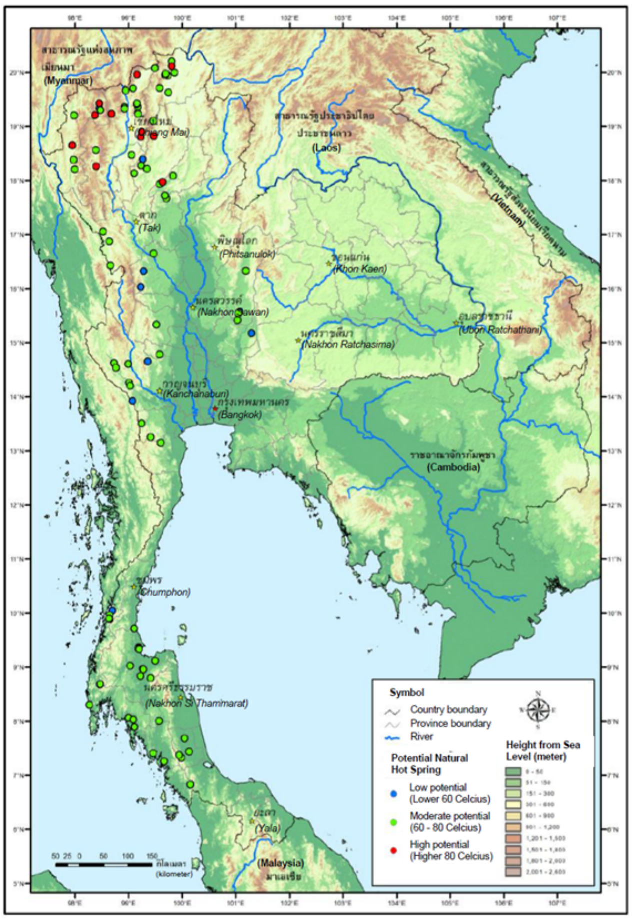

Figure 1: Location map of hot springs in Thailand.

Clements et al. [28], Young et al. [29] and Sadchang [30] also reported using single-stage vapor compression heat pump in the drying processes. Duddumpudi [31] presented CO_2 heat pump to generate hot water which reduced the severe environmental problems causing by synthetic refrigerants which corresponded with Stene [32] and Whitea [33].

From the literatures review, the various techniques are applied with hot spring. But, hot springs in Thailand are different with other geothermal resources. Thus, the main objective of this work is to study the suitable technique for using with each geothermal energy potential in Thailand. Moreover, the prototypes and case studies of each technique in Thailand are presented and tested for evaluating the system performances. And, the physical properties of hot springs in Thailand are used to analyze the appropriate technology of each geothermal energy potential.

System descriotions and equations

Figure 2 shows a cascade useful concept for geothermal energy as based on hot spring temperature. For high potential hot spring, the surface hot spring temperature at higher than 80°C is presented to generate electricity by oganic rankine cycle. For moderate potential at temperature between 60-80°C, the various technologies could be apply with the moderate hot spring temperature which are the absorption chiller for cooling process and an central drying room for drying process. For low potential hot spring, the vapor compression heat pump is combined with the drying room at surface hot spring temperature lower than 60°C. For the hot spring temperature lower than 60°C, the use in entertainment processes such as sauna and hot pool are introduced, after that, hot spring is leaved to the environment.

Organic rankine cycle

Figure 3 shows the main components of the ORC system which are boiler, turbine, generator, condenser and pump. In the conventional ORC, high temperature heat is absorbed at the boiler (QB) at temperature around 80-120°C which in this study is hot spring. After that the working fluid at the high pressure and temperature enters to the turbine (state 1) for producing the electricity at the generator (WTur). Next, the working fluid at the low pressure (state 2) is condensed at the condenser by cooling fluid at temperature around 30-40°C. The working fluid in liquid phase (state 3) is pumped to the boiler (state 4) and the new cycle is started again.

Absorption chiller

Absorption heat pump is one type of heat pump at using heat as the main energy which having 2 types are absorption chiller for cooling process and absorption heat transformer for boosting high temperature heat.

