Development of a Preliminary Energy Assessment Tool for Alternative Cooling System

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Energy Technology and Management

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การพัฒนาเครื่องมือประเมินด้านพลังงานเบื้องต้นสำหรับระบบทำความเย็นที่ใช้พลังงานทางเลือก

น.ส.ปิ่นสุดา เนตรผสม

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ปิ่นสุดา เนตรผสม : การพัฒนาเครื่องมือประเมินด้านพลังงานเบื้องต้นสำหรับระบบทำความเย็นที่ใช้พลังงานทางเลือก. (Development of a Preliminary Energy Assessment Tool for Alternative Cooling System) อ.ที่ปรึกษาหลัก : รศ. ดร.สมพงษ์ พุทธิวิสุทธิศักดิ์

การประยุกต์ใช้พลังงานแสงอาทิตย์ร่วมกับเครื่องทำความเย็นแบบดูดซึม (Absorption chiller) เป็นอีกทางเลือกนึงของการลดการใช้พลังงานไฟฟ้าในการผลิตน้ำเย็น เนื่องจากเครื่องผลิตน้ำเย็นชนิดนี้อาศัยพลังงานความร้อนในการผลิตน้ำเย็นแทนการใช้พลังงานไฟฟ้าที่นิยมใช้ในปัจจุบัน และที่สำคัญเทคโนโลยีผลิตน้ำเย็นประเภทนี้ยังสามารถใช้ประโยชน์จากพลังงานความร้อนเหลือทิ้งจากอาคารหรือโรงงาน รวมถึงพลังงานความร้อนที่ได้จากพลังงานทางเลือกได้อีกเช่นกัน นอกจากนี้ระบบทำความเย็นแบบดูดซึมที่มีการใช้พลังงานแสงอาทิตย์มาสนับสนุนนั้น ยังสามารถที่จะช่วยลดผลกระทบด้านสิ่งแวดล้อมในแง่ของการเกิดก๊าซคาร์บอนไดออกไซด์ได้อีกด้วย ในการศึกษาวิจัยนี้จะเน้นทางด้านการพัฒนาโปรแกรมหรือเครื่องมือที่จะช่วยในการประเมินประสิทธิภาพทางด้านพลังงานของระบบทำความเย็นแบบดูดซึมในเบื้องต้น ไม่ว่าจะเป็นโครงการที่กำลังวางแผนดำเนินการก่อสร้าง หรือโครงการที่มีการผลิตน้ำเย็นอยู่แล้วก็สามารถประเมินได้เช่นกัน โดยเครื่องมือประเมินประสิทธิภาพทางด้านพลังงานนี้ จะสามารถคำนวณและบอกถึงรายละเอียดความต้องการของขนาดอุปกรณ์ที่ต้องทำการติดตั้งในระบบทำความเย็นได้ เช่นขนาดและจำนวนที่ต้องใช้ของเครื่องทำความเย็นแบบดูดซึม ปั๊ม และหอระบายความร้อน รวมทั้ง รายละเอียดทางด้านเทคนิคของการติดตั้งเทคโนโลยีพลังงานแสงอาทิตย์ เช่น จำนวนของแผงโซลาร์เซลล์ของแผงผลิตไฟฟ้าพลังงานแสงอาทิตย์ (solar PV) และตัวเก็บความร้อนพลังงานแสงอาทิตย์ (thermal collector) เป็นต้น และผลลัพธ์ที่สำคัญของเครื่องมือนี้คือ การที่ผู้ใช้งานจะสามารถทราบถึงประสิทธิภาพการใช้พลังงานของอุปกรณ์ต่างๆ ในระบบได้ โดยจะแสfงออกในรูปของ พลังงานไฟฟ้าที่ใช้ต่อปริมาณน้ำเย็นที่ผลิตได้ทั้งระบบ และในส่วนของเครื่องทำความเย็นแบบดูดซึมจะมีการประเมินประสิทธิภาพในรูปของ Coefficient of Performance (COP) อีกด้วย และเนื่องจากเครื่องมือหรือโปรแกรมนี้เป็นการสร้างขึ้นมาจากการบูรณาการทฤษฎีด้านการคำนวณทั้งหมด ดังนั้นจึงมีการสอบเทียบโปรแกรมกับกรณีศึกษาของระบบทำความเย็นพลังงานแสงอาทิตย์ที่มีการตีพิมพ์ก่อนหน้านี้ ซึ่งกรณีศึกษาที่ใช้ในการสอบเทียบนี้คือโครงการระบบทำความเย็นพลังงานแสงอาทิตย์ ที่เกาะเรอูว์นียง ประเทษฝรั่งเศษ[8] ซึ่งมีการติดตั้งระบบทำความเย็นที่ขนาด 30 กิโลวัตต์ โดยผลลัพธ์ของการสอบเทียบนั้นแสดงให้เห็นว่าเครื่องมือที่ทำการพัฒนาขึ้นนี้มีความสอดคล้องกับการทำงานที่เกิดขึ้นจริงของระบบทำความเย็นชนิดนี้ในระดับหนึ่ง โดยความแตกต่างของค่าที่ได้อยู่ในช่วง 0 - 4 เปอร์เซ็นต์ เท่านั้น

จึงสามารถสรุปได้ว่า เครื่องมือการประเมินประสิทธิภาพด้านพลังงานในการศึกษาครั้งนี้ มีความสามารถที่จะใช้ประเมินประสิทธิภาพพลังงานของระบบทำความเย็นแบบดูดซึมได้ในเบื้องต้น ก่อนที่จะมีการดำเนินโครงการในขั้นตอนที่มีการลงทุนสูงขึ้น อย่างไรก็ตามแม้โปรแกรมนี้จะถูกออกแบบให้ผู้ใช้งานสามารถเข้าถึงและใช้งานได้ง่ายก็ตาม ตัวผู้ใช้งานเองจำเป็นต้องมีความรู้เบื้องต้นเกี่ยวกับระบบการทำความเย็นที่ใช้เครื่องทำความเย็นแบบดูดซึมด้วยเช่นกัน

สาขาวิชา	เทคโนโลยีและการจัดการพลังงาน (สหสาขาวิชา)	ลายมือชื่อนิสิต ....
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KEYWORD: Alternative cooling system, Single-effect absorption chiller, Solar Photovoltaic, Thermal collector, Simulation tool

Pinsuda Netphasom : Development of a Preliminary Energy Assessment Tool for Alternative Cooling System. Advisor: Assoc. Prof. SOMPONG PUTIVISUTISAK, Ph.D.

In recent years, an absorption chiller coupled with solar technologies has been presented as a solution to decrease the amount of electricity consumption. The absorption chiller technology primarily consumes thermal energy instead of electricity to generate the chilled water. In addition, this technology can take advantage of waste energy and renewable resources like solar power. Solar photovoltaic and thermal collectors produce electrical and thermal energy to assist the alternative cooling system as a renewable resource. These solar and absorption technologies are promising solutions to reduce energy consumption and reduce the environmental impact caused by greenhouse gases. This study aims to develop software to assess the energy performance of an alternative cooling system preliminarily. The mathematical model of thermodynamic analysis for a single-effect absorption chiller is employed in the software application for analyzing the characteristic of the alternative cooling system. This energy assessment tool will calculate and provide the preliminary design specification of the chiller and the ancillary equipment, such as the working flow rate of pumps, pump sizes, and the capacity of cooling towers. The tool will present the energy performance such as COP, Energy Efficiency coefficient, and the primary crucial technical specification of the alternative cooling system, such as the size of the chiller, pumps, cooling tower, including estimating the size of the solar photovoltaic and thermal collector fields as the final outputs of the simulation. The computational tool is carefully validated with an installed 30 kW solar cooling project in Reunion Island, France[8]. The comparison shows good agreement with approximately 0 - 4% different. This tool is principally applicable for elementary evaluating energy performance to aid investment decisions and the installation of an alternative cooling plant. This tool expects to simplify various users to predict the alternative cooling system performance easily.

Field of Study:	Energy Technology and Management	Student's Signature ....
Academic Year:	2021	Advisor's Signature ....

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Pinsuda Netphasom

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Chapter 1 Introduction

In the last decade, utilizing an alternative/renewable energy in the cooling and heating system has been presented as a promising energy saving solution to minimize the energy consumption and cause the greenhouse emission reduction, especially CO_2 production which is the most concern parameter of the greenhouse gas emission.

An absorption technology and the solar application as the main technology to solve the energy and greenhouse emission crisis and enhancing the green energy production. Additionally, both technologies will be implemented in Microsoft excel for assessing the energy performance of the alternative cooling plant.

1.1.The problem and its background

According to the Department of Alternative Energy Development and Efficiency (DEDE), it is clear that the commercial and residential sectors consumed 20 to 28 percent of the total energy consumption, especially in these two sectors, the electricity consumption reached approximately 53 percent of the total electricity production in Thailand [1]. Additionally, around 60 percent of the total electrical energy consumption in the building is used for air conditioning and cooling purpose [2].

For the air conditioning system, there are three types of air conditioning and cooling system commonly used in Thailand [3]:

1. Split Type Air Conditioner
2. Air package unit system
3. Centralized Air Conditioning system or Centralized Cooling system

This study will mainly focus on the centralized cooling system, widely used in residential, commercial building and industrial/manufacturing sectors due to its low cost of operation and maintenance but high efficiency compared to the split type-air conditioning system[3].

The centralized cooling system consists of three main components, illustrated in Fig. 1.1, Chilled water production plant as chiller plant, Distribution piping as piping network, and Energy Transfer Unit (ETS) as Air Handling Unit (AHU). Furthermore, the following Fig. 1.2 shows the operational flow of the cooling system [4].

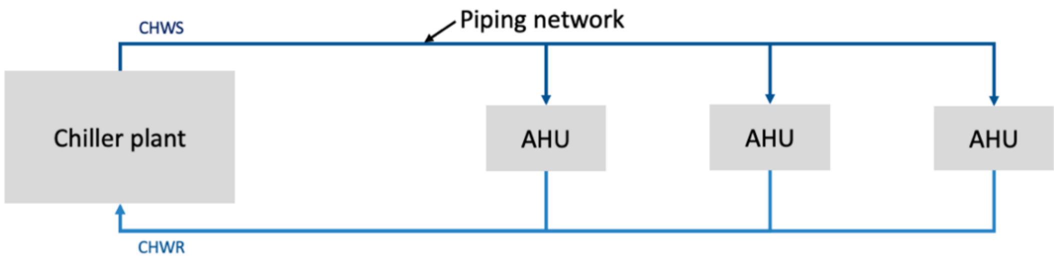


Figure 1.1 Basic components of a central cooling system

The primary cooling equipment of the central plant includes chillers, pumps, chemical treatment, and heat rejection equipment. One or several chiller technologies may be present in the main plant, which depends on the cost of local utilities or the availability of any waste heat like steam or hot water for use as a prime driver. The water-cooled chiller technology can be categorized as either mechanical vapor-compression or thermochemical (absorption with lithium bromide as absorbent and Ammonia as the refrigerant).

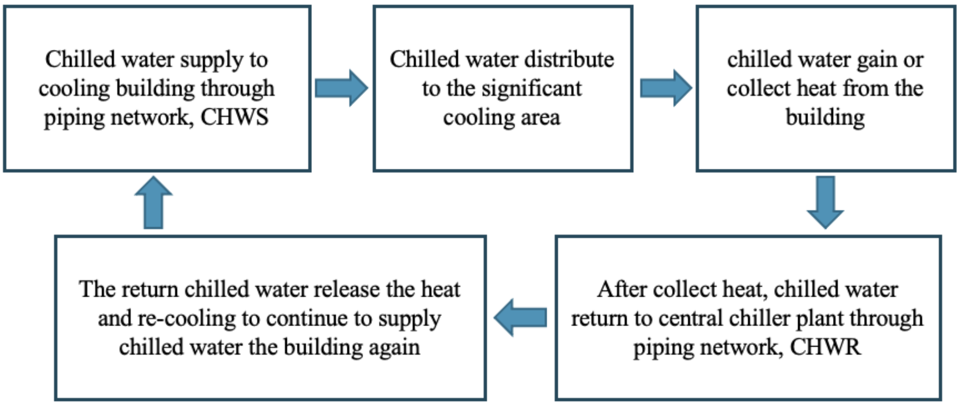


Figure 1.2 Basic process flow of the centralized cooling system

An absorption chiller, respectively, is one of the most significant technologies to mitigate the dependence on electricity and reduce the environmental impact caused by greenhouse gases. This technology takes advantage of waste energies and renewable resources [5].

Additionally, solar cooling and heating system has been recently presented as promising energy-saving solutions to decrease energy consumption, reduce greenhouse gas emissions, enhance the energy efficiency in the building, and significantly increase the share of renewable energy [6].

In Thailand, the building sector primarily uses energy for cooling processing rather than heating systems because of weather conditions such as ambient temperature, humidity, etc. Therefore, this study aims to develop an energy assessment tool for evaluating the energy performance of alternative cooling systems adopted by absorption chillers coupled with solar energy.

1.2.Research Problem

Thailand's alternative energy development plan 2018 [7] aims to increase the proportion of alternative/renewable energy to reach 30 percent of the final energy consumption in 2037.

As stated above, the alternative cooling system might be the solution to achieve this development plan. The primary purpose of this tool development is to evaluate the energy performance of the chiller plant with absorption chiller technology coupled system with solar technologies such as photovoltaic and thermal collectors in the cooling system.

Accordingly, this study proposes an energy assessment tool to achieve the energy performance of the alternative cooling plant by utilizing Microsoft Excel and allowing various users to use the excel tool easily. With this excel tool, the building or factory owners can use this tool to evaluate the energy performance and the financial prediction before making any other decision or investment in the alternative cooling plant project.

1.3. Research question

Do we have an energy assessment tool for the preliminary evaluation of the energy performance of the alternative cooling system?

1.4. Research objective

This study aims to develop an aiding tool (computer software) for assessing the energy performance of the alternative cooling system by absorption chiller coupled with solar photovoltaic and thermal technologies and use this tool to evaluate the energy consumption of the alternative cooling plant, including an estimation of cost and saving of the alternative cooling system.

1.5. Research limitations and constraints

There are some limitations to the development method. Firstly, the cooling capacity of single-effect absorption chillers depends on the case study or the machine's specification of your design chiller plant. Secondly, the LiBr crystallization problem is not considered in this study, and the percentage of the LiBr solution input is limited to 60 percent.

Furthermore, this computational tool will not automatically take the redundant equipment or system into account, and the users need to include the backup system by themselves manually. Fourthly, only three types of facilities are being applied to this computational tool, the facilities including factory, commercial and residential buildings. Lastly, the final output of the tool simulation is mainly calculated by the mathematical model in chapter 2, and the calculations will validate with the previously published research papers.

1.6. Scope of work

1.6.1. Software-Microsoft Excel

1.6.2. Plant location and weather data

Bangkok, Thailand, will be set as a default plant location for the first version of the tool. The weather data such as dry-bulb and wet-bulb temperature and relative humidity over the year will be automatically determined by plant location.

1.6.3. Absorption chillers

Only the single-effect absorption chiller technology is considered in this study, and Lithium Bromide and water as the absorbent and refrigerant, respectively.

1.6.4. Solar technologies

Two solar applications are applied to the software, solar photovoltaic and solar thermal collector. Both are considered to assist the chiller plant. Additionally, the solar production is mainly calculated from the solar radiation intensity, which is the monthly collected data by the Department of Alternative Energy Development and Efficiency (DEDE).

1.6.5. Ancillary system

The ancillary equipment such as the chilled water pump, condenser pump, and cooling tower will be sized based on the cooling capacity and energy input/output of the cooling system. The final report will present the specification of the equipment, such as working flow rate and motor size of pumps and cooling towers.

1.7.Methodology

1.7.1. Identify the scope of work

Define the study area, study assumption, additional cooling demand of the building and production processes, and plant location.

1.7.2. Technologies investigation

In this study, various technologies must be investigated: cooling systems, including chillers, solar applications, etc. The critical parameters of the cooling system, absorption chiller technologies, and solar applications are also included, respectively.

1.7.3. Energy performance evaluation

After investigating, setting up, and simulating the integration of solar technologies assisted absorption chiller in the cooling system. The mathematical and simulation model will calculate and solve the total energy consumption, energy efficiency, total cooling production, and energy saving.

1.7.4. Project cost analysis

Discounted Cash Flow model will be the financial tool to evaluate the project's cost. By this model, Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PP) will be used for the project financial evaluation. Cost parameters to be studied are Cash flow in - revenue, Cash flow out – CAPEX and OPEX.

1.8.Research conclusion

The energy assessment tool is possible to evaluate the energy performance of the alternative cooling system, including estimating the yearly energy consumption, total cooling load demand, and forecasting the solar production to assess the cost-saving of the cooling plant.

The financial analysis will define this case feasibility study of the solar project installation: If the internal rate of return is higher than the discounted rate, this project is feasible. Otherwise, if the value of IRR is lower than the discounted rate, this is not feasible.

1.9.Result expectation

1.9.1. The first version of the alternative cooling energy assessment tool is ready to preliminary evaluate the energy performance of the alternative cooling plant.

1.9.2. This energy assessment tool should be validated with the case study from previously published research papers and software testing with one project located in Thailand. Expectedly, errors or tolerances should not be over 20 percent difference between a published paper and this computational tool.

Chapter 2 Literature Review

This computational tool applies solar technologies as a part of the alternative cooling system. The operating performance of the solar plate/panel depend on the availability of the solar radiation intensity, which is also affected by the weather conditions. The size of the solar field capacity is required to match the chiller's cooling capacity if it is the leading resource supply to the cooling system, respectively, the recent studies of the solar cooling plant will be presented in the following section below.

2.1.Literature review

Several studies have presented solar power for cooling and heating systems, which absorption chillers apply. First, Marc et al. [8] proposed an experimental study of a solar cooling absorption system implemented on Reunion Island, France. The study area has been separated into two sections: developing a numerical model to predict the behavior of the whole plant installation and an experimental analysis with pilot plants to gain practical experience. This study aims to effectively cool four classrooms with a solar cooling system without any backup plan and maintain an indoor temperature of around 6 ºC. Additionally, when solar cooling cannot provide enough cooling demand, the ceiling fans will be operated to achieve thermal comfort for the classrooms. The cooling plant of this study consists of five main components, as presented in Table 2.1. The result showed the characteristics and operating strategy of the system in a specific month.

Table 2.1 Main components of the cooling plant

Equipment	Specification
1. LiBr-water single absorption chiller	30 kW cooling capacity
2. solar collectors' field	36 double-glazed flat plate solar collector
3. cooling tower	80 kW as a nominal capacity
4. hot and cold buffer tank	1500 L and 1000 L, which can provide 45 minutes for hot and cold-water production
5. fan coil unit	-

Another interesting solar cooling system from Lubis et al. [9] represents the study of solar-assisted absorption chillers utilized in Asian tropical climates. This study aims to characterize the performance of the single-double effect absorption chiller with variables in the cooling water and hot water inlet temperatures. The generator has two thermal energy supplies: hot water generated by the solar collectors and another from the gas combustion process. The cooling equipment for this study consists of single-effect and double-effect absorption chillers with 239 kW nominal capacity, 62 evacuated tube solar collectors with a total aperture area of approximately 181 sqm., a hot water storage tank, and other ancillaries such as a cooling tower, pumps, etc. The study results present the energy consumption and production COP and energy input ratio between solar energy and gas combustion heat for each working condition. The development of the study gave the solar cooling system characteristic and its energy performance.

Lastly, Arabkoohsar and Andresen [5] proposed a bifunctional solar-powered absorption chiller for the district cooling and heating system. The cooling components consist of a single-effect absorption chiller, an evacuated tube solar collector, thermal energy storage, heat source, and other ancillaries. This plant does not use the cooling tower to supply cooling water to extract heat from the condenser and absorber but instead uses cooling water from the district heating line. This paper [5] remarkably presented other ways to evaluate the solar cooling plant besides energy performance evaluation. NPV, IRR, and the Payback period methods are used to evaluate the financial profitability of the solar cooling project. Additionally, decreasing the amount of CO_2 emission is one of the attractive criteria for the energy project evaluation.

2.2.Absorption chiller

There are synergies between the cooling system and combined heat and power (CHP) for various absorption chillers; for instance, the single-effect chillers utilize low-grade waste heat to produce hot water with a temperature around 93 °C. Generally, the absorption chillers could be found in single, double, and triple effect configurations. The configuration with a higher number of effects presents higher coefficient of performance (COP) values, though it requires a higher driving temperature level. In single effect absorption technology, the heat input temperature ranges from 80 °C to 120 °C, achieving thermal COPs around 0.7 – 0.8 [10]. Double and triple effect chillers require driving temperatures around 180 °C to 240°C [4] and can reach COPs of the system up to 1.4, as illustrated in Fig. 2.1 [9,11].

Regardless of the various effect types of an absorption chiller, this technology can also be classified into two most common types: Lithium bromide-water (LiBr-H_2O) and water-Ammonia (H_2O- NH_3). A single-effect absorption chiller with LiBr-water as working fluids is the most appropriate type to be assisted by solar technologies. It requires a lower temperature range than double and triple effect absorption chillers, and Lithium bromide is non-toxic and safer than Ammonia.

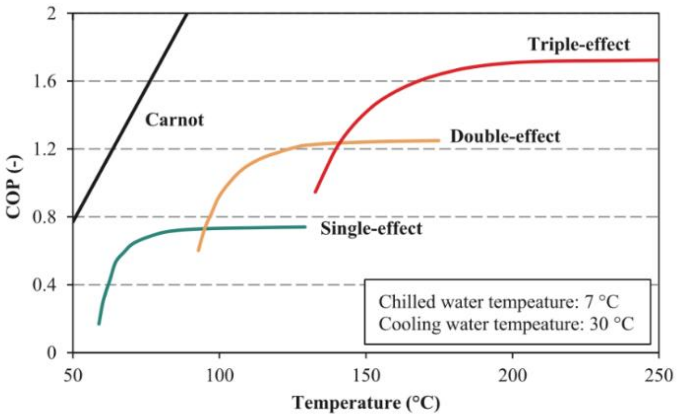


Figure 2.1 COP levels for LiBr-H2O single, double, and triple-effect absorption chillers vs. heat supply temperature

Absorption chillers can be categorized based on three main criteria: the firing method, the working fluids, and the number of effects [11].

The firing method depends on the type of driving heat input, i.e., direct-fired and indirect-fired. The direct-fired chillers operate heat directly from the combustion process, which has liquid fuel or natural gas circulating in the generator directly. While Indirect-fired type delivers or transfers heat through an intermediate component like a heat exchanger. Thus, the driving heat for an indirect type can be circulated in hot water, steam, or exhaust gas.

The performance and efficiency of an absorption chiller are effectively controlled by the thermo-physical properties of the working fluid pairs. Absorption chillers can also be classified by the operating fluids [12]: Lithium bromide-water (LiBr-H_2O) and water-Ammonia (H_2O-NH_3) are the most common types of working fluid pairs. Lithium bromide is mainly used for Heating, Ventilation, and Air Conditioning system (HVAC), whereas Ammonia is applicable for refrigeration purposes because it can achieve sub-zero temperatures. The H_2O-NH_3 absorption chillers generally require higher generator temperatures, but they have COPs levels lower than LiBr-H_2O-based chillers [13]. Not only the operating temperature range of the absorption cycle is an essential requirement for a suitable working fluid pair, but it also has other criteria that should be considered when selecting the working fluid pairs, for instance [12]:

a. The working fluid pair should be chemically stable, non-toxic, non-corrosive, and inexpensive.
b. The temperature difference between the boiling points of the refrigerant and absorber should be high.
c. The refrigerant (water) should be volatile, allowing it to be easily separated from the absorbent (Lithium bromide) inside the generator.

