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 kW. 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] reported 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 can provide 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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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 ($Q_b$) 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 ($W_T$). 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.

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 descriptions 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 organic 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
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 80ºC 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 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 (P1) and a generator temperature (Tg) 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 (Tc) 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 (Tc) 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.
Absorption chiller

For moderate potential geothermal energy, the hot spring temperature between 70-80°C 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 98°C 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 60-80°C 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 60°C 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 55°C from 85 m of slim hole,periences to run the system. The prototype of Fang geothermal power plant [34].

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

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

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

| 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 m² |
| 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 m² |
| Receiver | Vertical type | Volume 0.5 m³ |
| Evaporator | Fin and tube heat exchanger | Capacity 11.2 kW |
| | | Heating area 1.25 m² |
| 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 m² |

Table 3: Descriptions of drying room and equipment.

| 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 |

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

Figure 8: Prototype of heating coil.

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.

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
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.

### 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.

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

| 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 m²               |
| Hot water pump   | Centrifugal pump      | Capacity 0.37 kW                  |
|                  |                       | Flow rate 80 L/min                |
| Hot water receiver | Vertical steel tank  | Capacity 10 L                     |
| Compressor       | Open type compressor  | Capacity 3 kW                     |
|                  |                       | Volume flow rate 25 m³/h          |
| Condenser        | Plate heat exchanger  | Capacity 20 kW                    |
|                  |                       | Heating area 3.65 m²              |
| Evaporator       | Plate heat exchanger  | Capacity 15 kW                    |
|                  |                       | Heating area 2.88 m²              |
| Expansion valve  | Orifice type          | Capacity 15 kW                    |

**Table 5:** 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   | Capacity 2 kW                     |
|                  | R-134a                | Volume flow rate 11.46 25 m³/h    |
| Compressor 2     | Open type compressor  | Capacity 3 kW                     |
|                  | R-123                 | Volume flow rate 25 m³/h          |
| Condenser        | Plate heat exchanger  | Heat capacity 20 kW               |
|                  | (R-123 to hot water)  | Heating area 1.64 m²              |
| Economizer       | Plate heat exchanger  | Heat capacity 15 kW               |
|                  | (R-134a to R-123)     | Heating area 2.39 m²              |
| Evaporator       | Plate heat exchanger  | Heat capacity 8.75 kW             |
|                  | (hot water to R-134a) | Heating area 1.64 m²              |
| Expansion valve  | Orifice type          | Capacity 20 kW                    |
| Expansion valve  | Orifice type          | Pressure ratio 3.305              |
| valve 1          | Thermostat orifice 06 | Capacity 12 kW                    |
|                  |                       | Pressure ratio 3.87               |
| Sub cool 1       | Plate heat exchanger  | Capacity 2 kW                     |
|                  | (hot water to R-134a)| Heating area 0.64 m²              |
| Sub cool 2       | Plate heat exchanger  | Capacity 8 kW                     |
|                  | (hot water to R-123)  | Heating area 0.64 m²              |
| Drying coil      | Plate heat exchanger  | Capacity 20 kW                    |
|                  | (hot water to air)    | Heating area 2.88 m²              |
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 EER 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 for 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

Table 6: Geothermal resources with electricity generating.

Remarks: 1 Reservoir temperature from quartz (maximum stream loss) equation:

\[ T_{GS} = \left[ \frac{1,522}{(5.75 - \log(SiO_2))} \right] - 273.15 \] [35] SiO_2 based on the study result of CMU [2].

2 \( Q = \eta_{ORC} \cdot m \cdot C_p \cdot \Delta T \), \( \eta_{ORC} \) is 10% [34], \( m \) is mass of flow rate, \( C_p \) is 4.18 KJ/Kg-K, \( \Delta T \) is hot difference temperature at approximately 40°C [34] and density of hot string is 1,000 Kg/m^3.

3 \( Q = \eta_{ORC} \cdot m \cdot C_p \cdot \Delta T \), \( m \) is 75% maximum hot spring flow rate which the minimum value is 10 times of the surface hot spring flow rate [34].

Table 7: The average testing data of absorption chiller.

Remarks: ‘COP = \( Q_E / Q_G \) and ‘EER = \( Q_E / (Q_G + W_{sys}) \).
and density of hot spring is 1,000 kg/m².

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 construction giving an intake capacity of about 3 Ton (3,000 kg) of agricultural products.

### Table 8: Geothermal resources with cooling potential.

| Remarks | Descriptions | Data |
|---------|---------------|------|
| Remarks: 'Q = EER_{VCHP} \cdot mCpΔT, EER_{VCHP} is the surface hot spring flow rate, Cp is 4.18 kJ/kg·K, ΔT is hot spring difference temperature approximately 10°C and density of hot spring is 1,000 kg/m³. | 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 entering at the condenser (°C) | 72.80 |
| | Hot water temperature leaving 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} (kWh/kWe) | 3.02 |
| | EER_{Drying room} (kWh/kWe) | 1.39 |

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

| Hot spring | Province | Temp (°C) | Flow (L/s) | Heat pump (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             |
| Thapai     | 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 10: The testing results of geothermal drying room and 2-stage VCHP.

| Hot spring | Province | Temp (°C) | Flow (L/s) | Heat pump (kW) |
|------------|----------|-----------|------------|----------------|
| Pon 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 | 53.6 | 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 Khaol Noi | Surat Thani | 52.1 | 1.53 | 82 |
| Rat Ta Noi Sai | Surat Thani | 61 | 2.38 | 128 |

Table 11: Geothermal resources with boosting heat potential.

| Remarks: 'Q = EER_{VCHP} \cdot mCpΔT, EER_{VCHP} is the surface water flow rate, Cp is 4.18 kJ/kg·K, ΔT is 5°C and density of hot spring is 1,000 kg/m³. |

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.
are 3.02 kWh/kWe and 1.39 kWh/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 EER of heat pump 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 around 2.57 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 around 2.57 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 around 2.57 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 around 2.57 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 around 2.57 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 around 2.57 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 around 2.57 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 around 2.57 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 around 2.57 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 around 2.57 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 around 2.57 kWth/kWe, respectively. The drying room efficiency in term of EER is around 2.57 kWth/k

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 converted electricity from the surface heat and the reservoir heat are around 512 kW and 3,909 kW, 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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