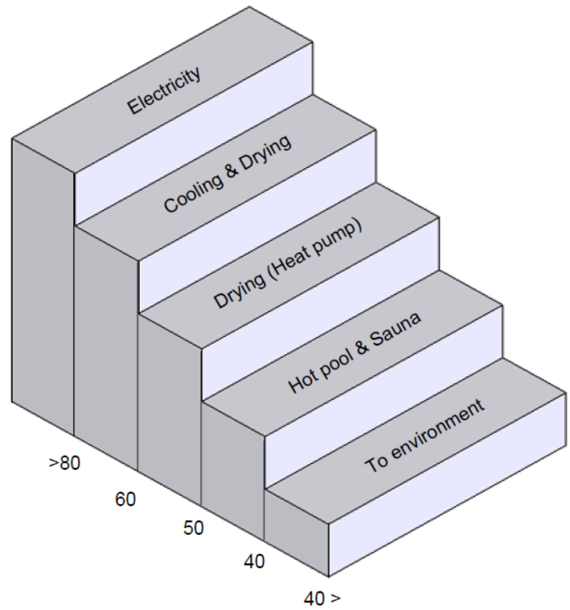

Figure 2: The concept of cascade useful for geothermal energy.

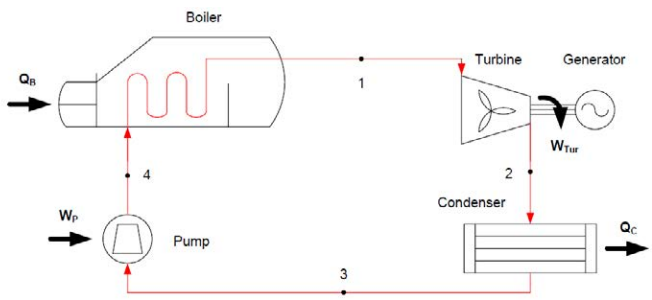

Figure 3: Schematic diagram of organic rankine cycle.

Figure 4 shows a schematic diagram of absorption chiller, at the generator, a binary liquid mixture consisting of a volatile component (absorbate) and a less volatile component (absorbent) is heated at a medium temperature around 80°C. Part of the absorbate boils at a high pressure (PC) and a generator temperature (TG) at state 1. The vapor fluid at concentration around 90% of absorbate is purified to be 100% of absorbate by analyzer and rectifier at state 2. The pure absorbate condenses in the condenser at a condenser temperature (TC) to be liquid at state 3. After that, the absorbate in liquid phase is throttled to the evaporator at state 4 of which an evaporator pressure (PE) is lower than that of the condenser. The evaporator is heated at a low temperature (TE) around 0-20°C and the absorbate in form of vapor enters the absorber which has the same pressure as the evaporator at state 5. Meanwhile, liquid mixture from the generator, at state 6 is sent through a solution heat exchanger at state 7 into the absorber to the low pressure at state 8 through expansion device. In the absorber, the strong solution absorbs the absorbate vapor and the weak solution leaves the absorber at state 9 at a medium temperature (TA) around 40-50°C which is same the condenser temperature (TC). The weak solution at state 9 from the absorber is then pumped to the high pressure through the solution heat exchanger at state 10 into the generator again at state 11 and new cycle restarts.

Drying room

A schematic diagram of geothermal drying room is shown Figure 5. Hot spring flows through a piping tube at point 1 to a heat exchanger at point 2. A blower at point 3 is used to drive low temperature air through the heat exchanger to be hot air at point 4. The high temperature heat is flowed to drying area, where agricultural products are contained at point 5. After that hot air transfers heat to the products, the air temperature will decrease while the air humidity will increase. For reducing the air humidity, the fresh air from outside is conducted to reduce the air humidity in the drying room via a small window at point 6 while the high humidity air is released to the ambient via a top duct at point 7.

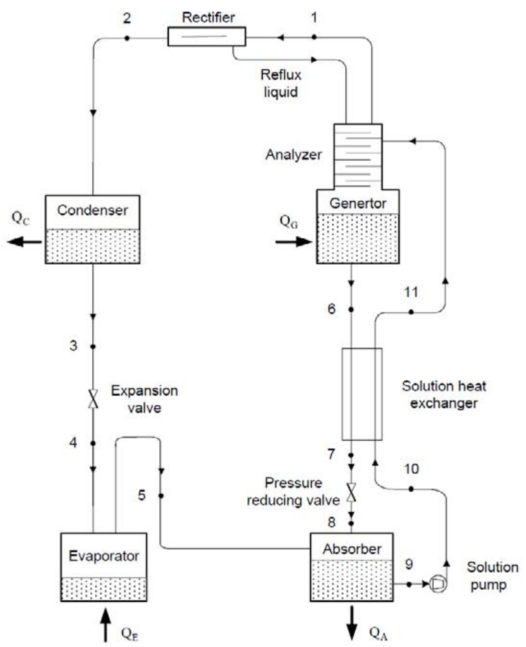

Figure 4: Schematic diagram of absorption chiller.