In Lithium bromide-water absorption chillers, crystallization may occur when the solution concentration is too high. An internal control system is generally installed inside the chiller to monitor the temperature at heat rejection inside the absorber to avoid crystallization problems.

The last criterion, the number of effects, refers to the number of times heat is recycled inside the chiller to generate cooling. Three types of absorption chillers can be categorized by this criteria, single-effect, double-effect, and triple-effect chillers.

2.2.1. Single-effect absorption chiller:

A single-effect absorption chiller consists of a generator, a condenser, an evaporator, an absorber, a solution heat exchanger (HEX), a solution pump, and two expansion valves, as demonstrated in Fig. 2.2. A diluted solution (LiBr-H_2O) pumps from the low-pressure absorber to a high-pressure generator, passing through the solution heat exchanger to receive heat from the concentrated LiBr solution and then entering the generator. Heat is added to the generator at temperature 80 °C to 120 °C, evaporates and separates the refrigerant from the absorber, then concentrated LiBr solution is sent back to the absorber, released heat to a heat exchanger, and decrease the pressure by an expansion valve before entering to the absorber. The high-pressure refrigerant vapor is condensed in the condenser to become the high-pressure saturated liquid. Then it runs through the expansion valve, where its pressure and temperature decrease. The leaving low-pressure saturated fluid enters the evaporator, which is evaporated to a low-pressure vapor. The absorbent absorbs the moisture in the absorber [14].

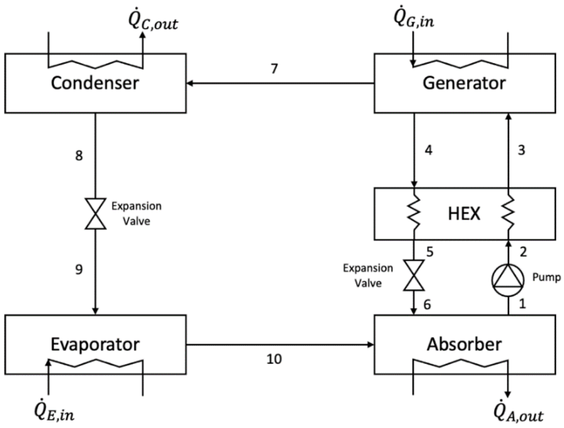


Figure 2.2 Schematic diagram of a single effect absorption chiller

According to Fig. 2.2, the temperature of each component of a single effect absorption chiller can be defined by [15],

$$T_e = T_{e,in} - 7 \tag{2.1}$$

$$T_a = T_{c,out} + 3 \tag{2.2}$$

$$T_g = T_{g,out} - 3 \tag{2.3}$$

$$T_c = T_{c,out} + 3 \tag{2.4}$$

where T_e is the temperature at the evaporator, T_a is the temperature at the absorber, $T_g$is the temperature at the generator, and T_c is the temperature at the condenser.

2.2.2. Thermodynamic analysis

The energy balance equation of single-effect absorption chillers can be written as follows [14]:

$$\dot{Q}_G + \dot{Q}_E = \dot{Q}_A + \dot{Q}_C \tag{2.5}$$

where $\dot{Q}_G$, $\dot{Q}_E$, $\dot{Q}_A$, and $\dot{Q}_C$ are the energy heat rate of the generator, evaporator, absorber, and condenser.

According to the second law of thermodynamics, the internally reversible absorption chiller can be expressed as

$$\frac{\dot{Q}_G}{T_G} + \frac{\dot{Q}_E}{T_E} = \frac{\dot{Q}_A}{T_A} + \frac{\dot{Q}_C}{T_C} \tag{2.6}$$

where T_G, T_E, T_A, andT_C are equilibrium temperatures of the generator, evaporator, absorber, and condenser. Practically, $T_A = T_C$, Eq. 2.2 can be written as

$$\frac{\dot{Q}_G}{T_G} + \frac{\dot{Q}_E}{T_E} = \frac{\dot{Q}_A}{T_C} + \frac{\dot{Q}_C}{T_C} \tag{2.7}$$

respectively, The COP of the single-effect absorption chiller can be defined as

$$COP = \frac{\dot{Q}_E}{\dot{Q}_G} \tag{2.8}$$

A single absorption chiller has one evaporator, one absorber, one solution heat exchanger, one generator, and one condenser. The mass and energy rate balance may be expressed as follows [16]:
mass and energy rate balance at the evaporator can be given as,

$$\dot{m}_9 = \dot{m}_{10} \tag{2.9}$$

$$\dot{Q}_{E,in} = \dot{m}_{10}h_{10} - \dot{m}_9 h_9 \tag{2.10}$$

mass and energy rate balance at the absorber as,

$$\dot{m}_1 = \dot{m}_6 + \dot{m}_{10} \tag{2.11}$$

$$\dot{Q}_{A,out} = \dot{m}_6 h_6 + \dot{m}_{10}h_{10} - \dot{m}_1 h_1 \tag{2.12}$$

and the circulation rate ratio (λ) of the mass flow rate of refrigerant ($\dot{m}_{10} = \dot{m}$) can be written as,

$$\lambda = \frac{\xi_{ws}}{\xi_{ss} - \xi_{ws}} \tag{2.13}$$

ξ_{ws} is the percent concentration of the weak LiBr solution ($\dot{m}_1 = \dot{m}_{ws}$), ξ_{ss} is the percent concentration of the strong LiBr solution ($\dot{m}_6 = \dot{m}_{ss}$).

The mass flow rate of concentrated LiBr solution ($\dot{m}_{ss}$) and diluted LiBr solution ($\dot{m}_{ws}$) can be calculated by,

$$\dot{m}_{ss} = \lambda\dot{m} \tag{2.14}$$

$$\dot{m}_{ws} = (1 + \lambda)\dot{m} \tag{2.15}$$

mass and energy rate balance at the generator as,

$$\dot{m}_3 = \dot{m}_4 + \dot{m}_7 \tag{2.16}$$

$$\dot{Q}_{G,in} = \dot{m}_4 h_4 + \dot{m}_7 h_7 - \dot{m}_3 h_3 \tag{2.17}$$

and mass and energy rate balance at the condenser as,

$$\dot{m}_7 = \dot{m}_8 \tag{2.18}$$

$$\dot{Q}_{C,out} = \dot{m}_7 h_7 - \dot{m}_8 h_8 \tag{2.19}$$

the heat transfer between weak and strong solutions at the heat exchanger can be written as

$$\dot{m}_1(h_4 - h_5) = \dot{m}_6(h_3 - h_2) \tag{2.20}$$

This study will use a single-effect absorption chiller with LiBr-water for the tool development. Standard mathematical formulations of solar technologies will be applied to calculate solar photovoltaic and solar thermal performance evaluation.

2.2.3. Enthalpy

Enthalpy per unit mass (H) in kJ/kg has typically represented the sum of internal energy per unit mass and the product of pressure and specific volume, which can be expressed as [17],

$$H = U + PV \tag{2.21}$$

where U is the internal energy per unit mass (kJ/kg), P is the pressure in kPa, and V is the specific volume in m^3/kg.

The enthalpy equations applied in this study are available for stage points 1-10 in Fig. 2.2. The enthalpy of water at a temperature, T in °C, is given by the following equations [17],

a. Liquid state

$$H_l = C_{p_w} \Delta T \tag{2.22}$$

where H_l is the enthalpy of water in a liquid state, C_{p_w} is the specific heat of water (~4.186 kJ/kg.°C), and ΔT is different between the dry bulb temperature (°C) and the reference temperature at 0 °C.

Accordingly, the final equation for calculating the enthalpy of water in a liquid state at temperature T (°C) is expressed as the following equation [18],

$$H_l = 4.186(T) \tag{2.23}$$

b. Vapor state

$$H_v = n_a LH_0 + n_a C_{p_v} T_a \tag{2.24}$$

where H_v is the enthalpy of water vapor, n_a represents the kilogram of water at a temperature T (°C), LH_0 is the latent heat of vaporization of water (~2,495.3 kJ/kg), C_{p_v} is the specific heat of vaporized water (~ 1.86 kJ/kg.°C), and T_a indicates the heated temperature under vapor form (°C).

Therefore, the final equation for calculating the enthalpy of vaporized water at a temperature T_a (°C) expressed as the following equation [18],

$$H_v = 2501 + 1.86T_a \tag{2.25}$$

2.3. Solar technologies

Solar energy has been applied to supply the energy demand in terms of electricity and thermal energy. Many solar technologies have been present as a promising solution for generating electricity considering zero-carbon created and providing thermal energy for other purposes such as cooling and heating in various buildings.

There are two modern ways to collect solar energy. One is to convert solar radiation into electrical power through photovoltaic material called the solar PV system. The other is the solar thermal system, which directly generates thermal energy by solar radiation using a solar collector [19].

2.3.1. Solar PV systems

Photovoltaics (PV) is one of the fastest-growing energy technologies in the modern energy sector. Its scalability and adaptability to any regional condition worldwide are significantly successful for the system implementation in the different global regions. The PV system sizing can be ranged from a small-isolated home system to a multimegawatt centralized power plant. The PV module or technologies selection depends on the different needs and conditions of the installed location, weather conditions, etc. [20]

The significant performance parameter of the PV module is the power input, power output, power conversion efficiency, and fill factor, which the mathematical formula illustrates as follows:

$$P_{in} = Area \times I \tag{2.26}$$

where P_{in} or power input is the amount of solar energy available, which is the product of the area of the PV module multiplied by solar radiation and has kW as a unit of power input.

$$P_{out} = V_{max} \times I_{max} \tag{2.27}$$

P_{out} is the product of maximum voltage (V_{max}), the current (I_{max}) is power output at the terminals, and the power output unit is kW.

$$PEC = \frac{P_{out}}{(Area \times I)} \times 100 \tag{2.28}$$

PEC or Power conversion efficiency is the ratio of the power output divided by the power input. Generally, this value represents the performance of PV cells.

$$FF = \frac{P_{out}}{(V_{OC} \times I_{SC})} \tag{2.29}$$

FF is the fill factor representing the quality of the PV cell, and this factor is the ratio of power output divided by the product of the open-circuit voltage (V_{OC}) and short-circuit current (I_{SC}).

The open-circuit voltage (V_{OC}) is the value of the voltage measured when putting the PV cell terminals set in the open circuit condition. Generally, the voltage value in this condition will be higher than the maximum voltage (V_{max}) attained at the maximum point. Additionally, the short circuit current (I_{SC}) is the maximum current generated when a solar PV cell output terminal is short-circuited. During the short circuit condition, the current is higher than the maximum power current (I_{max}) attained at the maximum point, as shown in Fig. 2.3 [20,21].

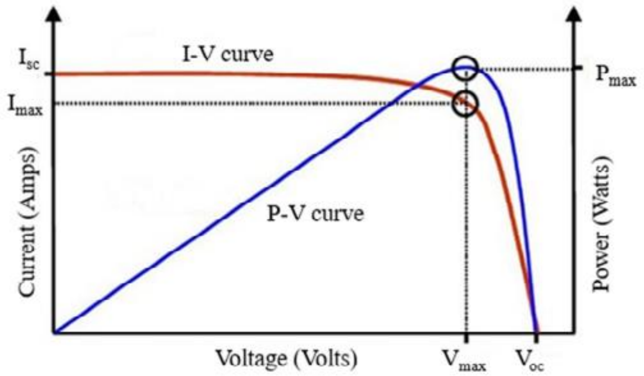


Figure 2.3 I-V and P-V curves indicate the maximum power point, open-circuit voltage, and short circuit current

2.3.2. Solar thermal systems

The solar collector is the device that absorbs solar radiation, collects heat, and transfers it to a working fluid flowing inside the collector. There are many types of thermal collectors, but the most commonly defined criteria are non-concentrating and concentrating, as illustrated in Table 2.2 [22]. Additionally, the thermal collector also can be classified by the range of the working temperature [19]: Low-temperature (< 100ºC), Medium-temperature (100ºC - 200ºC), and High-temperature (>200ºC) collectors.

Non-concentrating or stationary collectors are permanently fixed and do not track the sun. Respectively, non-concentrating collectors return lower temperature working fluid at the outlet and are suitable for low and medium-temperature applications. The concentrating collectors are suitable for high-temperature applications. They are sun-tracking solar collectors with small solar receiving areas, increasing the radiation flux.

Table 2.2 Solar Thermal Collectors

Motion	Collector Type	Absorber type	Concentration Ratio	Indicative Temperature Range (°C)
Stationary (non-concentrating)	1.Flat-plate collector (FPC)	Flat	1	30-80
	2.Evacuated tube collector (ETC)	Flat	1	50-200
	3.Compound parabolic collector (CPC)	Tubular	1-5	60-24
Single-axis tracking (concentrating)	1.Parabolic trough collector (PTC)	Tubular	10-85	60-400
	2.Linear Fresnel reflector (LFR)	Tubular	10-40	60-250
	3.Compound parabolic collector (CPC)	Tubular	5-15	60-300
	4.Cylindrical trough collector (CTC)	Tubular	15-50	60-300
Two-axis tracking (concentrating)	1.Parabolic dish reflector (PDR)	Point	600-2000	100-1500
	2.Heliostat field collector (HFC)	Point	300-1500	150-2000

The solar collector can be tested under two primary conditions: Steady-state or dynamic test procedure. The former method tests when the environmental conditions and collector operation are constant. The steady state may be challenging to achieve in many locations, and the testing may only be possible in a particular year. For this reason, the dynamic test method has been developed. The dynamic test method requires monitoring the transient response over several days, implying both clear and cloudy conditions for this testing method. Additionally, an advantage of the latter test method is that it can determine a broader range of the collector performance parameters than the steady-state method. [23]

However, this study only focuses on the first testing method due to the constraint of calculation and the software (MS Excel).

The solar collector thermal efficiency performs tests under steady-state conditions, including steady radiant energy falling on the collector surface, a regular fluid flow rate, constant wind speed, and ambient temperature [23]. Furthermore, an outlet fluid temperature from the collector can be maintained when a liquid inlet temperature is stable. Following this condition, the energy input (Q_{in}), and the energy gain (Q_u) in kW and collector efficiency (η) can be calculated by [22]:

$$Q_{in} = A_a I_t \tag{2.30}$$

$$Q_u = \dot{m}c_p(T_{out} - T_{in}) \tag{2.31}$$

$$\eta = \frac{\dot{m}c_p(T_{out} - T_{in})}{A_a I_t} \tag{2.32}$$

Furthermore, the energy collected from a solar collector and the thermal efficiency can be written as follows:

$$Q_u = A_a[I_t(\tau\alpha)_n - U_L(T_{in} - T_a)] \tag{2.33}$$

$$\eta = (\tau\alpha)_n - \left(\frac{U_L(T_{in} - T_a)}{I_t}\right) \tag{2.34}$$

where A_a is the gross collector aperture area (m^2), I_t is the global solar irradiance at the collector (kW/ m^2), T_a is the ambient air temperature, T_{in} is the fluid temperature inlet at the collector, T_{out} is the fluid temperature outlet at the collector, $\dot{m}$ is the fluid flow rate, and $(\tau\alpha)_n$ is the normal absorptance and the transmittance of collector characteristics.

In generating heated/hot water by a solar thermal collector, as shown in Fig. 2.4, the cold fluid/water is pumped to collect/absorb heat from the collector. Hot water leaves the collector and heads to the hot water tank, then discharges when hot water is required for the absorption cooling system.

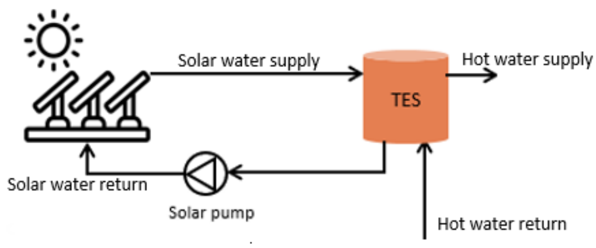


Figure 2.4 Schematic diagram of hot water generated by the solar thermal collector

2.4.Sizing ancillary equipment and Heat rejection system

The ancillary equipment in this study includes pumps and cooling towers. Pumps can separate into three types based on the operational purpose of the pumps, i.e., chilled water pump (CWP), condenser water pump (CDP), and hot water pump (HWP).

The heat input estimates the chilled water pump specification at the evaporator ($Q_{E,in}$), and the heat input at the generator ($Q_{G,in}$) calculates the hot water pump specification. The condenser pump and cooling tower utilize the heat output from the absorber and the condenser to estimate the specifications, such as working fluid flow rate and the power input of the pumps and cooling tower. The last working type of pump, the condenser water pump, is available to coordinate with the cooling tower to carry the heat out from the chiller.

Accordingly, a condenser pump pumps the cooling water from the condenser to the cooling towers, and the cooling tower rejects heat from the water to ambient air. Once the cooling water has cooled down, and the temperature is ready, return to the condenser to collect heat and sending back to the cooling tower again.

The working flow rate of pumps and cooling tower can be calculated by Eq. 2.35,

$$\dot{Q} = \rho V c(T_{in} - T_{out}) \tag{2.35}$$

Eq. 2.35 shows the equation of energy rate balance for calculating the flow rate of pumps (V,m^3/s), Q is the heat input/output of chiller operation (kW), ρ is the water density (~1,000 kg/m^3), c is the specific heat capacity of water (~4.184 kJ/kg.K), T_{in} and T_{out} is the temperature inlet and outlet of the chiller.

The power input of pumps and cooling tower can be calculated by the pump [24] and cooling tower [25] efficiency equation as follows,

$$\eta_{pump} = \frac{\rho \times g \times Q \times H}{P_m} \tag{2.36}$$

where η_{pump} is the pump efficiency, Q is the flow rate (m^3/s), H is the head of the pump, P_m is the mechanical power input of the pump (kW), ρ is the water density (~1000 kg/m^3), and g = 9.81 m/s^2,

$$\eta_{ct} = \left(\frac{T_{in} - T_{out}}{T_{in} - T_{wb}}\right) \times 100 \tag{2.37}$$

where η_{ct} is the tower efficiency, T_{in} is the inlet water temperature at the cooling tower (ºC or ºF), T_{out} is the temperature of cooled water at the cooling tower basin (ºC or ºF), and T_{wb} is the inlet air wet-bulb temperature (ºC or ºF).

2.5.Software evaluation

The energy performance assessment software is typically developed as an in-house application for confidentially using to assess the energy performance of the building's thermal and electrical energy system. However, there is also commercial software available in the market these days, such as a simulation tool named TRNSYS has been publicized commercially by thermal energy system specialists since the 1980s.

Transient System Simulation Tool (TRNSYS) has been established commercially for designing and assessing the energy performance of the thermal and electrical energy system with a package subscription for any user who wishes to use their software. However, this software is also available in the demo version with some limited features for everyone, which will expire annually in September.

This study aims to develop an excel application for assessing the energy performance of the alternative cooling system without any charge. The developed tool is easy to use as it utilizes one of the most familiar software, Microsoft excel, to develop this application. Moreover, once the users understand the tool processing and the concept of the tool design, this tool is also easy to adjust and modify.

2.6.Financial analysis

To evaluate the effectiveness and financial performance of a given system, discounted cash flow calculation is used to find the cash flow of each future period of the project to finalize Net Present Value (NPV). The NPV is the value of all future cash flow over the entire life of an investment discounted for determining the value of a project [26]. The value of NPV is illustrated in the form below [5]:

$$\mathrm{NPV} = \sum_{j=1}^{n} \frac{\left(B_j - C_j\right)}{(1 + R)^j} \tag{2.38}$$

B_j and C_j are the benefit and cost of the project during j to n years, and R refers to the discount rate. Additionally, to calculate the project's Payback Period based on this approach, we could consider the number of years in which the NPV = 0.

Another thing to point out is that the Internal Rate of Return (IRR) calculation is used to determine the overall rate of return on investment based on its future cash flow. IRR is another technique to re-evaluate an economic performance of a project, finding IRR, the discount rate that makes project NPV to be zero [26]. The IRR formula is as below [5]:

$$\sum_{j=1}^{n} \frac{\left(B_j - C_j\right)}{(1 + \mathrm{IRR})^j} = 0 \tag{2.39}$$

Chapter 3 Energy assessment tool development

The tool developing process and three alternative cooling plant models, and the tool validation by one of the published research projects already presented in Chapter 2, the solar cooling plant in France, will be explained in this chapter.

3.1. Alternative cooling system models

In the first version of the energy assessment tool, three base scenarios of the alternative cooling system are presented as a case study.

3.1.1. Absorption chiller with waste/excess heat

As illustrated in Fig. 3.1, the first scenario for this energy assessment tool consists of a single-effect absorption chiller, Heat rejection equipment, and other necessary equipment for the cooling plant. The driving heat source for this scenario mainly comes from the waste/excess heat source (indirect-fired) or direct heat source from the combustion process. Respectively, the solar application is not applied to this scenario.

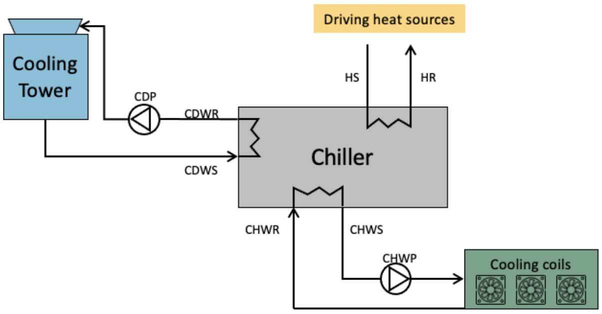


Figure 3.1 Absorption chiller with waste/excess heat

3.1.2. Absorption chiller coupled with waste/excess heat and solar thermal

This second scenario consists of a single-effect absorption chiller, heat rejection equipment, and other necessary equipment for the cooling plant. The driving heat source for this scenario mainly comes from the waste/excess heat source (indirect-fired) and working coupled with the solar thermal collector, as shown in Fig. 3.2.

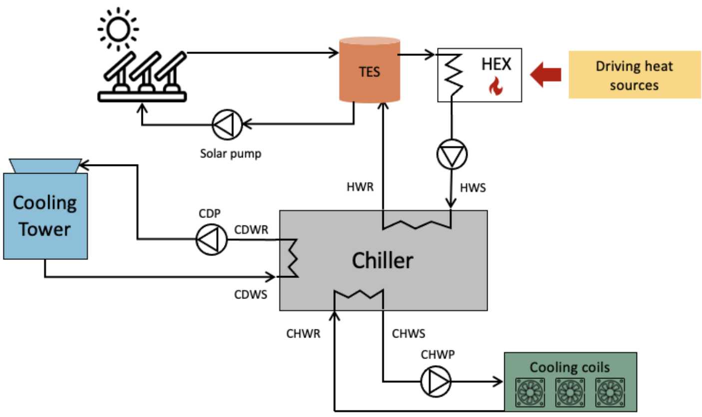


Figure 3.2 Absorption chiller coupled with waste/excess heat and solar thermal

3.1.3. Absorption chiller coupled with waste/excess heat, solar PV, and thermal

The last scenario for this tool consists of a single-effect absorption chiller, heat rejection equipment, and other necessary equipment for the cooling plant. The driving heat source for this scenario mainly comes from the waste/excess heat source (indirect-fired) and working coupled with the solar thermal collector. Additionally, solar PV application is applied to other ancillary equipment such as cooling towers and pumps, as displayed in Fig. 3.3.