Vapor compression heat pump for drying room

A conventional technique to upgrade low temperature heat to a higher temperature level is heat pump system. The common method could be performed by vapor compression heat pump (VCHP) which the main components are compressor, condenser, evaporator and expansion valve as shown in Figure 6. The working fluid has a low boiling temperature. At state 1, the fluid in vapor phase is compressed in the compressor to state 2 and the vapor condenses in the condenser at a high pressure and temperature to be liquid at state 3. The liquid is then throttled to a low pressure at state 4 via the expansion device and the temperature drops down thus the fluid could absorb low temperature heat at the evaporator where the fluid boils at low temperature to be vapor again and the new cycle restarts.

Materials and Methods

Organic rankine cycle

For high potential geothermal energy, hot spring temperature at more than 80°C has been introduced to generate electricity. At the present, only one geothermal electricity is available in Thailand at Fang District, Chiang Mai Province. The technology used is organic rankine cycle with 300 kWe capacity of power plant as shown the descriptions in Table 1.

From Table 1, it could be found that the ORC power plant of Fang, Chiang Mai uses the reservoir heat source from 86 m of hot spring hole to generate electricity. Thus, in this study, the reservoir temperature will be evaluated by the geochemistry of surface hot spring. After that, the surface and reservoir temperature are used to find out the potential of geothermal power plant in Thailand combined with the system performance of Fang geothermal power plant.

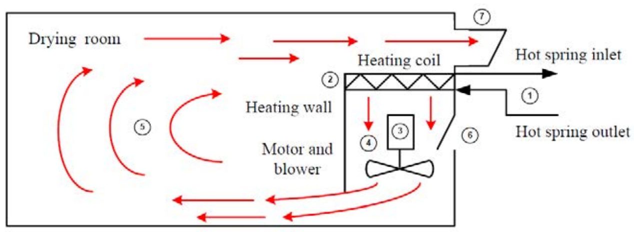

Figure 5: A schematic diagram of central drying room.

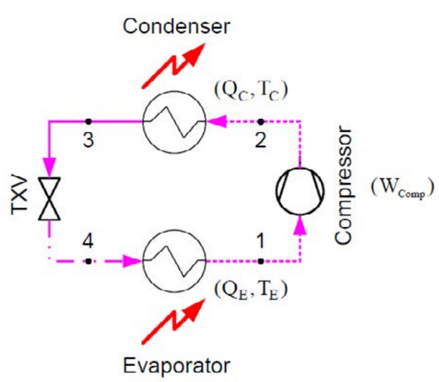

Figure 6: Schematic diagram of vapor compression heat pump.

Absorption chiller

For moderate potential geothermal energy, the hot spring temperature between 70-80ºC has been suggested to use in cooling process. The cooling unit in this study is absorption cooling system as shown a schematic diagram in Figure 4. A prototype of 10 kW ammonia-water absorption chiller is designed and constructed to freeze the agricultural products in a well- insulated room. Mae Jan hot spring, Chiang Rai, Thailand with having the hot spring temperature around 98ºC from 56 m of slim hole is used to test the cooling performance of the absorption chiller. The descriptions and photographs of the testing unit are shown in Table 2 and Figure 7, respectively. For the testing results, the geothermal energy potential will be presented with the absorption technique by the physical data of hot spring in Thailand.

Drying room

For moderate potential hot spring, the surface water temperature between 60-80ºC has been also suggested to use in drying process as shown the system descriptions in Figure 5. The geothermal drying room is developed to dry the agricultural products in a well-insulated room. Mae Jan hot spring, Chiang Rai, Thailand as shown in Figure 6(b) is also used to test the heating performance of drying system. The descriptions and photographs of the testing unit are shown in Table 3 and Figure 8, respectively. Finally, the testing results of prototype will be used to predict the guidelines of the geothermal drying room in Thailand.

Drying room by using single-stage vapor compression heat pump

For low potential hot spring, the surface water temperature lower than 60ºC has been used in drying process by using vapor compression heat pump (VCHP) to upgrade heat to be around 70°C and supply into drying room. The working steps of the drying room with heat pump system start with the hot water enters the system as shown in Figure 9. The hot water transfers heat to the working fluid, which evaporates accordingly. The resultant vapor is then pressurized by the compressor. After that, upgrading heat is extracted at the condenser and sent into heating coil in the drying room. The air inside the room is then heated by the heating coil.

The prototype of R-123 VCHP is set with the well-insulated testing room. Hot spring temperature around 55ºC from 85 m of slim hole, Huai Mak Liam hot spring, Chiang Rai, Thailand is used to test the integrated unit. The descriptions and prototypes of R-123 heat pump and testing room are shown in Table 4 and Figure 10, respectively.

Properties	Data
Operation system	Organic Rankine Cycle (ORC)
Working fluid	R-601a (Isopentane)
Hot spring flow rate[1] (L/s)	16.5 (75% of maximum flow rate)
Slim hole deep (m)	86
Hot spring temperature entering ORC (ºC)	115
Hot spring temperature leaving ORC (ºC)	77
Cooling water flow rate (L/s)	72.2
Cooling water temperature entering ORC (ºC)	20
Gross electrical power (kW_e)	300
Total electrical power (kW_e)	200

Table 1: Descriptions of Fang geothermal power plant [34].

Remark : 1Maximum hot spring flow rate is the reservoir flow rate which is around 10 times of the surface hot spring flow rate.

Devices	Type	Properties
Cold room	Isowall	· Thickness 3 in · Size 3.6 m x 3.6 m x 3 m
Generator	Flooded shell and tube heat exchanger	· Capacity 16 kW · Shell diameter 150 mm · Tube size 9.525 mm x 850 mm x 40 tube · Heating area 1.016 m^2
Analyzer	Steel column of analyzer	· Purified fluid to 99.95% of ammonia · Size 100 mm x 1,100 mm
Rectifier	Shell and tube heat exchanger	· Capacity 1 kW · Shell size 150 mm x 200 mm · Tube size 9.525 mm x 3,000 mm
Condenser	Plate heat exchanger	· Capacity 11.2 kW · Size 110 mm x 300 mm x 50 plate · Heating area 1.25 m^2
Receiver	Vertical type	· Volume 0.5 m^3
Evaporator	Fin and tube heat exchanger	· Capacity 11.2 kW · Heating area 1.25 m^2
Absorber	Shell and tube heat exchanger	· Capacity 15.3 kW · Shell size 150 mm x 850 mm · Tube size 9.525 mm x 26,000 mm · Heating area 0.98 m^2

Table 2: Descriptions of the cold room and absorption chiller.

(a) The absorption chiller unit

(b) Mae Jun hot spring, Thailand

Figure 7: The prototype of absorption chiller at Mae Jun hot spring, Thailand.

Devices	Properties
Dryer room	· Thickness 3 in · Size 3.3 m x 4.8 m x 3.2 m
Heating coil	· Fin and tube heat exchanger · Size 2.413 m x 1.197 m · Piping tube API 40, 1/2 in
Motor	· Power 5 hp · Speed 1,450 rpm
Blower	· Diameter 1.2 m

Table 3: Descriptions of drying room and equipment.

Drying room by using two-stage vapor compression heat pump

In this study, the 2-stage vapor compression heat pump is used to upgrade hot spring temperature around 40-50°C to be around 80-85°C for the drying room. R-134a and R-123 are chosen as the working fluids in the 2-stage heat pump system. Huai Mak Liam hot spring, Chiang

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(a) Heating coil and blower in drying room

(b) Hot spring piping system

Figure 8: The prototype of drying room at Mae Jun hot spring, Thailand.

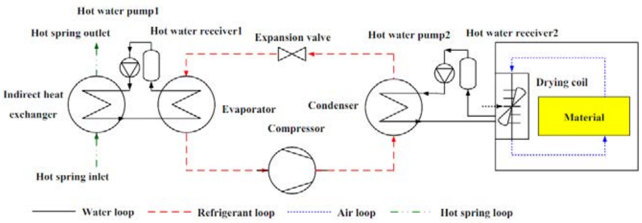


Figure 9: Schematic diagram of the geothermal drying room by using 2-stage VCHP.