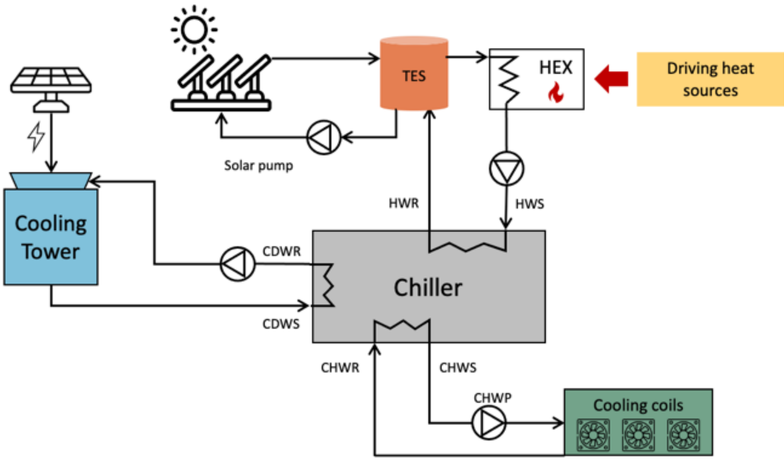


Figure 3.3 Absorption chiller coupled with waste/excess heat, solar PV, and solar thermal

3.2. Excel tool development

The tool's conceptual design and working flow chart, as demonstrated in Fig. 3.4, show the method of the tool development and guide the users to understand the working process of the energy assessment tool quickly. Additionally, this flow chart will also support the users in adequately evaluating the energy performance of the alternative cooling system.

According to Fig. 3.4, the essential primary input parameters for this computational tool are revealed in Table 3.1.

Table 3.1 Summary of the primary input for the energy assessment tool

No	Input parameter	Unit
1	Average Electricity price	THB/kWh
2	Fuel (Natural gas) price	THB/MMBTU
3	Available waste heat	kW
4	Peak cooling load demand	RT
5	Gross floor area	sqm
6	Chilled water supply temp.	°C
7	Chilled water return temp.	°C
8	Cooling water supply temp.	°C
9	Cooling water return temp.	°C
10	Hot water supply temp.	°C
11	Hot water return temp.	°C
12	The concentration of LiBr solution (60% limit)	%

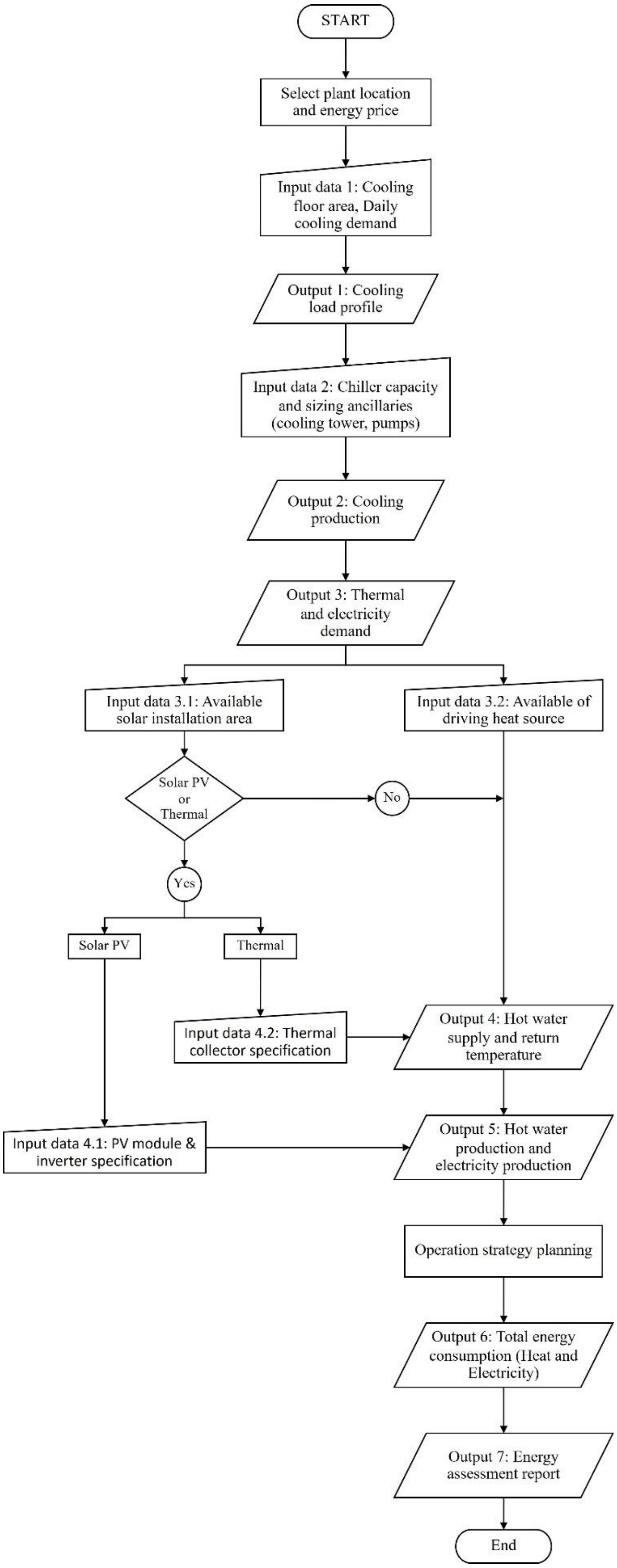


Figure 3.4 Flow chart of the developing preliminary alternative cooling system energy assessment tool

3.2.1. Plant location and energy price

In the first version of the tool, three locations/provinces of Thailand and the Philippines are prepared for site selection of the facility. The weather condition for every hour over the year of those areas will be provided and selected automatically once the users choose their plant location, as indicated in Fig. 3.4. Consequently, the users will need to set up the corrective coefficient for the monthly cooling demand adjustment over a year, as shown in Table 3.2.

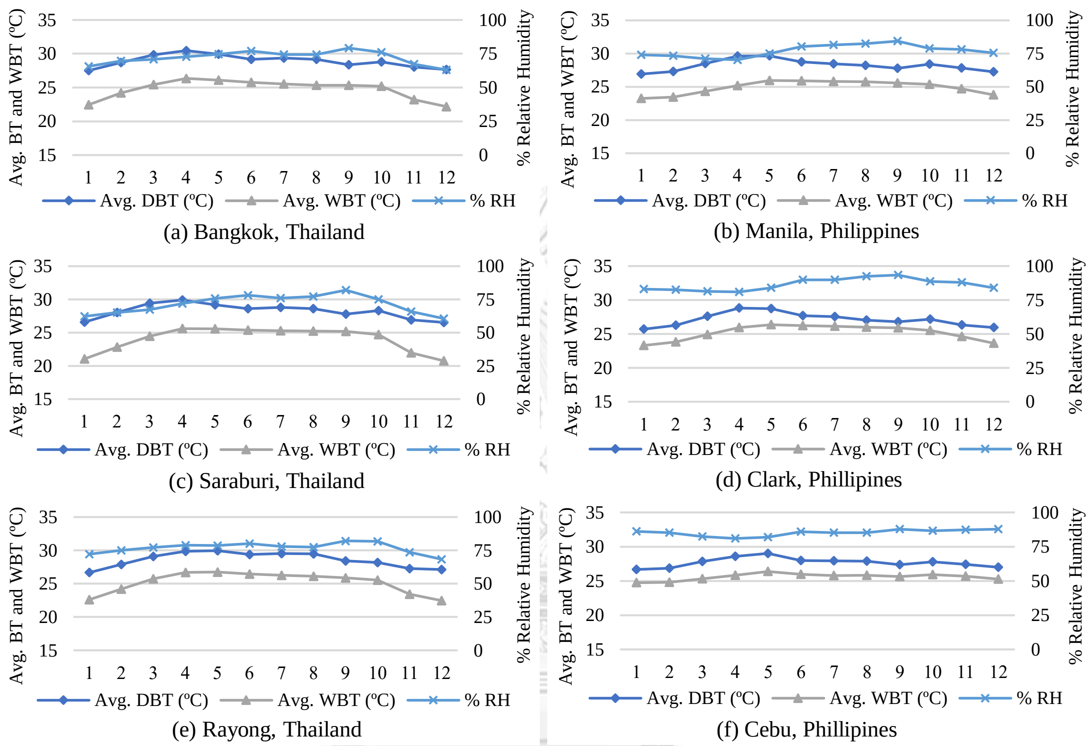


Figure 3.5 Monthly average dry-bulb temperature, wet-bulb temperature, and relative humidity

Table 3.2 The corrective coefficient of the facility located in Bangkok, Thailand

Month		Corrective coefficient	Month		Corrective coefficient
1	January	0%	7	July	11%
2	February	6%	8	August	10%
3	March	9%	9	September	5%
4	April	13%	10	October	6%
5	May	12%	11	November	3%
6	June	10%	12	December	1%

For the energy price selection part, users will be asked to define peak and off-peak hours of weekdays and day-off and input the electricity rate during peak and off-peak. For instance, Thailand's peak hours start from 09:00 AM to 10:00 PM on weekdays (Monday-Friday), and the rest are off-peak. Thus, the users also need to input the average electricity price and fuel price (natural gas cost), as shown in Table 3.1, to estimate the energy consumption cost of the cooling plant over the year. For instance, the average electricity price is 3.57 THB/kWh, and the fuel price is 242 THB/MMBTU.

3.2.2. Cooling load demand

Three types of facilities are present in this study, specifically, commercial and residential buildings and factories. The cooling load demand for commercial and residential buildings such as hotels, retail, and office are calculated based on the cooling floor area (sqm) and the cooling rate ratio (sqm /RT). In contrast, the cooling load demand of the factory will be estimated by the factory's daily peak load demand (RT). The cooling load ratio for each type of activity defines in Table 3.3, and the cooling load demand of commercial/residential buildings calculates following Eq 3.1.

$$\text{Cooling load demand} = \frac{\text{Total cooling floor area}}{\text{Cooling load ratio}} \tag{3.1}$$

Table 3.3 cooling load ratio for each type of activity

Type of activity	Ratio (sqm/RT)
Hotel	32
Retail	35
Residence	32
Office	44

After calculating the peak load demand of the cooling plant, the daily cooling load demand can be forecasted by the cooling load demand multiplied by the hourly cooling percentage for weekdays and day-offs shown in Eq. 3.2. The cooling load percentage depends on the type of building activity, as presented in Appendix II, and the example of daily cooling load demand demonstrates in Fig. 3.6.

$$\text{Daily cooling load demand} = \text{cooling load demand} \times \%\ \text{cooling load} \tag{3.2}$$

Example 1: Retail building A

The peak cooling load demand of retail Building A with 4,500 sqm with an 80 percent cooling load area is roughly 91 RT peak for weekdays and 103 RT peak for day-off.

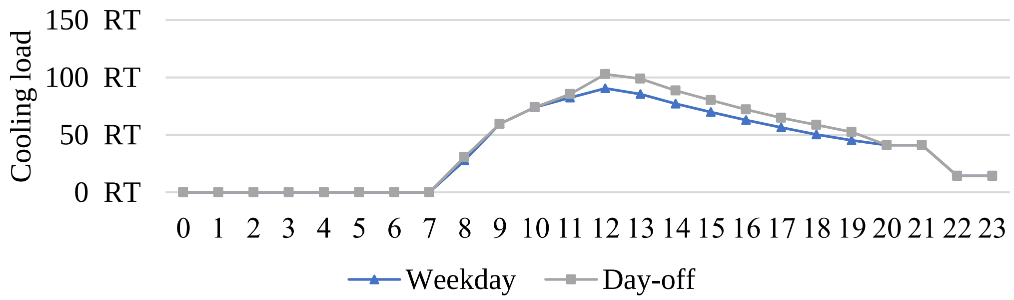


Figure 3.6 Hourly cooling load demand of retail Building A for weekdays and day-off

Following Fig. 3.6, the daily peak cooling load demand of Building A approximately 103 RT, then the chiller cooling capacity should be around 103 RT or

362.24 kW. Referring to the absorption list in the simulation tool, 118 RT chiller cooling capacity seems to be the most reasonable chiller size for Building A.

3.2.3. Chiller cooling capacity and the energy rate balance calculation

A single-effect absorption chiller consists of an evaporator, an absorber, a generator, a condenser, a solution heat exchanger (HEX), a solution pump, and two expansion valves [5], as illustrated in Fig. 2.2. Generally, the peak cooling load leads to the suitable chiller cooling capacity selection, representing the energy input rate at the evaporator ($\dot{Q}_{E,in}$).

The mass and energy balance calculation following the thermodynamic analysis and the mathematical models of each chiller component as described in Eq 2.1 – 2.25.

<u>The mass and energy rate balance calculation of single-effect absorption chiller:</u>

According to Eq. 2.1 – 2.4 and the primary operating temperature input in Table 3.4, the operational temperature of single-effect absorption for 10 stage points is expressed in Table 3.5.

Table 3.4 Alternative cooling system assumption of example 1

Primary input assumption	Inlet temperature	Outlet temperature
Chilled water	12°C	7°C
Hot water	90°C	80°C
Cooling water	30°C	36°C

The enthalpy of LiBr solution in stages 1 – 6 for calculating the energy input and output of each chiller component is presented in Fig. 3.7 [27,28], except in stage 3, the enthalpy in this stage point requires an estimate from the heat transfer formula as given in Eq. 2.20. The enthalpies of the working refrigerant are formulated by Eq. 2.23 and 2.25.

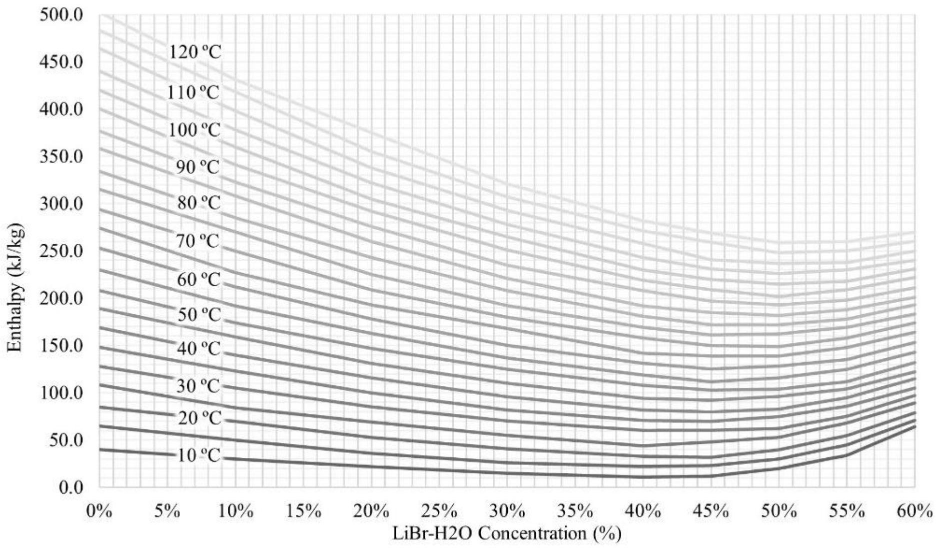


Figure 3.7 Lithium-Bromide solution concentration-Temperature-Enthalpy

Table 3.5 Operational parameters of the single-effect absorption chiller

Stage point	Working temperature (°C)	Enthalpy (kJ/kg)	LiBr concentration
1	39	80.04	0.48
2	39	80.04	0.48
3	-	-	0.48
4	77	175.48	0.56
5	39	97.16	0.56
6	39	97.16	0.56
7	77	2,644.22	-
8	39	163.25	-
9	39	163.25	-
10	5	2,510.30	-

According to the thermodynamic equations of the single-effect absorption chiller, the mass flow rate and energy rate balance of each chiller component are presented in Table 3.6, and the calculation is thoroughly solved as follows,

Table 3.6 Summary of the mass and energy input and output calculation of 118 RT single-effect absorption chiller

	Chiller components	Index	value	unit
1	Evaporator	$\dot{Q}_{E,in}$	414.99	kW
		$\dot{m}$,	0.177	kg/s
2	Absorber	$\dot{Q}_{A,out}$	447.86	kW
		λ	6	-
		$\dot{m}_{ss}$	1.061	kg/s
		$\dot{m}_{ws}$	1.238	kg/s
3	Solution heat exchanger	h_3	147.17	kJ/kg
4	Generator	$\dot{Q}_{G,in}$	472.54	kW
5	Condenser	$\dot{Q}_{C,out}$	438.67	kW

<u>Evaporator</u>:

The cooling capacity at 414.99 kW, then $\dot{Q}_{E,in} = 414.99$ kW. According to Eq. 2.9 and 2.10 and the enthalpy at working state points 9 and 10, a mass flow rate of refrigerant ($\dot{m}$) can be calculated by:

Eq. 2.10,

$$\dot{Q}_{E,in} = \dot{m}_{10}h_{10} - \dot{m}_9h_9$$

and Eq. 2.9,

$$\dot{m} = \dot{m}_9 = \dot{m}_{10}$$

finding h_9 and h_{10} by Eq. 2.23 and 2.25,

$$h_9 = 4.186(T_9) = 163.254 \text{ kJ/kg}$$

$$h_{10} = 2501 + 1.86(T_{10}) = 2{,}510.30 \text{ kJ/kg}$$

then, $\dot{m} = \dot{Q}_{E,in}/(h_{10} - h_9) = 414.99/(h_{10} - h_9)$

$$\dot{m} = 0.177 \text{ kg/s}$$

Absorber:

The heat input from the evaporator ($\dot{Q}_{E,in}$) and generator ($\dot{Q}_{G,in}$) approach to the absorber, respectively, during this process, the cooling water also circulates inside the absorber to collect the heat ($\dot{Q}_{A,out}$) and release it at the cooling tower. At this stage, the vaporized refrigerant mixes with the concentrated LiBr solution to become a weak LiBr solution, then pumped back into the generator.

The enthalpy at working state points 1, 6, and 10, and the concentration percentage of strong at 56% and weak solution at 48%. The calculation of the energy rate at the absorber and the mass flow rate of LiBr solution can be calculated as follows,

Eq. 2.13 – 2.15,

$$\lambda = \xi_{ws}/(\xi_{ss} - \xi_{ws}) = 0.48/(0.56 - 0.48) = 6,$$

then the mass flow rate of strong LiBr solution

$$\dot{m}_{ss} = \dot{m}_6 = 6 \times 0.177 = 1.061 \text{ kg/s}$$

and mass flow rate of weak LiBr solution

$$\dot{m}_{ws} = \dot{m}_1 = (1 + 6) \times 0.177 = 1.238 \text{ kg/s}$$

from Eq. 2.11 and 2.12, the energy rate at the absorber ($\dot{Q}_{A,out}$) calculates as follows,

$$\dot{Q}_{A,out} = \dot{m}_6 h_6 + \dot{m}_{10} h_{10} - \dot{m}_1 h_1$$

$$\dot{Q}_{A,out} = 1.061(h_6) + 0.177(2510.30) - 1.238(h_1)$$

Accordingly, the enthalpy of LiBr solution at working stage 1 (h_1) and 6 (h_6) are provided in Fig.3.7,

$$\dot{Q}_{A,out} = 447.86 \text{ kW}$$

Solution heat exchanger:

The heat transfer equation between strong and weak LiBr solution, as shown in Eq. 2.20, leads to the enthalpy of LiBr solution at working stage 3 estimation calculates as follows,

$$\dot{m}_1(h_4 - h_5) = \dot{m}_6(h_3 - h_2)$$

then,

$$h_3 = [(\dot{m}_1(h_4 - h_5))/\dot{m}_6] + h_2$$

thus, the enthalpy of LiBr solution at working stage 2 (h_2), 4 (h_4) and 5 (h_5) are provided in Fig.3.7,

$$h_3 = 147.17 \text{ kJ/kg}$$

Generator:

The absorption chiller requires the thermal energy ($\dot{Q}_{G,in}$) to separate absorbent and refrigerant. The heat load demand of 118 RT chiller size can be calculated by Eq. 2.16 and 2.17,

$$\dot{Q}_{G,in} = \dot{m}_4 h_4 + \dot{m}_7 h_7 - \dot{m}_3 h_3$$

According to Fig. 2.2, the mass flow rate at stage points 4 $(\dot{m}_4) = \dot{m}_5 = \dot{m}_6 = \dot{m}_{ss}$, the mass flow rate at stage points 3 $(\dot{m}_3) = \dot{m}_2 = \dot{m}_1 = \dot{m}_{ws}$, and $\dot{m}_7 = \dot{m}$
then,

$$\dot{Q}_{G,in} = 1.061(h_4) + 0.177(h_7) - 1.238(h_3)$$

therefore, the enthalpy of LiBr solution at working stage 4 (h_4) is provided in Fig.3.7, the enthalpy at working stage 3 (h_3) is calculated in the solution heat exchanger part, and the enthalpy at working stage 7 can be calculated by Eq. 2.25,

$$h_7 = 2501 + 1.86(T_7)$$
$$h_7 = 2{,}644.22 \text{ kJ/kg}$$

then,

$$\dot{Q}_{G,in} = 471.54 \text{ kW}$$

Condenser:

The cooling water was entered at the condenser to collect heat $(\dot{Q}_{C,out})$ and released at the cooling tower. The high-temperature vaporized refrigerant drops its heat temperature and condenses in this stage, then circulates to the evaporator and gathers building heat load again.

Following Eq. 2.18 and 2.19, the heat output at the condenser can be calculated as follows,

$$\dot{Q}_{C,out} = \dot{m}_7 h_7 - \dot{m}_8 h_8 \ ; \dot{m}_7 = \dot{m}_8 = \dot{m},$$

and the enthalpy at working stage 8 can be calculated by Eq. 2.23,

$$h_8 = 4.186(T_8) = 4.186(39) = 163.25 \text{ kJ/kg}$$

then,

$$\dot{Q}_{C,out} = 438.67 \text{ kW}$$

3.2.4. Sizing other related ancillary equipment

According to Eq. 2.35 and 2.36, calculating comply with the assumptions in Table 3.7. The conversion rate ratio and the cooling tower efficiency in Table 3.7 were set as a tool default in this computational tool.

Table 3.7 The assumptions for pumps and cooling towers specifications

	Assumption	Value	Unit
1	Pump efficiency	85%	-
2	Head of CWP	29	mH_2O
3	Head of CDP and HWP	35	mH_2O
4	HRT conversion ratio	1.2	HRT/RT
5	kW conversion ratio	3.52	kW/RT
6	Cooling tower efficiency	0.04	kW/RT

Flow rate and power input calculations for pumps and cooling towers:

Each chiller component's energy input and output estimate the ancillary equipment specifications, such as chiller pump, condenser pump, hot water pump, and cooling tower.