(a) The prototype of single-stage VCHP

(b) the geothermal drying room

Figure 10: The photograph of geothermal drying room by using single-stage VCHP.

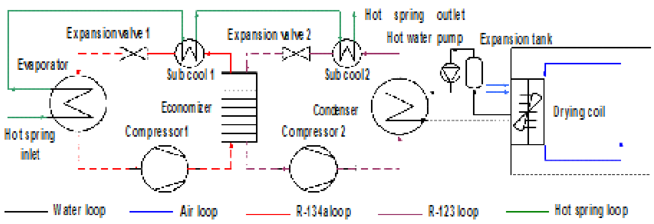


Figure 11: Schematic diagram of the geothermal drying room by using 2-stage VCHP.

Rai, Thailand with having the surface water temperature around 45°C from 30 m of the slim hole is used to test the heating efficiency of the prototype. A schematic diagram of geothermal drying room integrated with 2-stage VCHP is shown in Figure 11. The descriptions and photographs of testing unit are shown in Table 5 and Figure 12, respectively.

Devices	Type	Properties
Drying room	Isowall	· Thickness 3 in · Size 3.3 m x 4.8 m x 3.2 m
Indirect Heat Exchanger	Gasket plate heat exchanger (hot spring to hot water)	· Capacity 15 kW · Heating area 0.8 m^2
Hot water pump1	Centrifugal pump	· Capacity 0.37 kW · Flow rate 80 L/min
Hot water receiver 1 and 2	Vertical steel tank	· Capacity 10 L
Compressor	Open type compressor	· Capacity 3 kW · Volume flow rate 25 m^3/h
Condenser	Plate heat exchanger (R-123 to hot water)	· Capacity 20 kW · Heating area 3.65 m^2
Evaporator	Plate heat exchanger (R-123 to hot water)	· Capacity 15 kW · Heating area 2.88 m^2
Expansion valve	Orifice type	· Capacity 15 kW

Table 4: Descriptions of geothermal drying room and 2-stage heat pump components.

Devices	Type	Properties
Drying room	Isowall	· Thickness 3 in · Size 2.4 m x 4.8 m x 2.3 m
Hot water pump	Centrifugal pump	· Capacity 0.37 kW · Flow rate 60 L/min
Expansion tank	Vertical steel tank	· Capacity 10 L
Compressor 1	Hermetic compressor R-134a	· Capacity 2 kW · Volume flow rate 11.46 25 m^3/h
Compressor 2	Open type compressor R-123	· Capacity 3 kW · Volume flow rate 25 m^3/h
Condenser	Plate heat exchanger (R-123 to hot water)	· Heat capacity 20 kW · Heating area 1.64 m^2
Economizer	Plate heat exchanger (R-134a to R-123)	· Heat capacity 15 kW · Heating area 2.39 m^2
Evaporator	Plate heat exchanger (hot water to R-134a)	· Heat capacity 8.75 kW · Heating area 1.64 m^2
Expansion valve 1	Orifice type thermostatic orifice 04	· Capacity 20 kW · Pressure ratio 3.305
Expansion valve 2	Orifice type thermostatic orifice 06	· Capacity 12 kW · Pressure ratio 3.87
Sub cool 1	Plate heat exchanger (hot water to R-134a)	· Heat capacity 2 kW · Heating area 0.64 m^2
Sub cool 2	Plate heat exchanger (hot water to R-123)	· Heat capacity 8 kW · Heating area 0.64 m^2
Dying coil	Plate heat exchanger (hot water to air)	· Capacity 20 kW · Heating area 2.88 m^2

Table 5: Descriptions of geothermal drying room and 2-stage heat pump components.

Results and Discussions

Generating electricity process by using ORC technology

The geothermal resources in Thailand are evaluated and compared with Fang geothermal power plant to assess the primary energy potential. The results stated that 12 geothermal resources are capable to generate the electrical power as shown in Table 6.

From Table 6, it could be seen that 12 high potential hot springs at the surface temperature higher than 80°C could be produced the total electricity around 521 kWe. Moreover, if the reservoir energy is extracted, the higher power energy could be generated compared with the surface potential. Table 6 also shows the electricity from reservoir energy at around 3,909 kWe.