Table 3.8 Primary specification of pumps and cooling towers

	Ancillary	Index	Value	Unit
1	Chilled water pump	V	71.20	m^3/h
		P_{input}	6.62	kW
2	Condenser water pump	V	151.98	m^3/h
		P_{input}	17.05	kW
3	Hot water pump	V	40.42	m^3/h
		P_{input}	4.54	kW
4	Cooling towers	Heat load_{CT}	302.23	HRT
		$\text{Number of cell}_{CT}$	4	Cells
		$P_{input/cell}$	3.02	kW

The summary calculation results are shown in Table 3.8, and the solving method for finding the specifications of ancillary equipment is as follows,

Chilled water pump:

finding the working flow rate of the chilled water pump is estimated by Eq. 2.35,

$$V = \dot{Q}_{E,in}/\rho c(T_{in} - T_{out})$$

The chilled water temperature inlet and outlet are presented in Table 3.4, and the heat input at the evaporator is shown in Table 3.6,

then,

$$V = [414.99/1000 \times 4.184 \times (12 - 7)] \times 3600$$

$$V = 71.20\ m^3/h$$

and power input required of the chilled water pump is defined by Eq. 2.36,

$$P_{input} = \rho g V H/\eta_{pump}$$

$$P_{input} = 1000 \times 9.81 \times 71.20 \times 29/0.85 \times 3600$$

$$P_{input} = 6.62\ kW$$

Hot water pump:

finding the working flow rate of the hot water pump is calculated by Eq. 2.35

$$V = \dot{Q}_{E,in}/\rho c(T_{in} - T_{out})$$

The hot water temperature inlet and outlet are illustrated in Table 3.4, and the thermal energy demand at the generator is provided in Table 3.6,

then,

$$V = [471.54/1000 \times 4.184 \times (90 - 80)] \times 3600$$

$$V = 40.42\ m^3/h$$

finding power input of the hot water pump is calculated by Eq. 2.36,

$$P_{input} = \rho g V H/\eta_{pump}$$
$$P_{input} = 1000 \times 9.81 \times 40.42 \times 35/0.85 \times 3600$$
$$P_{input} = 4.54 \text{ kW}$$

Condenser water pump:
finding the working flow rate of the condenser pump is defined by Eq. 2.35,

$$V = (\dot{Q}_{A,out} + \dot{Q}_{C,out})/\rho c(T_{in} - T_{out})$$

The cooling water temperature inlet and outlet are presented in Table 3.4, and the heat input at the absorber and the condenser is shown in Table 3.6,
then $V = [886.53/1000 \times 4.184 \times (|30 - 36|)] \times 3600$

$$V = 151.98 \text{ m}^3\text{/h}$$

finding the power input required of the condenser pump is defined by Eq. 2.36,

$$P_{input} = \rho g V H/\eta_{pump}$$
$$P_{input} = 1000 \times 9.81 \times 151.98 \times 35/0.85 \times 3600$$
$$P_{input} = 17.05 \text{ kW}$$

Cooling Towers:
The cooling tower specifications include the heat load and the power input per cell of cooling towers. Respectively, the working flow rate at cooling towers is equivalent to the condenser water pump. The solving method of finding the cooling tower specifications is calculated by Eqs. 3.3 and 3.4.

$$\text{Heat load}_{CT} = \left[(\dot{Q}_{A,out} + \dot{Q}_{C,out})/\text{kW conversion ratio}\right] \times \text{HRT conversion ratio} \quad (3.3)$$

$$\text{Power}_{input/cell} = \text{CT eff.} \times \text{Heat load per cell} \quad (3.4)$$

Total heat load at cooling towers,

$$\text{Heat load}_{CT} = 302.23 \text{ HRT}$$

then,

$$\text{Heat load}_{per\ cell} = 75.56 \text{ HRT}$$

Finding power input per cell of the cooling towers calculated by Eq 3.4, then heat load per cell,

$$\text{Power}_{input/cell} = 3.02 \text{ kW}$$

3.2.5. Available heat source and solar production

The alternative cooling model in this study primarily consumes waste or excess heat or applies both resources in the same cooling system to cover the plant's thermal heat load demand rather than purely utilizing natural gas. Additionally, solar thermal and electricity production are the optional applications for assisting the alternative cooling system. The monthly solar radiation intensity estimates solar production in a year.

The solar radiation intensity applied to this computational tool over the year is based on the department of alternative energy development and efficiency (DEDE) database in 2017, as indicated in Fig. 3.8. However, if the users prefer to use their own solar radiation intensity data, replace them in the country tab in the tool.

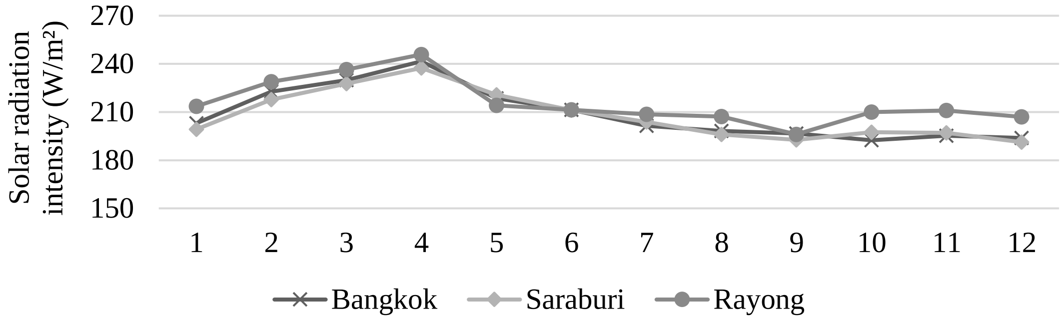


Figure 3.8 Monthly solar radiation intensity of Bangkok, Saraburi, and Rayong Thailand, 2017

Following Example 1, assume Building A has available waste heat is approximately 450 kWh and roughly 22 kWh of natural gas consumption to fulfill the thermal energy demand at the generator. Additionally, Building A requires the installation of 25 kW of thermal collector and 50 kW-DC of solar photovoltaic.

The solar thermal collector and PV module specifications applied in Example 1 are presented as follows,

Thermal collector specification

The flat plate thermal collector has a 2.36 m2 absorber area, and an efficiency coefficient is around 0.83.

Following the Eq. 2.30 – 2.32, the total absorber area required for 25 kW heat of thermal collector can be defined as follows,

$$\mathrm{A_a} = \mathrm{Q_u}/\eta \times \mathrm{I_t}$$
$$\mathrm{A_a} = 25 \times 1000/0.83 \times 208.73$$
$$\mathrm{A_a} = 144.30\ \mathrm{m}^2$$

The number of collector plates on-site can be estimated by Eq. 3.5 as follows,

$$\text{Number of collectors plate} = \mathrm{A_a}/\text{Absorber area per plate} \tag{3.5}$$

then,

$$\text{Number of collector plate} = 62 \text{ collector plates}$$

Photovoltaic module specification

PV module (model 550) with the module efficiency reaches 21.5% standard test conditions, and the thorough specification of the module is as follows,

- Max. Voltage 41.95 V, Max. current 13.12 A
- Dimension width 2256 mm x length 1131 mm x depth 35 mm

Following the Eq. 2.26 – 2.28, the power output of 550 PV modules can be defined as follows,

$$\mathrm{P_{out}} = \mathrm{V_{max}} \times \mathrm{I_{max}}$$
$$\mathrm{P_{out}} = 550.384\ \text{W, (\~0.55 kW)}$$

Then, the number of 550 PV modules for 50 kW-DC required on-site can be calculated as follows,

$$\text{Number of collectors plate} = 50/0.55$$

$$\text{Number of collector plate} = 90.9 \text{ modules } (\sim 91 \text{ modules})$$

Accordingly, the solar production is multiplied by the daily solar radiation available coefficient, as presented in Appendix III. The solar output of retail Building A is shown in Fig. 3.9.

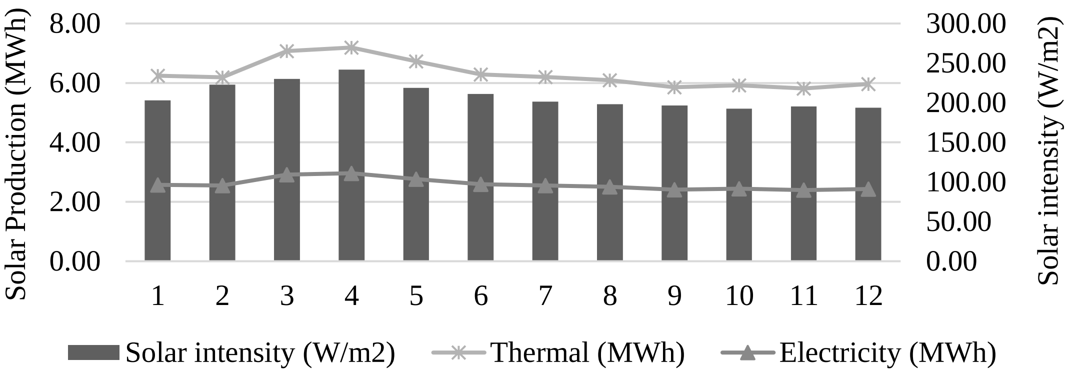


Figure 3.9 Monthly solar production of Example 1, Building A, located in Bangkok, Thailand

The monthly thermal energy demand in a year of Building A is demonstrated in Fig. 3.10. The total electricity demand is estimated by the summary of the power input (kW) of pumps and the cooling towers and the solar PV production demonstrated in Fig. 3.11.

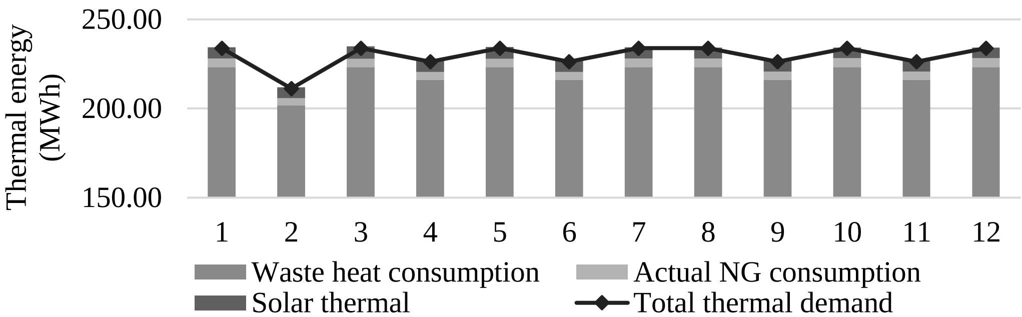


Figure 3.10 Monthly thermal energy consumption of Example 1, Building A

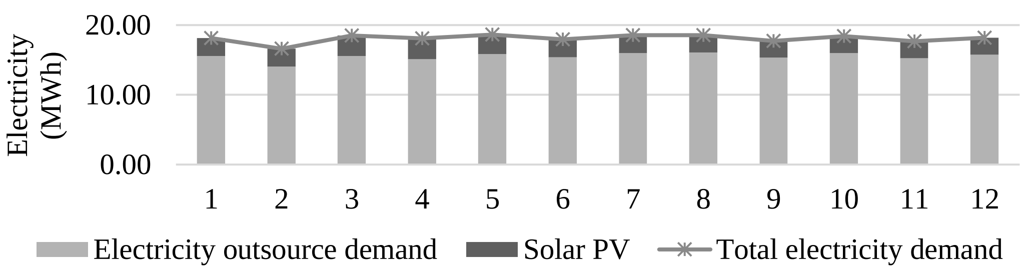


Figure 3.11 Monthly electricity consumption of Example 1, Building A

3.2.6. Total cooling production and energy consumption

The monthly cooling load demand over the year is adjusted by the monthly collective coefficient as illustrated in Table 3.2 and the 24-hours cooling load percentage, which depends on the building activity as indicated in Appendix II. This value relies on the user's decision to estimate from the weather data provided in the tool or by the number of clients in a typical month, if it is a retail or residential building.

This EA tool will summarize the cooling load demand or production and energy consumption of Example 1, Building A, over the year in monthly data as presented in Fig. 3.12, which includes thermal energy and the electricity in the MWh unit.

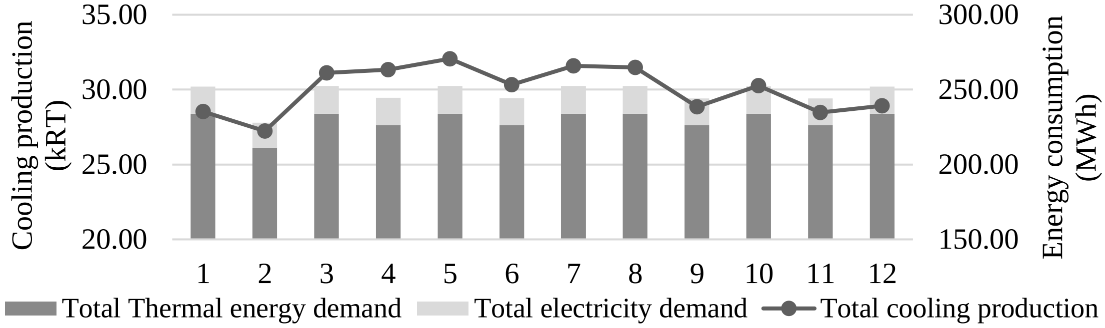


Figure 3.12 Monthly cooling load and energy consumption of Example 1, Building A

The solving method of the monthly cooling load demand of Example 1 can be calculated by Eqs. 3.6 and 3.7,

$$\text{Cooling load at } M_x = (1+\text{collective coefficient at } M_x) \times \text{Cooling load demand at } h_t \quad (3.6)$$

$$\text{Cooling load demand at } h_t = (1+\text{cooling percentage at } h_t) \times \text{peak load RT} \quad (3.7)$$

Following Example 1, the peak cooling load of Building A is roughly 91 RT for weekdays and 103 RT for day-off.

The cooling load percentage at $h_8 = 27\%$ for weekdays and $h_8 = 30\%$ for day-off and the collective coefficient at M_2 (February) $= 6\%$, then the estimation of cooling load demand is expressed as follows,

Weekdays cooling load at hour 8 in February,

$\text{Cooling load demand at } h_8 = 115.57 \text{ RT}$

$\text{Cooling load at } M_2 = 122.50 \text{ RT}$

Day-off cooling load at hour 8 in February,

$\text{Cooling load demand at } h_8 = 133.90 \text{ RT}$

$\text{Cooling load at } M_2 = 141.93 \text{ RT}$

3.2.7. Energy performance of an alternative cooling system

The energy performance of this study has presented in a two-term of the energy performance coefficient, Energy Efficiency coefficient (EE), and chiller's Coefficient of Performance (COP).

The energy efficiency is mainly represented by the two units' operational performance of the alternative cooling system. The first one is the electricity consumption of chillers and other related equipment in kWh/RT and the thermal energy consumption of the single-effect absorption chiller in kWh-heat/RT. The latter term of energy performance coefficient, COP, presents the absorption chiller's energy conversion performance by an energy output divided by energy input.

The total cooling plant energy performance of Example 1 is revealed in Fig. 3.13 and 3.14, and the performance calculations have been calculated as follows,

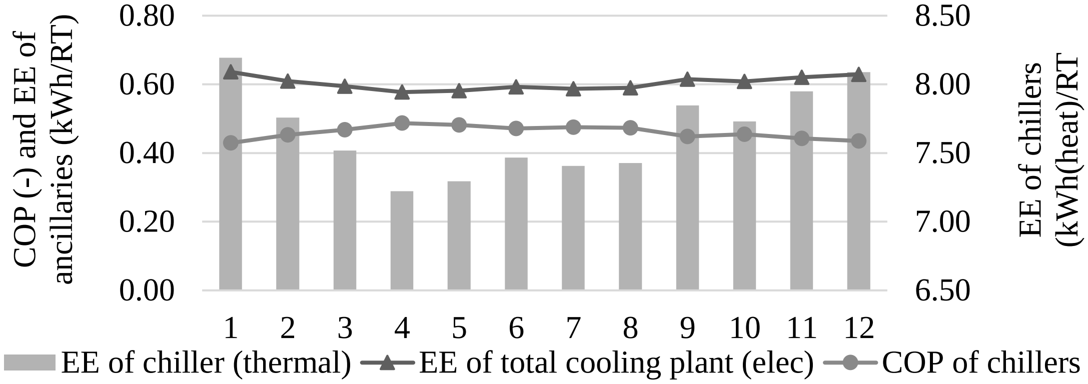


Figure 3.13 Monthly energy performance of the alternative cooling plant, Example 1

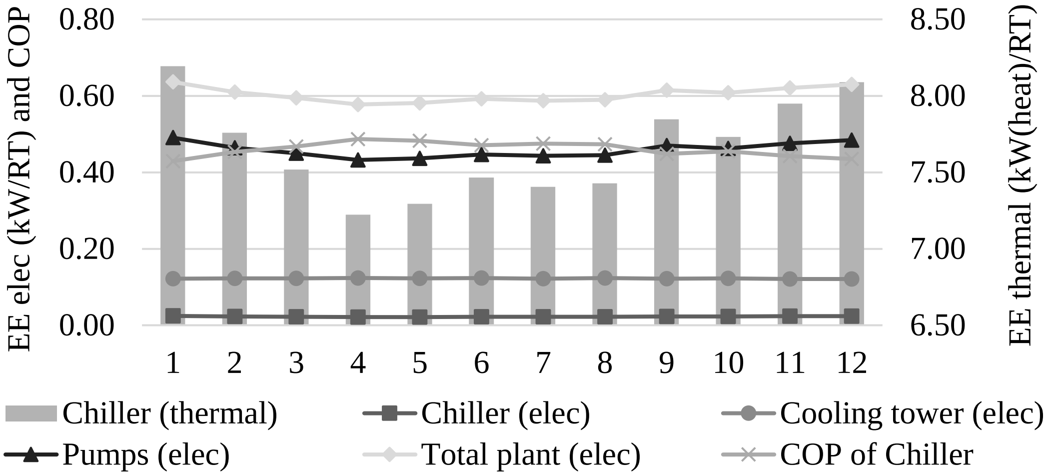


Figure 3.14 Monthly energy performance of chiller and ancillary equipment, Example 1

The solving method of the monthly Coefficient of Performance of the chiller can be calculated by Eq. 2.8.,

$$\mathrm{COP} = \dot{Q}_E / \dot{Q}_G$$

and the monthly energy efficiency of Example 1, retail building, can be calculated by Eq. 3.8,

$$\text{Energy Efficiency} = \text{Energy consumption}/\text{Cooling production} \tag{3.8}$$

According to Fig 3.12, the monthly cooling capacity in January is around 28,540.8 RT. In January, the total thermal energy consumption reached 233,885.3 kWh, and the total electricity consumption of the cooling plant was 18,157.33 kWh.

The average COP of the single-effect absorption chiller in January is approximately 0.429,

and the average Electrical Energy Efficiency in January

$$\text{Energy Efficiency} = 0.636\ \text{kWh/RT}$$

and the average Thermal Energy Efficiency in January

$$\text{Energy Efficiency} = 8.185\ \text{kWh(heat)/RT}$$

3.2.8. Energy consumption cost for a year operating an alternative cooling system

The total energy consumption cost over a year of plant operation for Example 1 is presented in Fig. 3.15. Respectively the chart also illustrates the cost-saving caused by the solar applications.

The cost-saving of the energy consumption is calculated based on solar production. For instance, solar electricity production is multiplied by the average electricity cost to estimate the cost-saving of electricity consumption. The thermal solar output is multiplied by the natural gas price to calculate the cost-saving of the natural gas.

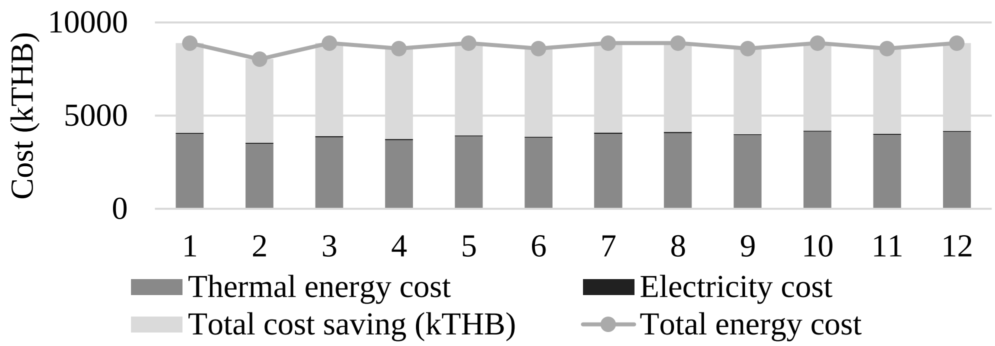


Figure 3.15 Monthly energy consumption cost and cost-saving, Example 1

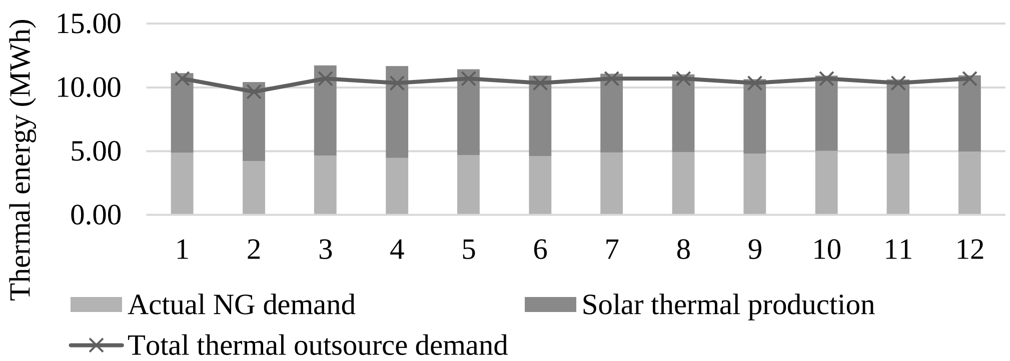


Figure 3.16 Thermal energy demand and solar production, Example 1

Following Fig. 3.16, the total thermal outsourcing requires around 10.69 MWh, and the average natural gas price is roughly 242 THB/MMBTU. Then the solving solution of the thermal energy cost in January for Building A calculated by Eq. 3.9 as follows,

$$\text{Thermal energy cost} = \text{Thermal energy demand} \times \text{Natural gas price} \quad (3.9)$$

then,

$$\text{Thermal outsource cost} = 8{,}823{,}170.05 \text{ THB}$$

According to Fig. 3.10, the total thermal energy consumption in January is approximately 233.89 MWh, and Fig.3.16 shows the actual natural gas demand is required for only 4.86 MWh (4,861.669 kWh) to cover the thermal demand of the cooling plant in January.

Then following Eq. 3.9, the actual thermal energy cost or the natural gas cost,

$$\text{Actual thermal cost} = 4{,}014{,}417.20 \text{ THB}$$

The following Eq. 3.10 can calculate the thermal cost-saving of the solar thermal production,

$$\text{Total thermal cost-saving} = \text{Thermal outsource cost - Actual thermal cost} \quad (3.10)$$

then,

$$\text{Total thermal cost saving} = 4{,}808{,}752.85 \text{ THB}$$

The electricity cost is projected by the total electricity consumption at the plant multiplied by the average electricity cost of the plant, as presented in Eq. 3.11 below,

$$\text{Total electricity cost} = \text{Electrical energy demand} \times \text{Avg. electricity price} \quad (3.11)$$

Following Fig. 3.11, in January, the total electricity demand at the plant is roughly 18,175.33 kWh, with total electricity outsourcing demand being around 15,585.49 kWh, and the average electricity cost of Example 1, retail building A, is 3.57 THB/kWh, then the actual electricity cost can be estimated as follows,

$$\text{Total electricity cost} = 55{,}640.20 \text{ THB}$$

The thermal cost-saving of the solar PV production can be calculated by Eq3 .3.12 as follows,

$$\text{Electricity cost saving} = \text{Solar PV produciton} \times \text{Avg. electricity price} \quad (3.12)$$

then,

$$\text{Electricity cost saving} = 9{,}181.47 \text{ THB}$$

The total energy cost-saving of the Building A in January indicates as follows,

$$\text{Total energy cost saving} = 4{,}817{,}934.32 \text{ THB}$$

3.3. Tool validation

The mathematical models applied in this computational tool are validated by the previously published research.

Accordingly, The installed solar cooling project in Saint Pierre in Reunion Island, France [8], established LiBr-water single-effect absorption chiller with a 30 kW cooling capacity for cooling four classrooms coupled with a double-glazed flat plate solar collector with a 90 sqm aperture area, the solar cooling project in France specification presented in Tables 3.9 and the validation result illustrated in Table 3.10.

Table 3.9 Solar cooling project specification in Saint Pierre in Reunion Island, France

Parameter		Value	Operation
1	Cooling load	20.29 kW	-
2	Chiller water return	16.60 ° C	Chilled water flow rate = 1.19 L/s
3	Chiller water supply	12.54 ° C	
4	Hot water return	65.04 ° C	Hot water flow rate = 1.01 L/s Heat supply to generator = 32.2 kW
5	Hot water supply	72.75 ° C	
6	Cooling water return	27.60 ° C	Cooling water flow rate = 3.02 L/s Cooling cap. = 50.7 kW
7	Cooling water supply	31.62 ° C	

Following Table 3.9, the second column shows the input data for validating the chiller working process. This validation part tends to validate whether the formula implemented in the energy assessment tool works appropriately and correctly or not, including finding the differential of the operation parameter between operational data from the published research paper and the output of the tool simulation, as expressed in Table 3.10.

Table 3.10 The validation result of the solar cooling project in France versus the tool

	Parameters	Unit	Research case study	EA tool	Difference
1	Cooling load (chiller)	kW	20.29	20.29	-
2	Chilled water flow rate	L/s	1.19	1.19	0.08%
3	Hot water flow rate	L/s	1.01	1.03	2.19%
4	Cooling water flow rate	L/s	3.02	3.05	0.95%
5	Thermal supply	kW	32.20	33.42	3.79%
6	Cooling tower capacity	kW	50.70	51.47	1.53%
7	COP	-	0.63	0.61	3.64%

According to Table 3.10, the cooling load of the chiller at 20.29 kW is input to the EA tool. The working flow rate and the energy rate balance of each chiller's component, including COP of the single-effect absorption chiller, are brought out as the operational outputs of the system.

The slightly different percentage of around 0 – 4% between the research case study and the EA tool, as illustrated in Table 3.10, shows that this computational tool is applicable for utilizing and evaluating the alternative cooling system.

3.4. Instruction for user

The user manual or the guideline book serves in Appendix IV for any users unfamiliar with this kind of computational tool, and the necessary input parameters have already been presented in Table 3.1.

Generally, four-color codes appear in the tool application to specify the input cell, the dropdown list cell, the reference cell (no action required), and the formula cell (no action required), as demonstrated in Fig 3.17.

Input data	Dropdown list	Reference to other sheet	Formula contains

Figure 3.17 The color codes referenced in the energy assessment tool

The white and pink cells should not be touched unless the tool modifications are needed because they contain the formula calculation and refer to the data from other sheets. Accordingly, regarding which parameter should be input or selected for every part of the tool, the users can follow the user manual guideline in Appendix IV.

Chapter 4 Case study and result discussion

Following the tool, the validation result shows the exceptional agreements between the tool application and the previously published research, and the tool development methods have been already explained in Chapter 3 then in this chapter will present the case study. The excel tool will give the cooling load demand, the energy consumption, and the energy performance of the utility plant and aims to deliver the energy report of the alternative cooling plant to the users.

4.1. Case study: Hotel building

The Hotel building, Hotel A, located in Bangkok, Thailand, has a total gross floor area of approximately 47,000 sqm and an 80% cooling floor area. The necessary primary inputs for the tool application are expressed in Table 4.1.

Table 4.1 The primary input of the case study, Hotel A

No	Input parameter	Value	Unit
1.	Average Electricity price	3.79	THB/kWh
2.	Fuel (Natural gas) price	242	THB/MMBTU
3.	Available waste heat	8,000	kW
4.	Gross floor area	47,000	sqm
5.	Chilled water supply temp.	5	°C
6.	Chilled water return temp.	13	°C
7.	Cooling water supply temp.	36	°C
8.	Cooling water return temp.	31	°C
9.	Hot water supply temp.	90	°C
10.	Hot water return temp.	80	°C
11.	The concentration of LiBr solution (60% limit)	56	%

The weather characteristic of Hotel A location is illustrated in Fig. 3.4(a), and the monthly corrective coefficient has been expressed in Table 3.2.

4.1.1. The cooling load demand of Hotel A

Following Fig. 4.1, Hotel A's peak cooling load demand for weekdays and day-off is roughly 1,175 RT, and the total daily cooling load consumption reaches around 22,713 RTh. Accordingly, the cooling load percentage of hotel buildings is demonstrated in Appendix III.

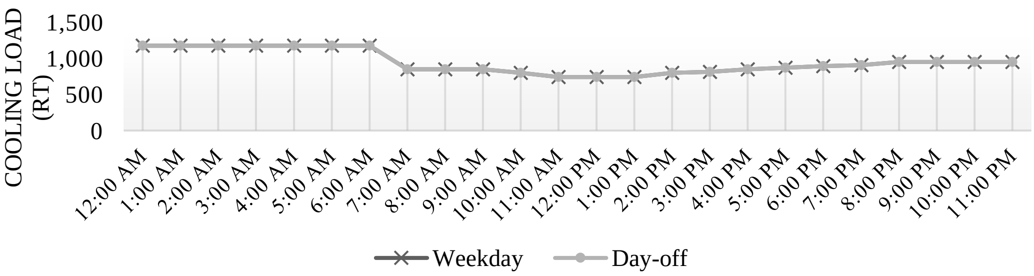


Figure 4.1 Hourly cooling load consumption of Hotel A for weekdays and day-off

4.1.2. Chiller and ancillary equipment specification

According to Hotel A's peak cooling load demand, two single-effect absorption chillers plan to install at the cooling plant. The chiller specification is expressed in Table 4.2 and the following Fig. 4.2 illustrates the alternative cooling plant schematic diagram of Hotel A.

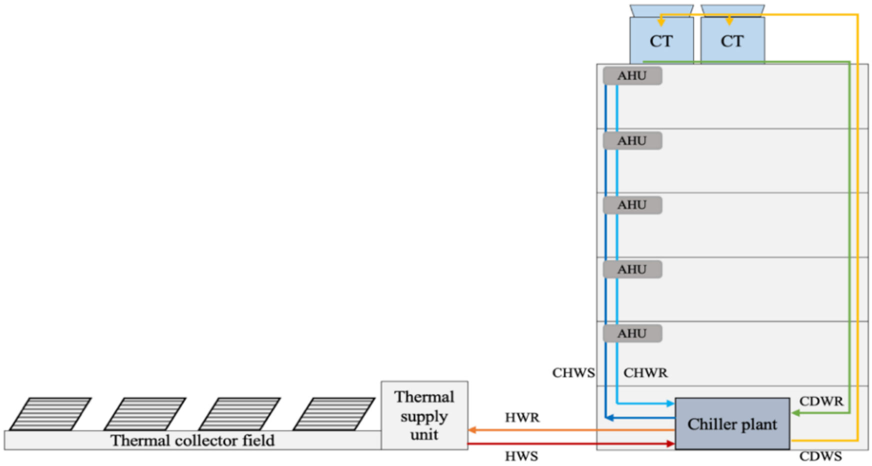


Figure 4.2 Schematic diagram of the alternative cooling plant of Hotel A

Following the schematic diagram presented in Fig 4.2, assume pump efficiency is around 85%, and head of the chilled water pump is 31 mH2O, the condenser pump is 34 mH2O, the hot water pump is 10 mH2O, and the solar pump is roughly 2 mH2O. Then, pumps and cooling tower specifications have been estimated, as demonstrated in Table 4.3.

Table 4.2 The chiller selection of chiller plant at Hotel A

	Chiller components	Index	Value	Unit
1	Evaporator	$\dot{Q}_{E,in}$	3,619	kW
2	Absorber	$\dot{Q}_{A,out}$	3,905	kW
3	Generator	$\dot{Q}_{G,in}$	4,109	kW
4	Condenser	$\dot{Q}_{C,out}$	3,823	kW
	*2x single-effect absorption chillers 1,029 RT			

Table 4.3 The ancillary equipment specification of the chiller plant at Hotel A

	Ancillary	Index	Value	Unit
1	Chilled water pump x2	V	388.08	m^3/h
		P_{input}	38.57	kW
2	Condenser water pump x2	V	1,589.73	m^3/h
		P_{input}	173.28	kW
3	Hot water pump x2	V	352.18	m^3/h
		P_{input}	11.29	kW
4	Cooling towers x2	Heat $load_{CT}$	2,634.49	HRT
		Number of $cells_{CT}$	4	Cells
		$P_{input/cell}$	26.34	kW

The equipment specification that has been expressed in Table 4.2 and 4.3 will guide the various to select the equipment for the alternative cooling plant, respectively.

4.1.3. Thermal heat source

The total thermal energy requires for supplying the generator is around 8,218 kW for 2 single-effect absorption chillers—the outsourcing requirement is roughly 218 kW to cover all the heat load demand at the generator. Additionally, the thermal collector of 120 kW is planned to install to assist the alternative cooling system, and then the thermal collector field specification is expressed in Tables 4.4 and 4.5.

Table 4.4 The thermal collector specification

	System specification	Value	Unit
1	Field capacity	120	kW
2	Model efficiency coefficient	0.83	-
3	The total collector area requires	692.65	sqm
4	Absorber area per plate	2.36	sqm
5	Number of panels	294	plates
6	Total installation area (30% markup)	980	sqm

Table 4.5 The ancillary equipment specification of the solar field

	Ancillary	Index	Value	Unit
1	Solar pump x1	Water temp. inlet/outlet	65/80	°C
		V	4.43	m^3/h
		P_{input}	0.03	kW

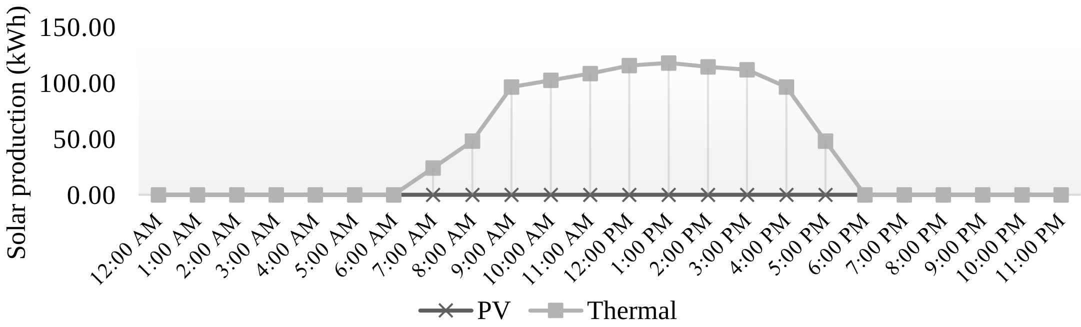


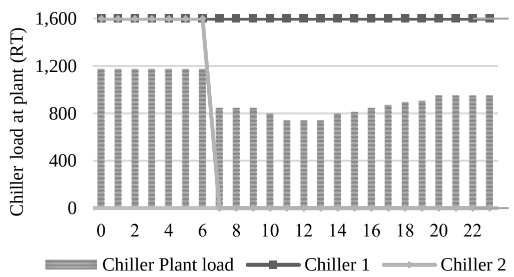
Figure 4.3 Hourly average solar production for a year

The daily average solar production presented in Fig 4.3 applies to the yearly average of solar radiation intensity, around 208.73 W/m^2, with a total solar daily output of approximately 982.09 kWh-day. Accordingly, by the tool's default, the solar radiation was the data from the department of alternative energy development and efficiency (DEDE) database in 2017.

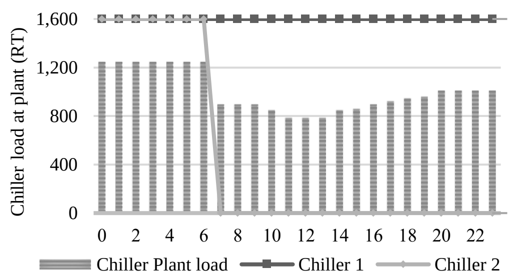
4.1.4. Operation strategy of the alternative cooling plant

The users will be required to set up the absorption chiller and cooling tower operation plan in the operation strategy part. For the chiller operation strategy, input 1 for running the machine and 0 for stopping as presented in Fig. 4.4, and the latter equipment, cooling towers, is required to set the number of working cells of the cooling towers as demonstrated in Fig.4.5.

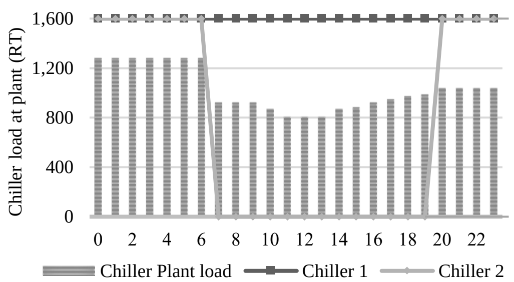
Also, Hotel A's total monthly solar thermal production is provided in this part, as presented in Fig. 4.6.



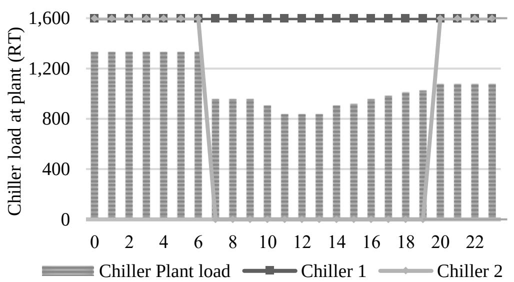
(a) Hourly operation strategy of chiller in January



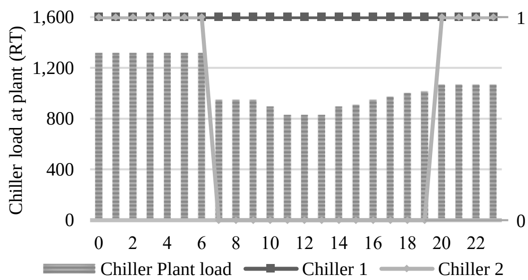
(b) Hourly operation strategy of chiller in February



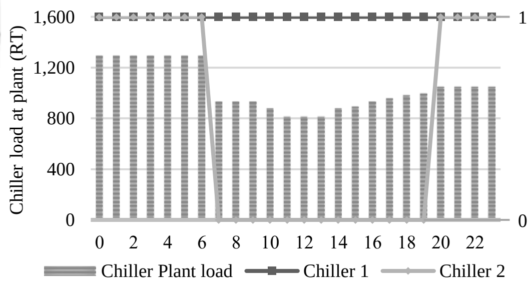
(c) Hourly operation strategy of chiller in March



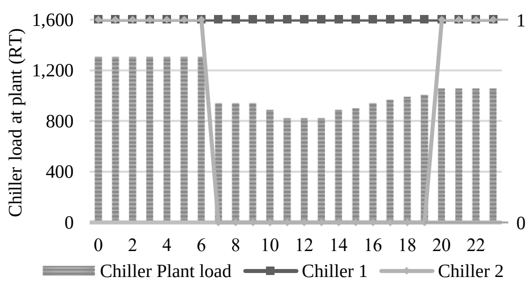
(d) Hourly operation strategy of chiller in April



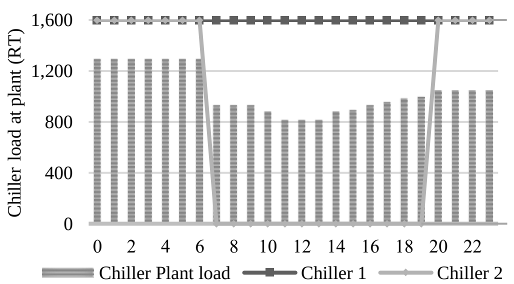
(e) Hourly operation strategy of chiller in May



(f) Hourly operation strategy of chiller in June

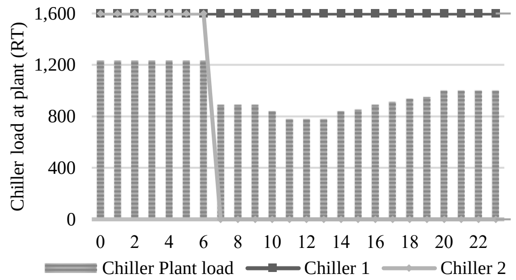


(g) Hourly operation strategy of chiller in July

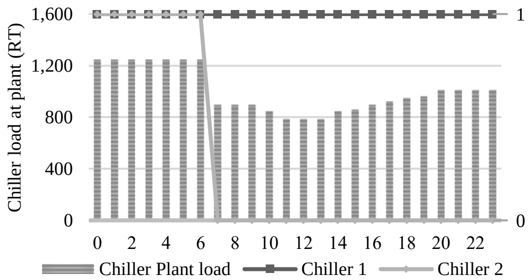


(h) Hourly operation strategy of chiller in August

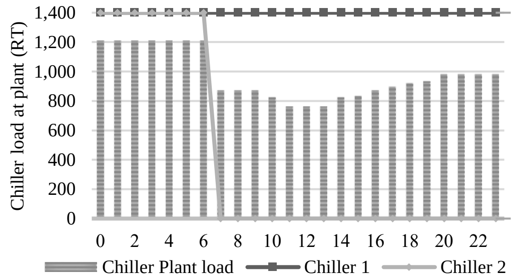
Figure 4.4 Hourly operation strategy of the single-effect absorption chiller in a year



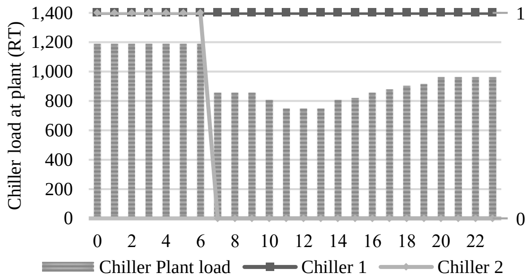
(i) Hourly operation strategy of chiller in September



(j) Hourly operation strategy of chiller in October

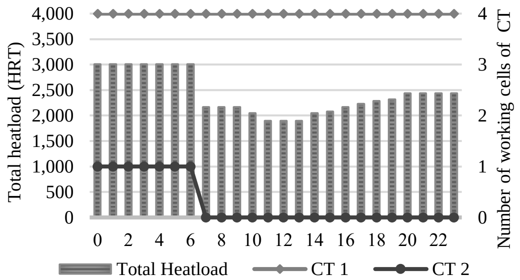


(k) Hourly operation strategy of chiller in November

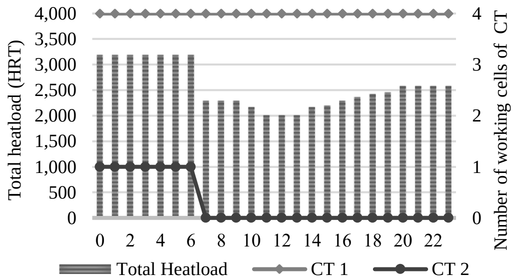


(l) Hourly operation strategy of chiller in December

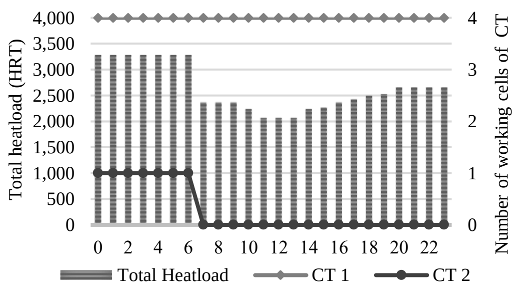
Figure 4.4 (continue) Hourly operation strategy of the single-effect absorption chiller in a year



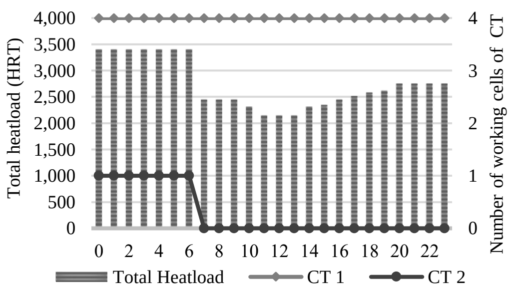
(a) Hourly operation strategy of cooling tower in January



(b) Hourly operation strategy of cooling tower in February

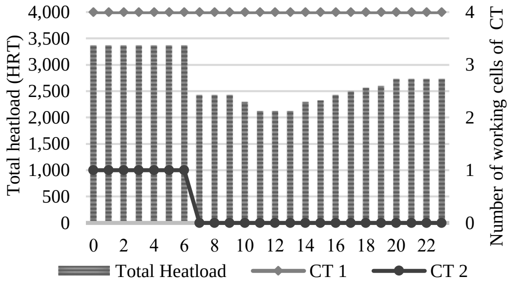


(c) Hourly operation strategy of cooling tower in March

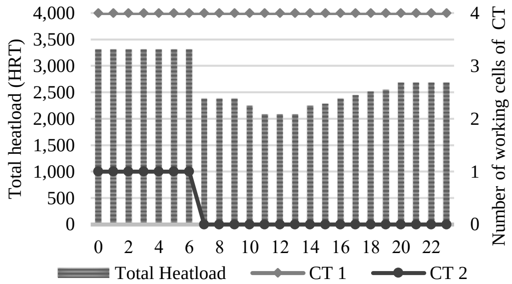


(d) Hourly operation strategy of cooling tower in April

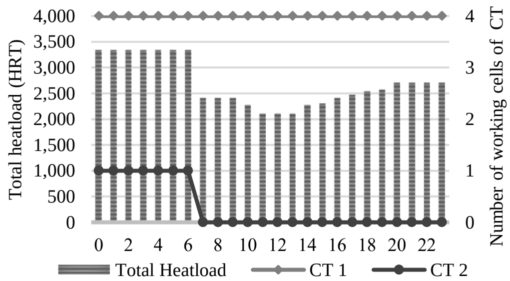
Figure 4.5 Hourly operation strategy of cooling towers in a year



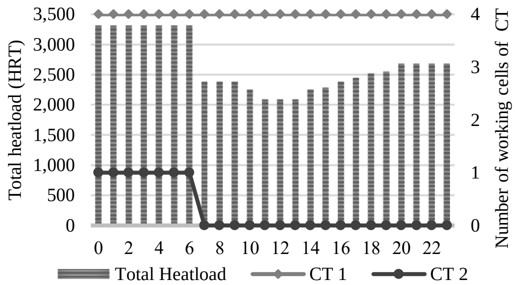
(e) Hourly operation strategy of cooling tower in May



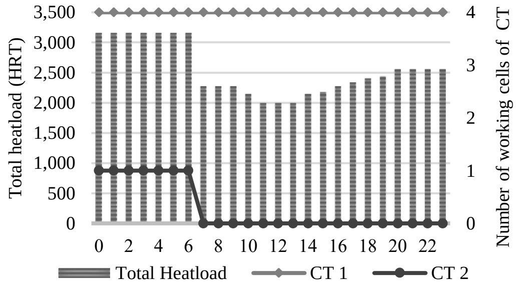
(f) Hourly operation strategy of cooling tower in June