Hot springs	Province	Temp (°C)	Quartz[1] (°C)	Flow (L/s)	ORC[2] (kWe)	ORC[3] (kWe)
Mae Jan1	Chiang Rai	93	163.35	1.1	18.39	137.94
Mae Jan2	Chiang Rai	93	160.75	5.56	92.89	696.67
San Kam Phaeng	Chiang Mai	88.5	147.64	5.56	92.89	696.67
Doi Sa Ket	Chiang Mai	96.3	144.65	0.26	4.35	32.60
Fang	Chiang Mai	98.1	142.59	1.56	26.08	195.62
Pong Duead	Chiang Mai	95	142.59	5.56	92.89	696.67
Thep Pha Nom	Chiang Mai	98.9	141.70	1.65	27.59	206.91
Pong Pa	Mae Hong Sorn	87.4	126.40	0.23	3.85	28.84
Mueang Paeng	Mae Hong Sorn	96	125.42	5.56	92.89	696.67
Nong Haeng	Mae Hong Sorn	81.1	122.07	3	50.16	376.20
Chae Son	Lampang	83.7	120.69	1.1	18.39	137.94
Mae Jork	Phare	80.7	116.35	0.05	0.84	6.27
Sum					521	3,909

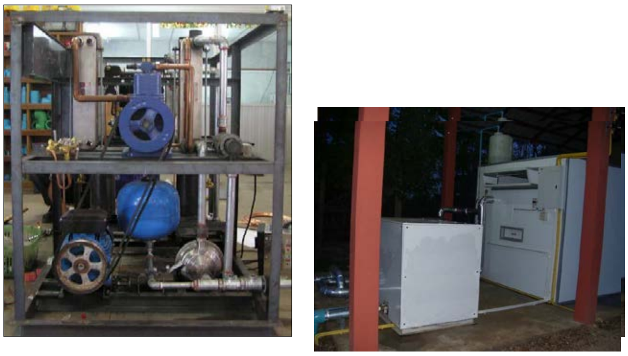
Table 6: Geothermal resources with electricity generating.

Remarks: [1]Reservoir temperature from quartz (maximum stream loss) equation.
T_{GS} = [1,522/(5.75 – log(SiO_2))] – 273.15 [35] SiO_2 based on the study result of CMU [2].
[2]$Q = \eta_{ORC}\, mCp\Delta T$, η_{ORC} is 10% [34] m: Mass of flow rate, Cp is 4.18 KJ/Kg-K, ΔTis hot difference temperature at approximately 40°C [34] and density of hot string is 1,000 Kg/m^3
[3]$Q = \eta_{ORC}\, mCp\Delta T$, m is 75% maximum hot Spring flow rate which the minimum value is 10 times of the surface hot spring flow rate [34].

$T_{air,i,E}$ (°C)	$T_{air,o,E}$ (°C)	$T_{CW,i}$ (°C)	$T_{HW,i}$ (°C)	$T_{HW,o}$ (°C)
9.86	6.04	24.78	97.95	85.88
T_G (°C)	Q_G (kW)	Q_E (kW)	COP[1]	EER[2] (kWth/kWe)
91.17	15.13	9.56	0.63	0.59

Table 7: The average testing data of absorption chiller.

Remarks: [1]$COP_{AB} = Q_E/Q_G$ and [2]$EER_{AB} = Q_E/(Q_G + W_{Sys})$



a) The 2-stage VCHP   b) the geothermal drying room

Figure 12: The geothermal drying room by using 2-stage VCHP.

Figure 13: The photograph of evaporator at the air temperature in cold room around 1 °C.

Cooling process by using absorption chiller

Absorption chiller is constructed and tested the cooling efficiency. Table 7 shows the testing data of ammonia-water single-stage absorption refrigeration. It could be seen that the absorption unit could be decreased the minimum air temperature in the cold room to be around 1°C as shown in Figure 13 which is given hot spring temperature around 98°C. The testing results is also shown the EERAB at around 0.6 which is lower than the other researches because a big size of refrigerant pump at power consumption around 1.03 kWe is taken in the absorption unit.

For economic evaluation, the cold room at capacity 3,000 kg by using the 10 kW absorption system is also carried out with 10 sets of cooling per month, 24 hours per freezing set. At the time of assessment with the construction cost about 20,000 USD and the payback period is 22 months.