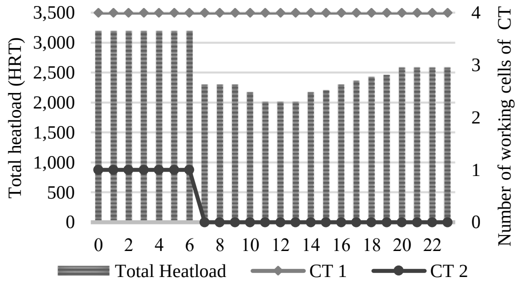
(g) Hourly operation strategy of cooling tower in July



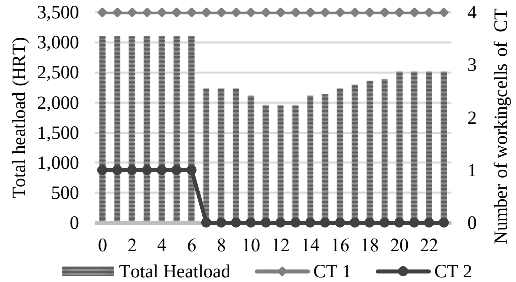
(h) Hourly operation strategy of cooling tower in August



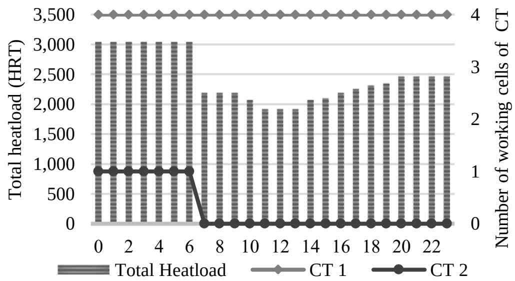
(i) Hourly operation strategy of cooling tower in September



(j) Hourly operation strategy of cooling tower in October



(k) Hourly operation strategy of cooling tower in November



(l) Hourly operation strategy of cooling tower in December

Figure 4.5 (continue) Hourly operation strategy of cooling towers in a year

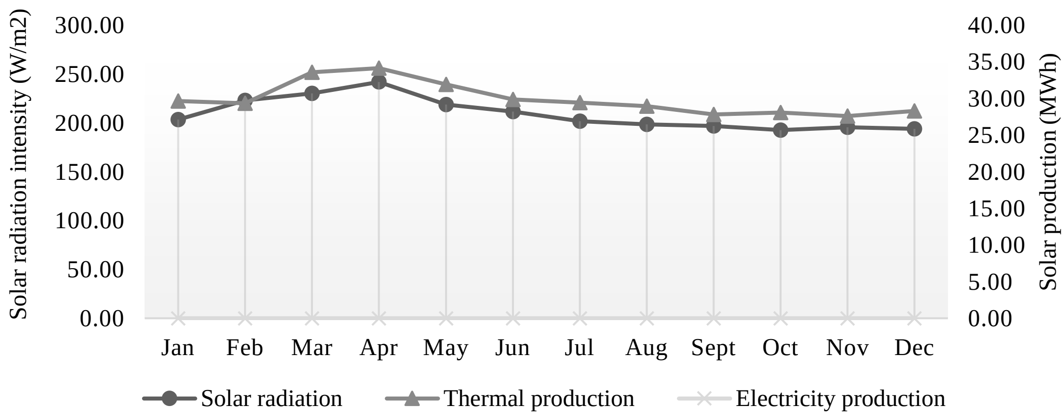


Figure 4.6 Total monthly solar production and monthly average solar intensity

4.1.5. Energy performance of the alternative cooling plant

The energy performance of the alternative cooling system, such as the energy efficiency coefficient, the COP of the chiller, and the total energy consumption of the cooling plant, will present in two terms monthly and daily energy performance.

According to Fig. 4.7 and 4.8, the user will see the monthly energy performance for a whole year of operation. Fig. 4.9 and 4.10 will present a daily working performance of the alternative cooling plant of Hotel A.

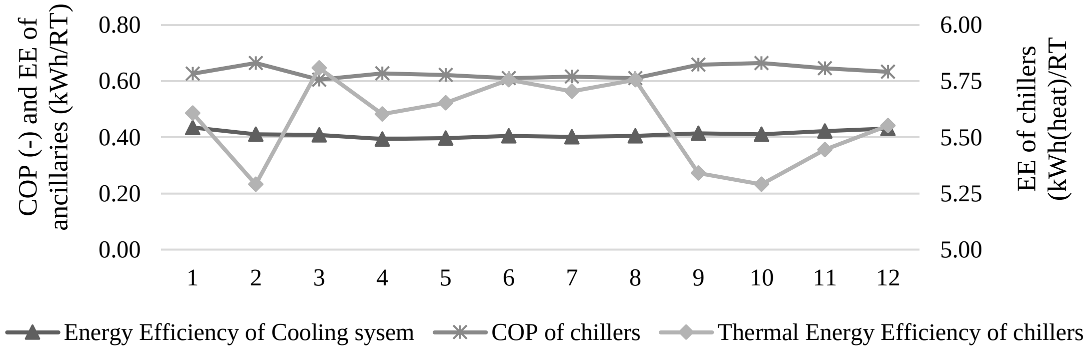


Figure 4.7 Monthly energy performance of the alternative cooling system

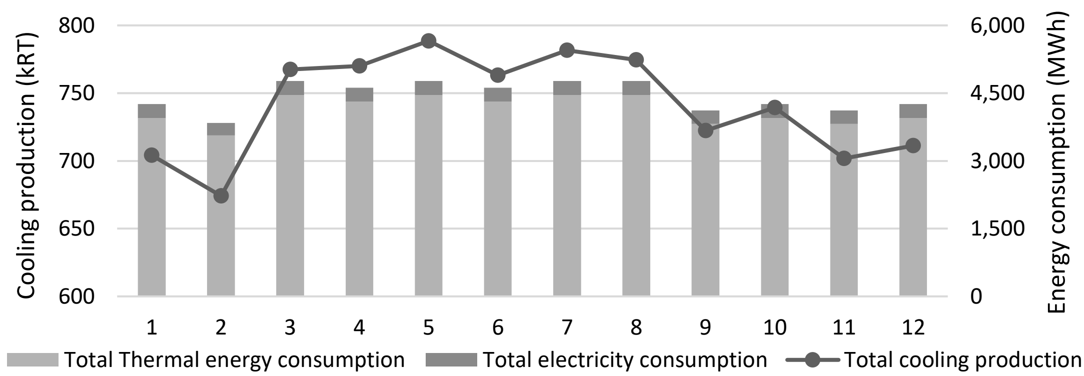


Figure 4.8 Total monthly energy consumption vs the total monthly cooling production

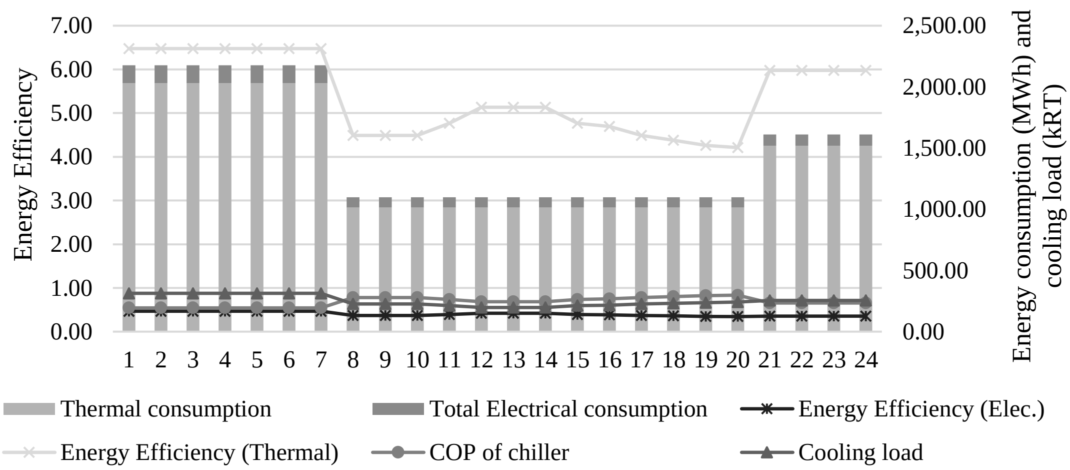


Figure 4.9 Hourly energy performance and cooling load demand for weekdays

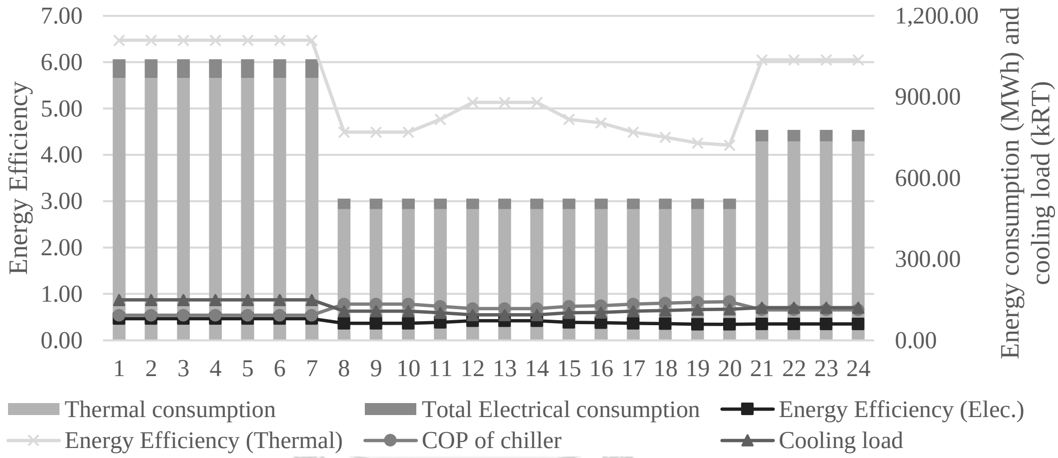


Figure 4.10 Hourly energy performance and cooling load demand for day-off

4.1.6. The final output of the energy assessment tool (Report)

The final part of the tool will bring you a summary of the chiller and ancillary equipment specification, the energy performance, the energy consumption, the total cooling production, and the solar production, including the energy cost and the cost-saving of the solar output, respectively, the example of the report output of this energy assessment tool can be written as follows,

<u>The report of the energy assessment of the alternative cooling system of Hotel A</u>

1. The primary specification of the single-effect absorption chiller and the ancillary equipment

With a 47,000 sqm total gross floor area, Hotel A requires two single-effect absorption chillers to install at the chiller plant to cover all the building requirements. Accordingly, the operational characteristics presented in Table 1 and the chilled water and hot water pumps are demonstrated in Tables 2 and 3.

Table 1 The single-effect absorption chiller specification

	Chiller 1	Chiller 2	Chiller 3
Technology	Absorption	Absorption	-
Type	Single-stage	Single-stage	-
Cooling capacity	1,029 RT	1,029 RT	-
Heat load requirement	4,109 kW	4,109 kW	-
Chilled water supply temperature	5 °C		
Chilled water return temperature	13 °C		
Hot water supply temperature	90 °C		
Hot water return temperature	80 °C		

Table 2 The specification of the chilled water pumps

	PCWP 1	PCWP 2	PCWP 3
Flow rate	388.08 m3/h	388.08 m3/h	-
Head of pump	31 mH2O	31 mH2O	-
Motor size	45.00 kW	45.00 kW	-

Table 3 The specification of the hot water pumps

	HWP 1	HWP 2	HWP 3
Flow rate	352.18 m3/h	352.18 m3/h	-
Head of pump	10 mH2O	10 mH2O	-
Motor size	15.00 kW	15.00 kW	-

Following the heat load received from the building and the thermal energy input at the generator, the cooling system requires cooling towers to release the heat out of the system. Accordingly, the cooling towers and the condenser pump specifications are illustrated in Tables 4 and 5.

Table 4 The specification of the cooling towers

	CT 1	CT 2	CT 3
Total Heat load	2,634 HRT	2,634 HRT	-
Number of cells	4	4	-
Motor size per cell	30.00 kW	30.00 kW	-
Condenser water supply temperature	31 °C		
Condenser water return temperature	36 °C		

Table 5 The specification of the condenser pumps

	CDWP 1	CDWP 2	CDWP 3
Flow rate	1589.73 m3/h	1589.73 m3/h	-
Head of pump	34 mH2O	34 mH2O	-
Motor size	200.00 kW	200.00 kW	-

Hotel A plans to install the solar thermal collector to generate the heat supply to the generator. Only 1 chiller runs during the day, which means 120 kW of the thermal collector field is enough for the system demand. The thermal collector field specification presents in Tables 6 and 7.

Table 6 The thermal collector field specification

System no.	1	2	3
Total heat required	120.00 kW	-	-
Efficiency coefficient	0.83	-	-
Number of plates	294	-	-
Total installation area	980.00 m²	-	-

Table 7 The specification of the solar pump

	Solar pump 1	Solar pump 2	Solar pump 3
Flow rate	4.43 m3/h	-	-
Head of pump	2 mH2O	-	-
Motor size	1.10 kW	-	-

2. The energy requirement of the alternative cooling plant

Table 8 presents the total cooling load production on the plant, Hotel A's thermal and electrical energy usage, and the different resource consumption declared thoroughly in Fig. 1 and 2. In a year of operation, the total energy demand is approximately 53,164.33 MWh, 7% electricity consumption, and the vast amount of 93% required for the thermal energy consumption.

Table 8 Monthly cooling load demand and energy consumption

Month		Total cooling production (kRT)	Total Thermal energy demand (MWh)	Total electricity demand (MWh)
1	January	704.10	3,948.52	306.35
2	February	674.11	3,566.40	276.70
3	March	767.46	4,458.00	313.54
4	April	769.96	4,314.20	303.42
5	May	788.59	4,458.00	313.54
6	June	763.15	4,314.20	303.42
7	July	781.55	4,458.00	313.54
8	August	774.50	4,458.00	313.54
9	September	722.27	3,821.15	296.47
10	October	739.30	3,948.52	306.35
11	November	701.82	3,821.15	296.47
12	December	711.14	3,948.52	306.35
Total		8,897.95	49,514.65	3,649.68

Table 6 presents the thermal collector field capacity with the number of plates and total area installation. The solar production over the year with 358.22 MWh and the monthly output also is remarkably presented in Table 9.

Table 9 Monthly solar production

Month		Solar Production		
		Solar intensity (W/m2)	Thermal (MWh)	Electricity (MWh)
1	January	203.05	29.62	0.00
2	February	222.61	29.33	0.00
3	March	229.90	33.53	0.00
4	April	241.58	34.10	0.00
5	May	218.56	31.88	0.00
6	June	211.27	29.82	0.00
7	July	201.43	29.38	0.00
8	August	198.19	28.91	0.00
9	September	196.69	27.76	0.00
10	October	192.41	28.06	0.00
11	November	195.30	27.57	0.00
12	December	193.80	28.27	0.00
Total year			358.22	0.00

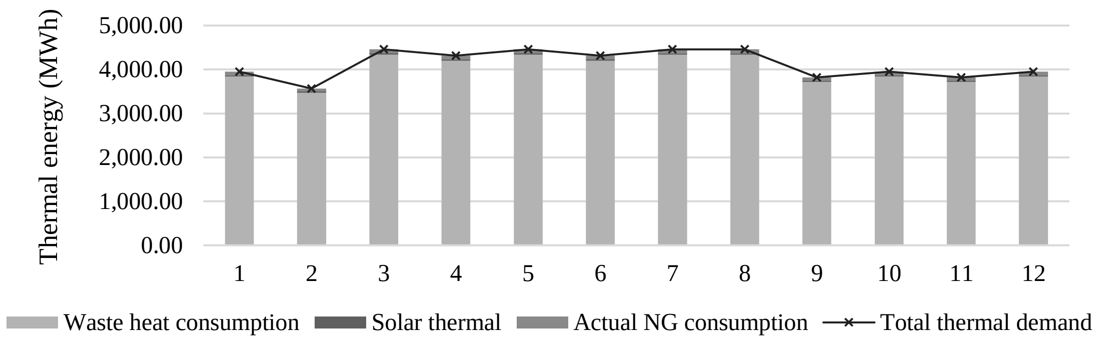


Figure 1 Monthly thermal energy consumption

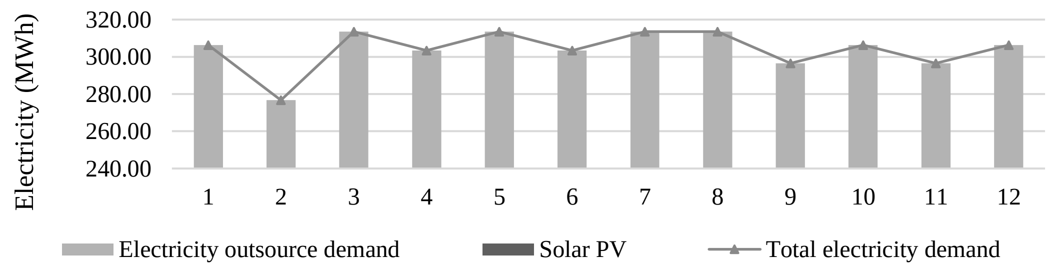


Figure 2 Monthly electricity consumption

3. The forecasting of the energy performance of the alternative cooling system

The energy efficiency of the electricity consumption of the absorption chiller seems too constant as its technology was designed to consume less electricity but thermal energy. The energy performance of Hotel A has presented in Table 10 and Fig. 3.

The energy efficiency of the whole cooling plant is around 0.411 kW/RT yearly, including the chiller, cooling towers, and pump electricity conversion to the cooling load supply. In addition, the yearly average thermal energy efficiency is roughly 5.567 kW/RT.

The COP of the absorption chiller reaches 0.632 as a yearly average. This value performed due to the chiller is not planning to run the full load of the chiller capacity. For example, in January, 1 chiller runs with the best load between 72% to 93% during the 07:00 AM to 12:00 AM, and the rest of the time, both chillers have part load run at 58% precisely.

Table 10 Monthly energy performance coefficient of the alternative cooling plant

Month		Energy Efficiency coefficient (kW/RT)					Thermal COP
		Chiller (Elec)	Chiller (Thermal)	Cooling tower (Elec)	Pumps (Elec)	Total plant (Elec)	Chiller
1	January	0.011	5.608	0.119	0.305	0.435	0.627
2	February	0.010	5.291	0.113	0.287	0.410	0.665
3	March	0.011	5.809	0.110	0.287	0.409	0.605
4	April	0.011	5.603	0.106	0.277	0.394	0.628
5	May	0.011	5.653	0.107	0.280	0.398	0.622
6	June	0.011	5.653	0.107	0.280	0.398	0.622
7	July	0.011	5.704	0.108	0.282	0.401	0.617
8	August	0.011	5.756	0.109	0.285	0.405	0.611
9	September	0.010	5.291	0.113	0.287	0.410	0.665
10	October	0.011	5.341	0.114	0.290	0.414	0.658
11	November	0.011	5.445	0.116	0.296	0.422	0.646
12	December	0.011	5.552	0.118	0.302	0.431	0.633
Yearly average		0.011	5.559	0.111	0.288	0.411	0.633

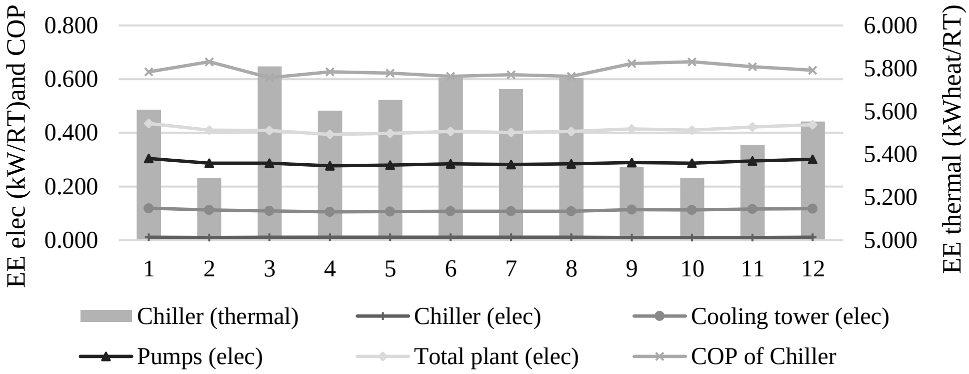


Figure 3 Monthly energy performance coefficient of Hotel A

4. The energy consumption cost and cost-saving

The cost-saving of Hotel A includes only the thermal energy saving by the solar collector field production, which is presented in Table 11.

Thus, the following table has also shown the actual energy cost of the thermal energy with the natural gas price of 242 THB/MMBTU, causing the massive amount of the energy cost for the cooling plant. And the electricity consumption with the average electricity price of Hotel A is 3.79 THB/kWh.

Table 11 Monthly actual energy cost and the cost-saving

Month		Thermal energy		Electricity		Total cost saving (kTHB)
		Actual NG demand (MWh)	Energy cost (kTHB)	Outsource demand (MWh)	Energy cost (kTHB)	
1	January	75.26	62,146.26	306.35	1,161.07	24,156.36
2	February	66.80	55,157.24	276.70	1,048.70	22,793.52
3	March	87.10	71,923.39	313.54	1,188.30	25,515.05
4	April	83.92	69,295.71	303.42	1,149.97	24,999.56
5	May	87.68	72,403.38	313.54	1,188.30	25,035.06
6	June	85.29	70,426.53	303.42	1,149.97	23,868.73
7	July	88.90	73,408.16	313.54	1,188.30	24,030.29
8	August	89.22	73,668.71	313.54	1,188.30	23,769.74
9	September	73.45	60,649.82	296.47	1,123.61	22,868.85
10	October	76.45	63,129.53	306.35	1,161.07	23,173.09
11	November	73.62	60,792.23	296.47	1,123.61	22,726.44
12	December	76.27	62,978.06	306.35	1,161.07	23,324.56
Total year		963.97	795,979.03	3,649.68	13,832.28	286,261.24

5. The CO_2 emission saving

Yearly carbon dioxide emission saving is presented in Table 12. The intensity ratio of the natural gas saved by solar thermal production is 53.00 kgCO2/MMBTU. The carbon dioxide intensity ratio of electricity production is around 0.438 kgCO2/kWh.

Table 12 Annual CO_2 emission saving

	Thermal energy	Electricity	Total
CO2 Emission	64,780.76 tons	0.00 tons	64,780.76 tons

6. Results and discussion

The monthly average ambient air temperature over the year in Bangkok, Thailand, is mainly high temperatures from March to August, except at the beginning and the end of the year when the ambient air temperature is a bit low.

However, the cooling load demand and the energy consumption rate in February were less than in other months shown in Table 8. The number of operation days in this month was less than others.

The single-effect absorption chiller's thermal energy efficiency coefficient (kW-heat/RT) is presented in Fig. 3. It highly shows thermal energy consumption to generate 1 RT during the summer and rainy times of the year due to the second chillers in the cooling plant having a part load running hours more than the winter season. For example, the chiller's thermal energy efficiency in March is 5.809 kW-heat/RT shows an inefficient energy performance compared to December, with a thermal efficiency of 5.552 kW-heat/RT. Contrastingly, the COP of the chiller during the summer and rainy season is a bit low because the part-load running hours of the second chiller are higher than in the winter.