Table 8 shows 8 moderate potential hot springs at temperature between 70-80°C at the most found in the northern area of Thailand. Moreover, Table 8 also shows the total cooling capacity at around 304 kW of absorption chiller from 8 hot spring resources.

Drying process by central drying room

The central drying room is constructed with a dimension of 3.30 m×4.80 m×3.20 m at capacity of about 3 Ton (3,000 kg) of agricultural products. It generates room temperatures to be over 80°C. The hot water transfers heat into the heating coil in the drying room. The air inside the room is heated by the 20 kW heating coil. Efficiency test of the empty drying room showed that the room temperature increases from 25°C to be over 80°C within 5 minutes. The heating efficiency of drying room is around 80% (η_{Drying}) with the water temperatures entering and leaving

Hot spring	Province	Temp	Flow	Absorption[1]	Drying[2]
		(°C)	(L/s)	(kW)	(kW)
Pu Feang	Chiang Rai	73.3	4.5	113	150
Sop Pong	Chiang Rai	79.3	0.44	11	15
Pong Phra Bat	Chiang Rai	73.1	3.8	95	127
Thung Pong	Chiang Mai	75	1.19	30	40
Tha Pai	Mae Hong Sorn	78.9	1.44	36	48
Mae Um Long	Mae Hong Sorn	78.8	0.19	5	6
Pho Thong	Tak	74.8	0.1	3	3
Klong Plag Pau	Phangnga	74.8	0.48	12	16
Sum				304	406

Table 8: Geothermal resources with cooling potential.

Remarks: [1]$Q = EER_{AB} mCp\Delta T$, EER_{AB} is 0.59, *m* is the surface hot spring flow rate, *Cp* is 4.18

kJ/kg·K, ΔT is hot spring difference temperature approximately 10 oC and density of hot spring is 1,000 kg/m^3

[22]$Q = \eta_{Drying} mCp\Delta T$, η_{Drying} is hot spring difference temperature approximately 10°C and density of hot spring is 1,000 kg/m^3.

a) Cherry before drying process   b) Cherry after 12 hours of drying process

Figure 14: The photograph of cherry in drying room at hot air temperature around 95 °C.

Descriptions	Data
Mass flow rate of hot spring (kg/s)	0.75
Hot spring temperature entering at the evaporator (°C)	49.60
Hot spring temperature leaving at the evaporator (°C)	48.61
Heat capacity of hot spring (kW)	3.10
Mass flow rate of hot water entering at the condenser (kg/s)	1.33
Hot water temperature leaving at the condenser (°C)	72.80
Hot water temperature entering at the condenser (°C)	71.40
Heat capacity of hot water (kW)	7.78
Electrical power consumption of single-stage VCHP (kWe)	2.58
Electrical power consumption of drying room (kWe)	5.60
EER_{VCHP} (kWth/kWe)	3.02
$EER_{Drying\ room}$ (kWth/kWe)	1.39

Table 9: The average testing results of geothermal drying room and single-stage VCHP.

of the system as 98°C and 87°C, respectively. And, Figure 14 also shows the drying product at 12 hours of cherry.

For economic results, the evaluation is also carried out with 15 sets of drying per month, 24 hours per drying set. At the assessment with the drying room and operation system cost about 11,000 USD and the payback period at around 15 months is found.

From the testing data of the central drying room, it could be seen that if moderate potential hot springs as shown Table 8 are used in the drying process, the total heating capacity at around 406 kW could be used for extracting moisture of the agricultural products.

Drying process by vapor compression heat pump

The drying room integrating with the heat pump system is constructed giving an intake capacity of about 3 Ton (3,000 kg) of agricultural products. It generates the air room temperatures between 60-75°C. From the testing results as shown in Table 9, it could be seen that efficiency test of the empty drying room showed that the room temperature increased from 25°C to be 70°C within 3 hours. The energy efficiency ratios (EERs) of the VCHP and the drying room

Descriptions	Data
Mass flow rate of hot spring (kg/s)	0.22
Hot spring temperature entering at the evaporator (°C)	44.80
Hot spring temperature leaving at the evaporator (°C)	37.60
Heat capacity of hot spring (kW)	6.52
Mass flow rate of hot water entering at the condenser (kg/s)	1.03
Hot water temperature leaving at the condenser (°C)	84.10
Hot water temperature entering at the condenser (°C)	79.40
Heat capacity of hot water (kW)	20.67
Electrical power consumption of 2-state VCHP (kWe)	4.62
Electrical power consumption of drying room (kWe)	7.37
EERVCHP (kWth/kWe)	4.17
EERDrying room (kWth/kWe)	2.57

Table 10: The average testing results of geothermal drying room and 2-stage VCHP.

Hot spring	Province	Temp (oC)	Flow (L/s)	Heat pump[1] (kW)
Pong Na Kham	Chiang Rai	65.9	0.52	28
Houy Mhak Leam	Chiang Rai	56.6	7	376
Pha Sert	Chiang Rai	66.2	2.38	128
Huay Sai Khaow	Chiang Rai	56.5	1.96	105
Pong Arong	Chiang Mai	52.3	0.78	42
Ban Yang Pu Toa	Chiang Mai	51.7	0.2	11
Non Klang	Chiang Mai	68.8	3.5	188
Pa dauk	Chiang Mai	55.8	0.81	44
Mal Li Ka	Chiang Mai	68.1	0.25	13
Pha Bong	Mae Hong Sorn	65.5	0.67	36
Wiang Nuea	Lampang	61.2	0.94	50
Ban Pong Nam Ron	Lampang	56.2	1.12	60
Ban Pan Jen	Phare	53.8	0.23	12
Wad Slang	Phare	65.7	0.8	43
Ban Pong Lam Pang	Sukhothai	55.6	0.16	9
Pa Ja Lern	Tak	60	0.36	19
Boek Lueng	Rachburi	57.3	5	269
Pong Long	Ranong	56.2	0.26	14
Ban Khao Noi	Surat Thani	52.1	1.53	82
Rat Ta No Go Sai	Surat Thani	61	2.38	128

Table 11: Geothermal resources with boosting heat potential.

are 3.02 kWth/kWe and 1.39 kWth/kWe, respectively, with the water temperatures entering and leaving of the VCHP system as 49.60°C and 48.61°C, respectively. Economic evaluation is also carried out with 15 sets of drying per month, 24 hours per drying set. At the time of assessment with the construction budget of about 20,000 USD, the payback period is 13 months.

Table 10 shows the average testing results of the 2-stage vapor compression heat pump combining with the geothermal drying room. It could be found that hot spring temperatures entering and leaving at the evaporator are around 44.80°C and 37.60°C, respectively, and heat capacity of hot spring is around 6.52 kW. While, the heat pump system could be upgraded heat to be hot water temperature around 84.10°C at the useful heat capacity and the EERVCHP around 20.67 kW and 4.17 kWth/kWe, respectively. The drying room efficiency in term of EER is around 2.57 kWth/kWe. For economic results, the investment costs of the drying room and the 2-stage VCHP are 25,000 USD and the cost of electrical power consumption is around 1,000 USD/y with 15 sets of drying per month, 24 hours per drying set. While the revenue from the geothermal drying room is around 10,500 Baht/y, thus the payback period is around 29 months.

From the testing results of heat pump dryer, it could be found that 26 low potential hot springs as shown Table 11 could be developed for boosting heat process at the total heating capacity around 2,002 kW, and the agricultural products as around 200 Ton/d could be dried in the heat pump drying room.

From the above results, it could be noted that 46 hot springs in Thailand could be useful in generating electricity process, cooling process, heating process and boosting heat process. Moreover, 6.6 MW useful capacity from geothermal energy could be developed in Thailand.

Conclusions

From this study, the conclusions are as follows:

1. The geothermal energy potential at around 6.6 MW could be developed in Thailand by 4 technologies which are organic rankine cycle for generating electricity, absorption chiller for cooling process, central drying room for heating process and drying room integrating with vapor compression heat pump for boosting heat process.

2. For the ORC technique, 12 high potential hot springs could be generated electricity from the surface heat and the reservoir heat are around 512 kWe and 3,909 kWe, respectively.

3. Absorption chiller and 8 moderate potential hot springs could be produced the total cooling capacity around 304 kW and the payback period of absorption chiller is 22 months.

4. Central drying room and 8 moderate potential hot springs could be used in the heating process at the total capacity around 406 kW and the payback period of the central drying room is 15 months.

5. For the boosting technique, 26 hot springs could be upgrading heat around 2,002 kW by using the drying room integrating with the vapor compression heat pump and the payback period of this method around 29 months.

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