4.2. Solar project cost

The solar cost project sheet will be a supporting part of this computational tool, as the main task of the study only to assess the energy performance of the alternative cooling system

This part will estimate the payback period, Net Present Value (NPV), including the internal rate of return (IRR). The primary input parameters required for this part of the tool are illustrated in Table 4.6. Accordingly, Eqs. 2.38 and 2.39 will be applied to the tool calculation.

Table 4.6 The primary input of the financial parameters

No	Input parameter	Unit
1	Project life	years
2	Weighted Average Cost of Capital (WACC)	%
3	Depreciation rate per year	%
4	Income tax	%
5	Escalation rate of CAPEX and OPEX	%
6	Capital Expenditures (CAPEX)	THB
7	Operational Expenditures (OPEX)	THB

The revenue of the solar project will consider electricity cost-saving and thermal energy cost-saving. Even though the cost-saving varied in the solar production and the energy price during a typical period, the financial conclusion was quite common. If the internal rate of return is higher than the discounted rate, this project is feasible. Otherwise, if the value of IRR is lower than the discounted rate, this is not feasible.

4.3. Discussion

The purpose of developing the energy assessment tool is not only to evaluate the energy performance of the coming alternative cooling plant, but an existing plant can also assess the energy performance.

However, using the tool for an existing plant may need to adjust the daily cooling load demand because the tool only provides input parts for weekdays and day-off. For instance, the users may require averaging the cooling load demand from Monday to Friday for weekdays consumption and Saturday to Sunday for day-off.

This computational tool is also designed to plan the operational strategy of chiller and cooling towers. The operation strategy will help the users design which machine to run and which to stop at a typical time. This part will support the users to specify the suitable size and the number of installations and operation of each machine on site. Thus, the maintenance plan can also form following the plant strategy.

For the cooling plant operating, this tool can lead to the energy efficiency guarantee rate of the alternative cooling plant if the users are the facility management supplier. The tool application also implements the safety factor to add some energy efficiency tolerance to guarantee the energy performance for buildings.

To conclude, this application allows users to forecast the energy performance of the alternative cooling plant and the plant operation strategies of the single-effect absorption chillers and the cooling towers when installed on more than one machine. Plus, the output result can guide the energy efficiency guarantee rate if you are the building and energy management system provider.

Chapter 5 Conclusions and recommendations

This study has presented the possible ways to assess the energy performance of the alternative cooling system by one of the most powerful and well-known software, Microsoft excel. Additionally, the validation results show that this energy assessment tool is applicable for preliminary evaluate the energy performance of the alternative cooling plant.

5.1. Conclusions

There are two main parameters to be considered for assessing the energy performance of the alternative cooling plant,

1. The cooling demand of the building

   In this study, to calculate the cooling demand, the users must have the total gross floor area of the building and the monthly collective coefficient for adjusting the monthly cooling load. Otherwise, if the users have the daily cooling load demand of the plant, it can be directly input into the tool.

2. The total energy demand of the alternative cooling plant

   This part of the tool is mostly automatically calculated by the tool application. However, some parameters must be input or adjusted manually to estimate energy consumption in a year, such as the operating hours of the single-effect absorption chiller and the cooling towers.

This study only presents the first version, which is not cover all the equipment typically located in the cooling plant. Even though the tool works quite well, the thorough research and design of the cooling plant are still necessary for actual plant development.

5.2. Result expectations

The first version of the energy assessment tool for the alternative cooling system is ready to preliminary evaluate the energy performance of the cooling plant. Additionally, this version can provide the total energy demand on the plant thoroughly and estimate the solar thermal energy and electricity yearly production to assist the cooling plant.

Furthermore, the validation results between the published paper and this computational tool show that the mathematical model can assess the energy performance, also estimating the total energy requirement of the cooling plant of the actual operation plant or the experimental pilot plant quite well.

5.3. Limitations

Some parameters such as plane tilt, azimuth angle, and weather conditions like the sky clearness or the air quality index are not considered in the solar application, which means only the solar module specifications and the monthly solar radiation intensity are included.

This tool did not include the thermal energy storage for solar thermal production in the calculation part. However, if the tank storage is counted, the energy performance, the energy consumption, and the energy cost of the alternative cooling plant would be improved significantly.

5.4. Recommendations

Following the methodology and theory applied in this study, users who want to utilize the tool efficiently must have basic knowledge of the cooling system, the characteristic of the absorption chiller, and the cooling system's working process before using this computational tool.

The tool application guideline book is served in Appendix IV. Following this book, various users can use the tool correctly and efficiently.

5.5. Future work

The next version of the tool shall add the thermal energy storage part to calculate the actual energy saving of the plant and cost-saving. In addition, the application may consider applying other alternatives/renewable energy or other solar application technologies such as the solar Photovoltaic-Thermal (PV thermal) model.

Appendix

Appendix I LiBr solution concentration-Temperature-Enthalpy Chart

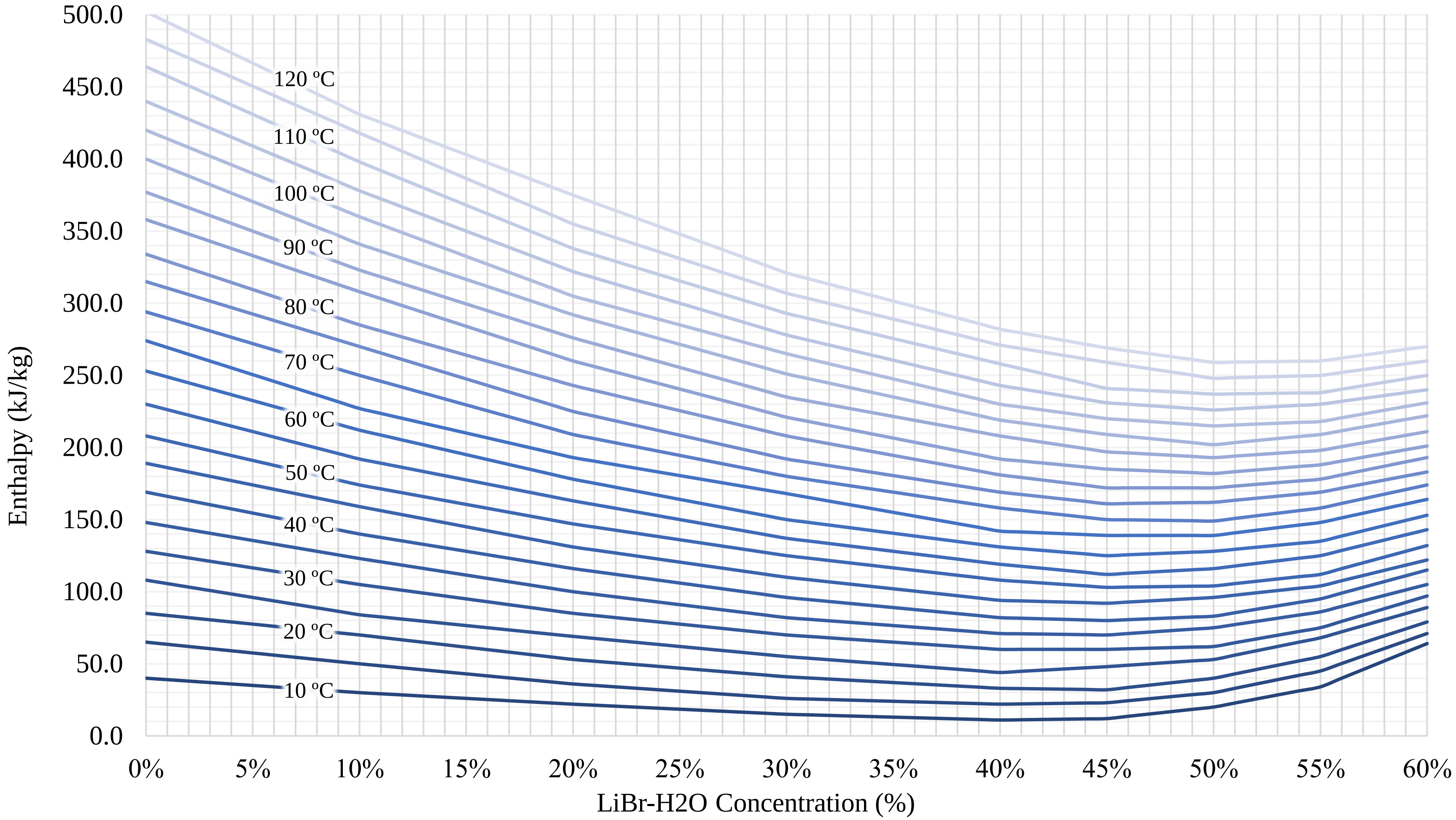


Figure 1 LiBr solution concentration-Temperature-Enthalpy Chart

Appendix II The cooling load percentage

Table 1 The cooling load percentage of factory

Time		Weekday	Day-off
0	12:00 AM	32%	14%
1	1:00 AM	32%	14%
2	2:00 AM	32%	14%
3	3:00 AM	32%	14%
4	4:00 AM	32%	14%
5	5:00 AM	32%	14%
6	6:00 AM	50%	32%
7	7:00 AM	50%	50%
8	8:00 AM	80%	80%
9	9:00 AM	100%	100%
10	10:00 AM	100%	100%
11	11:00 AM	100%	100%
12	12:00 PM	100%	100%
13	1:00 PM	100%	100%
14	2:00 PM	100%	100%
15	3:00 PM	100%	100%
16	4:00 PM	90%	90%
17	5:00 PM	80%	80%
18	6:00 PM	80%	50%
19	7:00 PM	60%	14%
20	8:00 PM	32%	14%
21	9:00 PM	32%	14%
22	10:00 PM	32%	14%
23	11:00 PM	32%	14%

Table 2 The cooling load percentage of hotel

Time		Weekday	Day-off
0	12:00 AM	100%	100%
1	1:00 AM	100%	100%
2	2:00 AM	100%	100%
3	3:00 AM	100%	100%
4	4:00 AM	100%	100%
5	5:00 AM	100%	100%
6	6:00 AM	100%	100%
7	7:00 AM	72%	72%
8	8:00 AM	72%	72%
9	9:00 AM	72%	72%
10	10:00 AM	68%	68%
11	11:00 AM	63%	63%
12	12:00 PM	63%	63%
13	1:00 PM	63%	63%
14	2:00 PM	68%	68%
15	3:00 PM	69%	69%
16	4:00 PM	72%	72%
17	5:00 PM	74%	74%
18	6:00 PM	76%	76%
19	7:00 PM	77%	77%
20	8:00 PM	81%	81%
21	9:00 PM	81%	81%
22	10:00 PM	81%	81%
23	11:00 PM	81%	81%

Table 3 The cooling load percentage of retail

Time		Weekday	Day-off
0	12:00 AM	0%	0%
1	1:00 AM	0%	0%
2	2:00 AM	0%	0%
3	3:00 AM	0%	0%
4	4:00 AM	0%	0%
5	5:00 AM	0%	0%
6	6:00 AM	0%	0%
7	7:00 AM	0%	0%
8	8:00 AM	27%	30%
9	9:00 AM	58%	58%
10	10:00 AM	72%	72%
11	11:00 AM	80%	83%
12	12:00 PM	88%	100%
13	1:00 PM	83%	96%
14	2:00 PM	75%	86%
15	3:00 PM	68%	78%
16	4:00 PM	61%	70%
17	5:00 PM	55%	63%
18	6:00 PM	49%	57%
19	7:00 PM	44%	51%
20	8:00 PM	40%	40%
21	9:00 PM	40%	40%
22	10:00 PM	14%	14%
23	11:00 PM	14%	14%

Table 4 The cooling load percentage of residential building

Time		Weekday	Day-off
0	12:00 AM	100%	100%
1	1:00 AM	100%	100%
2	2:00 AM	100%	100%
3	3:00 AM	100%	100%
4	4:00 AM	100%	100%
5	5:00 AM	100%	100%
6	6:00 AM	100%	100%
7	7:00 AM	72%	72%
8	8:00 AM	72%	72%
9	9:00 AM	72%	72%
10	10:00 AM	68%	68%
11	11:00 AM	63%	63%
12	12:00 PM	63%	63%
13	1:00 PM	63%	63%
14	2:00 PM	68%	68%
15	3:00 PM	69%	69%
16	4:00 PM	72%	72%
17	5:00 PM	74%	74%
18	6:00 PM	76%	76%
19	7:00 PM	77%	77%
20	8:00 PM	81%	81%
21	9:00 PM	81%	81%
22	10:00 PM	81%	81%
23	11:00 PM	81%	81%

Table 5 The cooling load percentage of office

Time		Weekday	Day-off
0	12:00 AM	0%	0%
1	1:00 AM	0%	0%
2	2:00 AM	0%	0%
3	3:00 AM	0%	0%
4	4:00 AM	0%	0%
5	5:00 AM	0%	0%
6	6:00 AM	0%	0%
7	7:00 AM	0%	0%
8	8:00 AM	27%	30%
9	9:00 AM	58%	58%
10	10:00 AM	72%	72%
11	11:00 AM	80%	83%
12	12:00 PM	88%	100%
13	1:00 PM	83%	96%
14	2:00 PM	75%	86%
15	3:00 PM	68%	78%
16	4:00 PM	61%	70%
17	5:00 PM	55%	63%
18	6:00 PM	49%	57%
19	7:00 PM	44%	51%
20	8:00 PM	40%	40%
21	9:00 PM	40%	40%
22	10:00 PM	14%	14%
23	11:00 PM	14%	14%

Appendix III Solar radiation intensity

Table 6 Daily solar radiation available coefficient

Time		Daily radiation available coefficient
0	12:00 AM	0%
1	1:00 AM	0%
2	2:00 AM	0%
3	3:00 AM	0%
4	4:00 AM	0%
5	5:00 AM	0%
6	6:00 AM	0%
7	7:00 AM	20%
8	8:00 AM	40%
9	9:00 AM	80%
10	10:00 AM	85%
11	11:00 AM	90%
12	12:00 PM	96%
13	1:00 PM	98%
14	2:00 PM	95%
15	3:00 PM	93%
16	4:00 PM	80%
17	5:00 PM	40%
18	6:00 PM	0%
19	7:00 PM	0%
20	8:00 PM	0%
21	9:00 PM	0%
22	10:00 PM	0%
23	11:00 PM	0%

Appendix IV The energy assessment tool guideline book

The energy assessment tool guideline book

1) Enter project name TAB → Cover & Legend

Energy Assessment tool - Alternative/renewable cooling system			
Project Name/Title	Energy assessment tool development		
File version	First draft		
Review no.	Date	Editor Name	Remark

Note:	Input data	Dropdown list	Reference to other sheet

Enter project name

Update the list of reviews

1. Yellow cell > data needs to input in this cell
2. Orange cell > select the list of data provides in the cell
3. Pink cell > values in this cell is celled from another sheet or tab in the file

2) Summary all tab in the energy assessment tool TAB → Table of Contents

Introduction		
1. Country	OK	Updated

Operation		
2.Cooling load		Updated
3.Specs	OK	Updated
4.Specs_ref		
5.Heat_Source&PV	OK	Updated
6.Strat	OK	Updated
7.Efficiency	OK	Updated
8.Efficiency_graph		Updated
9.Absorption list		Updated
10.Solar list		Updated

Result		
11.Report		

Finance support		
12.Solar project		

Summary of error check of each sheet

Status of each sheet to be updated in the cell A1 of each sheet
- Updated
- Not updated

3) Choose the plant location and enter the energy price and carbon intensity $\xrightarrow{\text{TAB}}$ Country

	OK
Project country	Thailand
Project area	Bangkok
Local currency (LC)	THB
Carbon intensity in electricity production	0.438 kgCO2/kWhe

Select the location to apply the related weather condition

Thailand	Thailand	Philippines	Country
THB	THB	PHP	Local currency
0.438 kgCO2/kWhe	0.438 kgCO2/kWhe	0.589 kgCO2/kWhe	-
Bangkok	Bangkok	Manila	City 1
Saraburi	Saraburi	Clark	City 2
Rayong	Rayong	Cebu	City 3

If the country did not match your site location, the users can input new location to the tool

No. Month	Month	Avg. DBT (ºC)	%RH	Avg. WBT (ºC)	Corrective coefficient
1	January	27.51	65.71	22.46	0%
2	February	28.69	69.73	24.18	6%
3	March	29.81	70.94	25.43	9%
4	April	30.46	72.85	26.35	13%
5	May	29.91	74.75	26.10	12%
6	June	29.16	76.97	25.76	12%
7	July	29.35	74.36	25.53	11%
8	August	29.17	74.36	25.35	10%
9	September	28.35	79.21	25.32	7%
10	October	28.77	76.05	25.21	6%
11	November	28.03	67.20	23.19	3%
12	December	27.64	63.05	22.18	1%

The users require to manually input the corrective coefficient for adjusting the monthly cooling load demand of the operating year

Time		Peak/Off-Peak	
		Weekday	Day-off
0	12:00 AM	O	O
1	1:00 AM	O	O
2	2:00 AM	O	O
3	3:00 AM	O	O
4	4:00 AM	O	O
5	5:00 AM	O	O
6	6:00 AM	O	O
7	7:00 AM	O	O
8	8:00 AM	O	O
9	9:00 AM	P	O
10	10:00 AM	P	O
11	11:00 AM	P	O
12	12:00 PM	P	O
13	1:00 PM	P	O
14	2:00 PM	P	O
15	3:00 PM	P	O
16	4:00 PM	P	O
17	5:00 PM	P	O
18	6:00 PM	P	O
19	7:00 PM	P	O
20	8:00 PM	P	O
21	9:00 PM	P	O
22	10:00 PM	O	O
23	11:00 PM	O	O

Import the periods peak (P) and off-peak hour (O) (This part in not mandatory, it only to reveal the characteristic of the electricity bill of the selected location)

Electricity rate : Peak hour:	3.68 LC/kWh
Electricity rate: Off-Peak hour:	2.18 LC/kWh
Contracted Capacity Rate:	132.93 LC/kW/month

Input the electricity tariff
- electricity rate during peak and off-peak time
- including the contracted capacity rate of electricity bills

Average electricity price	4.50 LC/kWh

Input the average electricity price at the facility, the estimation may require if you have no existing plant

Contracted Capacity based on:	All days & All hours

Select the period consider the contracted capacity calculation:
- All days & All hours
- Weekdays only
- Peak hours only

Fuel price&carbon intensity	
Natural gas price	200.00 LC/MMBTU
Carbon intensity for NG	53.00 kgCO2/MMBTU

Input the Fuel price you need on the cooling plant, including the carbon production intensity of the fuel you've selected

Average Solar Radiation	208.73 W/m²

No. Month	Month	Solar radiation (W/m²)
1	January	203.05
2	February	222.61
3	March	229.90
4	April	241.58
5	May	218.56
6	June	211.27
7	July	201.43
8	August	198.19
9	September	196.69
10	October	192.41
11	November	195.30
12	December	193.80

The summary of the solar radiation intensity over the year in unit W/m^2.

Please do not input the solar radiation directly to this table.

Select the unit of the solar radiation

MJ/m2-day	Thailand			Philippines	
Latitude	13.75 °N	14.53 °N	12.67 °N		
Longitude	100.49 °E	100.91 °E	101.28 °E		
No. Month	Bangkok	Saraburi	Rayong	Manila	Clark
1	17.55	17.22	18.46		
2	19.24	18.82	19.79		
3	19.87	19.67	20.43		
4	20.88	20.52	21.25		
5	18.89	19.07	18.50		
6	18.26	18.25	18.26		
7	17.41	17.62	18.03		
8	17.13	16.94	17.91		
9	17.00	16.65	16.95		
10	16.63	17.07	18.15		
11	16.88	17.03	18.23		
12	16.75	16.53	17.89		

Input the solar radiation in tensity to the column of the location of your plant location

As the tool default, the solar radiation of Thailand is already prepared, is the users prefer to use the value from another database please feel free to input it manually by yourself

4) Select building activity or import direct the cooling load demand $\xrightarrow{\text{TAB}}$ Cooling load

Type of Facility	Commercial/Residential building

Select the building activity:
- Commercial/Residential building
- Factory

Do you have daily cooling load demand of the facility?

if "No" daily cooling load of factory, Enter average cooling peak load damand of factory

Note: Factory should have the data of cooling load demand

No

Select:
"Yes" if you have the actual daily cooling load demand, "No" when you don't know the daily cooling load demand.

If "Factory" was selected and "No" you don't know the actual cooling load demand, then enter the roughly peak load demand on the plant.

Cooling area (%)	80%

Enter the cooling area percentage if your building activity is commercial/residential type.

Type of activity	Ratio
-	sqm/RT
Hotel	32
Retail	35
Residence	32
Office	44

No.	Building Name	Type of activity	Gross floor area	Cooling floor area	Cooling load
			sqm	sqm	RT
1	A	Retail	2880	2304	66
2					
3					
4					

Enter the cooling activity ratio. If it unknow, you can use the tool default ratio here.

Enter the building name.

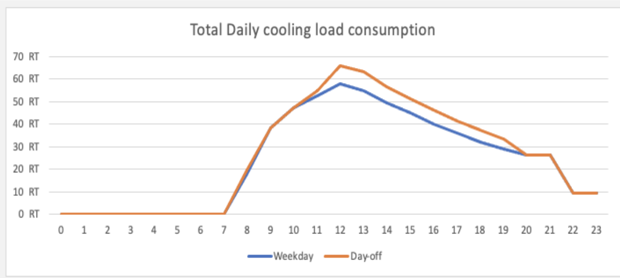
Select the building activity.

Enter the gross floor area of the building.

Daily cooling load demand

Factory		Cooling load percentage	
Time		Weekday	Day-off
0	12:00 AM	32%	14%
1	1:00 AM	32%	14%
2	2:00 AM	32%	14%
3	3:00 AM	32%	14%
4	4:00 AM	32%	14%
5	5:00 AM	32%	14%
6	6:00 AM	50%	32%
7	7:00 AM	50%	50%
8	8:00 AM	80%	80%
9	9:00 AM	100%	100%
10	10:00 AM	100%	100%
11	11:00 AM	100%	100%
12	12:00 PM	100%	100%
13	1:00 PM	100%	100%
14	2:00 PM	100%	100%
15	3:00 PM	100%	100%
16	4:00 PM	90%	90%
17	5:00 PM	80%	80%
18	6:00 PM	80%	50%
19	7:00 PM	60%	14%
20	8:00 PM	32%	14%
21	9:00 PM	32%	14%
22	10:00 PM	32%	14%
23	11:00 PM	32%	14%

Total daily cooling demand			
Time		Weekday	Day-off
0	12:00 AM	0 RT	0 RT
1	1:00 AM	0 RT	0 RT
2	2:00 AM	0 RT	0 RT
3	3:00 AM	0 RT	0 RT
4	4:00 AM	0 RT	0 RT
5	5:00 AM	0 RT	0 RT
6	6:00 AM	0 RT	0 RT
7	7:00 AM	0 RT	0 RT
8	8:00 AM	18 RT	20 RT
9	9:00 AM	38 RT	38 RT
10	10:00 AM	47 RT	47 RT
11	11:00 AM	53 RT	55 RT
12	12:00 PM	58 RT	66 RT
13	1:00 PM	55 RT	63 RT
14	2:00 PM	49 RT	57 RT
15	3:00 PM	45 RT	51 RT
16	4:00 PM	40 RT	46 RT
17	5:00 PM	36 RT	41 RT
18	6:00 PM	32 RT	38 RT
19	7:00 PM	29 RT	34 RT
20	8:00 PM	26 RT	26 RT
21	9:00 PM	26 RT	26 RT
22	10:00 PM	9 RT	9 RT
23	11:00 PM	9 RT	9 RT



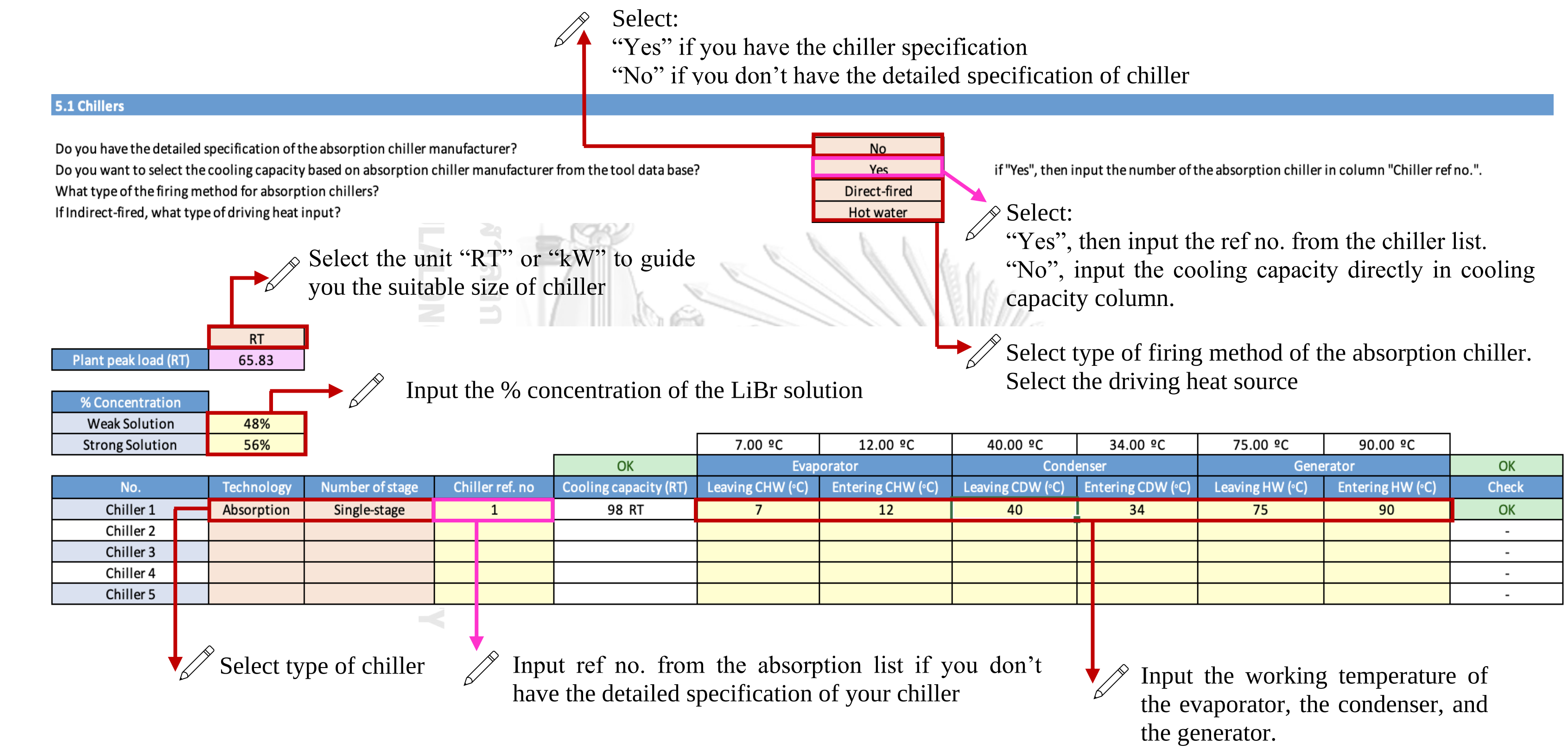
	Weekday	Day-off
Daily cooling load demand	571 RTh	627 RTh
Peak load (RT)	58 RT	66 RT
Peak load (kWh)	204 kWh	232 kWh

The daily cooling load will serve automatically, once you've completed all of input requires in this sheet.

The daily cooling load percentage presented in Appendix II. (This part can change if the users have their own values.

If "Factory" was selected and "Yes" you have the actual cooling load demand, then enter the cooling load demand of the factory.

5) Input the equipment specifications TAB Specs



Note: the number of chillers require to install in the cooling plant, it depends on the chiller plant design from the users.

Select the unit of the working flow rate of pumps.

Select the unit of head of pumps.

5.2 PCWP

No.	Flow rate (m3/h)	Head (mH2O)	Efficiency (%)	Input Power (kW)	Motor Size	Check Motor Size (OK)
PCWP 1	59.14	29	85%	5.50	7.5	OK
PCWP 2	Missing input			Missing input		-
PCWP 3	Missing input			Missing input		-
PCWP 4	Missing input			Missing input		-
PCWP 5	Missing input			Missing input		-

An error occurs when the motor size you've selected less than 11% of input power.

Note: Do the same things in the CDWP part

Entering head of pumps and the pumps efficiency.

Select the motor size of pumps

Select the unit of the working flow rate of pumps.

Input the number of cells include in the cooling tower.

5.4 Cooling Tower

No.	Flow rate (m3/h)	Entering Temperature (ºC)	Leaving Temperature (ºC)	Heat load (HRT)	Nber of cell	Heat load per cell (HRT)	Input Power per cell (kW)	Motor Size	Check Motor Size (OK)
CT 1	125.65	40	34	249.87	4	62.47	2.50	3	OK
CT 2	Missing input	Missing input	Missing input	Missing input		Missing input	Missing input		-
CT 3	Missing input	Missing input	Missing input	Missing input		Missing input	Missing input		-
CT 4	Missing input	Missing input	Missing input	Missing input		Missing input	Missing input		-
CT 5	Missing input	Missing input	Missing input	Missing input		Missing input	Missing input		-

Select the motor size of pumps

6) Specs-ref —TAB→ Specs_ref

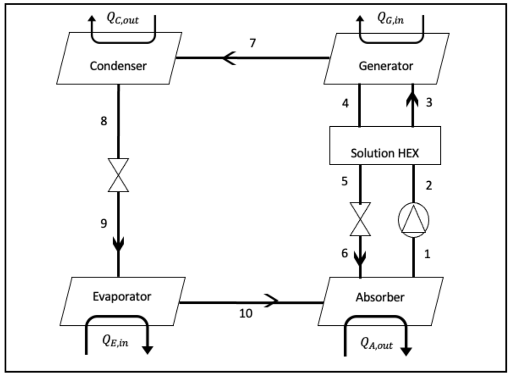
ⓘ No action requires on this part

Temperatures

Approach	2.00 ºC

DT cond	6.00 ºC
DT evap	5.00 ºC
DT gen	15.00 ºC

CHWS temp	7.00 ºC
TH	5.00 ºC



No.	Te	Ta	Tg	Tc
Chiller 1	5.00 ºC	43.00 ºC	72.00 ºC	43.00 ºC
Chiller 2				
Chiller 3				
Chiller 4				
Chiller 5				

No.	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Chiller 1	43.00 ºC	43.00 ºC	-	72.00 ºC	43.00 ºC	43.00 ºC	72.00 ºC	43.00 ºC	43.00 ºC	5.00 ºC
Chiller 2										
Chiller 3										
Chiller 4										
Chiller 5										

No.	h1	h2	h3	h4	h5	h6	h7	h8	h9	h10
Chiller 1	90.72	90.72	143.90	166.28	104.24	104.24	2,634.92	179.83	179.83	2,510.30
Chiller 2										
Chiller 3										
Chiller 4										
Chiller 5										

COP of chillers

Weak Solution	48%
Strong Solution	56%
lamda	6.0

No.	m_ref	m_ws	m_ss	Qe	Qa	Qg	Qc	Wp	COP
Chiller 1	0.148	1.035	0.887	345 kW	370 kW	388 kW	363 kW	0.01 kW	0.887598
Chiller 2									
Chiller 3									
Chiller 4									
Chiller 5									

7) Available heat source and solar applications $\xrightarrow{\text{TAB}}$ Heat_Source&PV

To check the answer condition

"Yes", then enter the available waste heat in kW to the Available waste heat" column.
"No" when no heat available on site.

	OK			
Does the plant have available heat supply to a generator?	Yes	if "Yes", enter the total available heat on plant.		
Does the plant need solar PV or Thermal on site?	Yes	if "Yes", select solar type.	Solar PV+Thermal	
If need solar PV or Thermal on site, enter available solar installation area (m2).	2,500	Total installation area (m2)	653.00	

Select which solar technology to be applied on the cooling plant or both are needed.

"Yes" when need solar PV or solar thermal on site.
"No" when not require solar application on site.

Input the available area to install the solar applications

1. Available thermal energy on site

To check the heat load supply to the cooling plant

System No.	Heat load demand (kW)	Available waste heat (kW)	Heat requires from NG (kW)	HWT-S (ºC)	HWT-R (ºC)	DT (ºC)
		OK				
1	388.28	350	38.28	90	75	15
2						
3						
4						
5						

Input the amount of the available waste

Select the unit of the working flow rate of pumps.

Select the unit of head of pumps.

No.	Flow rate	Head	Efficiency (%)	Input Power (kW)	Motor Size	Check Motor Size
	m3/h	mH2O				OK
HWP 1	22.19	35	85%	2.49	3	OK
HWP 2	Missing input			Missing input		-
HWP 3	Missing input			Missing input		-
HWP 4	Missing input			Missing input		-
HWP 5	Missing input			Missing input		-

An error occurs when the motor size you've selected less than 11% of input power.

Entering head of pumps and the pumps efficiency.

Select the motor size of pumps

An error occurs when the total installation area higher than the available area.

2. Solar Thermal

Does the available waste heat fulfil the heat load demand? | No | if "Yes", does the plant still need to install Thermal collector? Please re-check the questions above.

Thermal collector	OK	OK						OK	
System No.	Heat requires from thermal collector (kW)	Thermal collector ref no.	Efficiency coefficient	Total area of collector plate (m2)	Gross collector area per plate (m2)	Absorber area per plate (m2)	Nber of panel	Total installation area (m2)	Heat loss coefficient (W/m2K)
1	50.00	7	0.83	288.60	2.56	2.36	123	410.00	3.933
2			Missing input	Missing input	Missing input	Missing input	Missing input	Missing input	Missing input
3			Missing input	Missing input	Missing input	Missing input	Missing input	Missing input	Missing input
4			Missing input	Missing input	Missing input	Missing input	Missing input	Missing input	Missing input
5			Missing input	Missing input	Missing input	Missing input	Missing input	Missing input	Missing input

Input the thermal collector field capacity.

Input the reference number of thermal collector from the solar list.

Select the unit of the working flow rate of pumps.

Select the unit of head of pumps.

Input an expect hot water inlet temperature.

		OK		m3/h	mH2O				OK
No.	Hot water temp. outlet (ºC)	Hot water temp. inlet (ºC)	Heat loss (kW)	Flow rate	Head	Efficiency (%)	Input Power (kW)	Motor Size	Check Motor Size
Solar pump 1	76.44	50	30.01	0.65	35	85%	0.07	1.1	OK
Solar pump 2	Missing input		Missing input	Missing input			Missing input		-
Solar pump 3	Missing input		Missing input	Missing input			Missing input		-
Solar pump 4	Missing input		Missing input	Missing input			Missing input		-
Solar pump 5	Missing input		Missing input	Missing input			Missing input		-

Entering head of pumps and the pumps efficiency.

Select the motor size of pumps

An error occurs when the motor size you've selected less than 11% of input power.

3. Solar PV

NOTE:
Plane tilt and Azimuth weren't considered in this tool.

	OK
Available PV installation area (m2)	2,090.00
Power supply demand (kW AC)	32.08

Inverter	
Inverter ref no.	10
Model name	10000 UE
Brand	Growatt
Phase	3-phase
Maximum DC input (kW)	11.0 kW
AC output (kW)	10.0 kW
Pnom ratio	1.1

Summary	
Nber of module	73
Nber of inverter	3
Nominal PV power	40 kWp
Nominal AC power	30.00 kWAC
Estimate total installation area (m2)	243.00

Power supply demand (kW DC)	35.29
Size of solar PV field (kW)	40.00

Input the solar PV field capacity.

Solar PV	
Solar PV ref no.	6
Model name	550
Max Power (kW)	0.55
Panel size (m2)	2.56
Module eff.	21.50%
Nber of PV panel	73
Module area (m2)	186.59

Input the inverter reference number from the solar list

Input the inverter reference number from the solar list

3. Solar production load profile

Average Solar Radiation		208.73 W/m²
Time		Daily radiation available coeff.
0	12:00 AM	0%
1	1:00 AM	0%
2	2:00 AM	0%
3	3:00 AM	0%
4	4:00 AM	0%
5	5:00 AM	0%
6	6:00 AM	0%
7	7:00 AM	20%
8	8:00 AM	40%
9	9:00 AM	80%
10	10:00 AM	85%
11	11:00 AM	90%
12	12:00 PM	96%
13	1:00 PM	98%
14	2:00 PM	95%
15	3:00 PM	93%
16	4:00 PM	80%
17	5:00 PM	40%
18	6:00 PM	0%
19	7:00 PM	0%
20	8:00 PM	0%
21	9:00 PM	0%
22	10:00 PM	0%
23	11:00 PM	0%

Input the daily solar radiation coefficient

Time		Daily production	
		kWh (DC)	kWh (Heat)
0	12:00 AM	0.00 kWh	0.00 kWh
1	1:00 AM	0.00 kWh	0.00 kWh
2	2:00 AM	0.00 kWh	0.00 kWh
3	3:00 AM	0.00 kWh	0.00 kWh
4	4:00 AM	0.00 kWh	0.00 kWh
5	5:00 AM	0.00 kWh	0.00 kWh
6	6:00 AM	0.00 kWh	0.00 kWh
7	7:00 AM	1.67 kWh	10.06 kWh
8	8:00 AM	3.35 kWh	20.12 kWh
9	9:00 AM	6.70 kWh	40.23 kWh
10	10:00 AM	7.12 kWh	42.75 kWh
11	11:00 AM	7.54 kWh	45.26 kWh
12	12:00 PM	8.04 kWh	48.28 kWh
13	1:00 PM	8.21 kWh	49.28 kWh
14	2:00 PM	7.96 kWh	47.78 kWh
15	3:00 PM	7.79 kWh	46.77 kWh
16	4:00 PM	6.70 kWh	40.23 kWh
17	5:00 PM	3.35 kWh	20.12 kWh
18	6:00 PM	0.00 kWh	0.00 kWh
19	7:00 PM	0.00 kWh	0.00 kWh
20	8:00 PM	0.00 kWh	0.00 kWh
21	9:00 PM	0.00 kWh	0.00 kWh
22	10:00 PM	0.00 kWh	0.00 kWh
23	11:00 PM	0.00 kWh	0.00 kWh
Total daily production		68.41 kW	410.87 kW

This part only to forecast the daily solar production. These values maybe refer to the availability of the sunlight during the day. However, this data set can be used if prefer.

8) Enter the operation strategy of chillers and cooling towers $\xrightarrow{\text{TAB}}$ Strat

Chiller	Weekday	Day-off
January	OK	OK
February	OK	OK
March	OK	OK
April	OK	OK
May	OK	OK
June	OK	OK
July	OK	OK
August	OK	OK
September	OK	OK
October	OK	OK
November	OK	OK
December	OK	OK

CT	Weekday	Day-off
January	OK	OK
February	OK	OK
March	OK	OK
April	OK	OK
May	OK	OK
June	OK	OK
July	OK	OK
August	OK	OK
September	OK	OK
October	OK	OK
November	OK	OK
December	OK	OK

Solar	Weekday
January	OK
February	OK
March	OK
April	OK
May	OK
June	OK
July	OK
August	OK
September	OK
October	OK
November	OK
December	OK

No. Month	Month	Solar radiation (W/m²)	Thermal production	Electricity production
1	Jan	203.05	12.39 MW	2.06 MW
2	Feb	222.61	12.27 MW	2.04 MW
3	Mar	229.90	14.03 MW	2.34 MW
4	Apr	241.58	14.27 MW	2.38 MW
5	May	218.56	13.34 MW	2.22 MW
6	Jun	211.27	12.48 MW	2.08 MW
7	Jul	201.43	12.29 MW	2.05 MW
8	Aug	198.19	12.09 MW	2.01 MW
9	Sept	196.69	11.62 MW	1.93 MW
10	Oct	192.41	11.74 MW	1.95 MW
11	Nov	195.30	11.53 MW	1.92 MW
12	Dec	193.80	11.83 MW	1.97 MW

ⓘ To check error calculation of chillers, cooling towers and solar applications.

1 January

Chiller			Weekday						Partload	OK
			Nber install	1						
			Chiller cap.	98 RT						
Time	From	To	Chiller Plant load	Chiller 1	Chiller 2	Chiller 3	Chiller 4	Chiller 5	Part load	Check production
0	12:00 AM	1:00 AM	0 RT	0	0	0	0	0	0%	OK
1	1:00 AM	2:00 AM	0 RT	0	0	0	0	0	0%	OK
2	2:00 AM	3:00 AM	0 RT	0	0	0	0	0	0%	OK
3	3:00 AM	4:00 AM	0 RT	0	0	0	0	0	0%	OK
4	4:00 AM	5:00 AM	0 RT	0	0	0	0	0	0%	OK
5	5:00 AM	6:00 AM	0 RT	0	0	0	0	0	0%	OK
6	6:00 AM	7:00 AM	0 RT	0	0	0	0	0	0%	OK
7	7:00 AM	8:00 AM	0 RT	0	0	0	0	0	0%	OK
8	8:00 AM	9:00 AM	18 RT	1	0	0	0	0	19%	OK
9	9:00 AM	10:00 AM	38 RT	1	0	0	0	0	39%	OK
10	10:00 AM	11:00 AM	47 RT	1	0	0	0	0	49%	OK
11	11:00 AM	12:00 PM	53 RT	1	0	0	0	0	54%	OK
12	12:00 PM	1:00 PM	58 RT	1	0	0	0	0	60%	OK
13	1:00 PM	2:00 PM	55 RT	1	0	0	0	0	56%	OK
14	2:00 PM	3:00 PM	49 RT	1	0	0	0	0	51%	OK
15	3:00 PM	4:00 PM	45 RT	1	0	0	0	0	46%	OK
16	4:00 PM	5:00 PM	40 RT	1	0	0	0	0	41%	OK
17	5:00 PM	6:00 PM	36 RT	1	0	0	0	0	37%	OK
18	6:00 PM	7:00 PM	32 RT	1	0	0	0	0	33%	OK
19	7:00 PM	8:00 PM	29 RT	1	0	0	0	0	30%	OK
20	8:00 PM	9:00 PM	26 RT	1	0	0	0	0	27%	OK
21	9:00 PM	10:00 PM	26 RT	1	0	0	0	0	27%	OK
22	10:00 PM	11:00 PM	9 RT	1	0	0	0	0	10%	OK
23	11:00 PM	12:00 AM	9 RT	1	0	0	0	0	10%	OK

Input “1” or “0”:
1 for operating chiller
0 for no chiller running

ⓘ An error occurs when the part load percentage > 100%

ⓘ Show the part load running percentage of chiller 0 – 100%

Do the same for both weekdays (WD) and Day-off (DO)

Cooling tower			Weekday							OK
			Nber cell of CT	4	0	0	0	0		
			Heatload per cell	62 HRT	0 HRT	0 HRT	0 HRT	0 HRT		
Time	From	To	Total Heatload	CT 1	CT 2	CT 3	CT 4	CT 5	Part load	Check production
0	12:00 AM	1:00 AM	0 HRT	0	0	0	0	0	0%	OK
1	1:00 AM	2:00 AM	0 HRT	0	0	0	0	0	0%	OK
2	2:00 AM	3:00 AM	0 HRT	0	0	0	0	0	0%	OK
3	3:00 AM	4:00 AM	0 HRT	0	0	0	0	0	0%	OK
4	4:00 AM	5:00 AM	0 HRT	0	0	0	0	0	0%	OK
5	5:00 AM	6:00 AM	0 HRT	0	0	0	0	0	0%	OK
6	6:00 AM	7:00 AM	0 HRT	0	0	0	0	0	0%	OK
7	7:00 AM	8:00 AM	0 HRT	0	0	0	0	0	0%	OK
8	8:00 AM	9:00 AM	45 HRT	1	0	0	0	0	73%	OK
9	9:00 AM	10:00 AM	97 HRT	2	0	0	0	0	78%	OK
10	10:00 AM	11:00 AM	121 HRT	3	0	0	0	0	64%	OK
11	11:00 AM	12:00 PM	134 HRT	3	0	0	0	0	72%	OK
12	12:00 PM	1:00 PM	148 HRT	3	0	0	0	0	79%	OK
13	1:00 PM	2:00 PM	139 HRT	3	0	0	0	0	74%	OK
14	2:00 PM	3:00 PM	126 HRT	3	0	0	0	0	67%	OK
15	3:00 PM	4:00 PM	114 HRT	3	0	0	0	0	61%	OK
16	4:00 PM	5:00 PM	102 HRT	3	0	0	0	0	55%	OK
17	5:00 PM	6:00 PM	92 HRT	2	0	0	0	0	74%	OK
18	6:00 PM	7:00 PM	82 HRT	2	0	0	0	0	66%	OK
19	7:00 PM	8:00 PM	74 HRT	2	0	0	0	0	59%	OK
20	8:00 PM	9:00 PM	67 HRT	2	0	0	0	0	54%	OK
21	9:00 PM	10:00 PM	67 HRT	2	0	0	0	0	54%	OK
22	10:00 PM	11:00 PM	23 HRT	1	0	0	0	0	38%	OK
23	11:00 PM	12:00 AM	23 HRT	1	0	0	0	0	38%	OK

Input the number of operating cells

An error occurs when the part load percentage > 105%

Show the part load running percentage of cooling towers 0 – 105%

Do the same for both weekdays (WD) and Day-off (DO)

OK			Daily					
Solar Thermal			Efficiency coeff.	0.83	0.00	0.00	0.00	0.00
			Heat loss coeff.	3.93	0.00	0.00	0.00	0.00
Time	From	To	Solar production	1	2	3	4	5
0	12:00 AM	1:00 AM	0.00 kWh	0.00	0.00	0.00	0.00	0.00
1	1:00 AM	2:00 AM	0.00 kWh	0.00	0.00	0.00	0.00	0.00
2	2:00 AM	3:00 AM	0.00 kWh	0.00	0.00	0.00	0.00	0.00
3	3:00 AM	4:00 AM	0.00 kWh	0.00	0.00	0.00	0.00	0.00
4	4:00 AM	5:00 AM	0.00 kWh	0.00	0.00	0.00	0.00	0.00
5	5:00 AM	6:00 AM	0.00 kWh	0.00	0.00	0.00	0.00	0.00
6	6:00 AM	7:00 AM	0.00 kWh	0.00	0.00	0.00	0.00	0.00
7	7:00 AM	8:00 AM	9.78 kWh	9.78	0.00	0.00	0.00	0.00
8	8:00 AM	9:00 AM	19.57 kWh	19.57	0.00	0.00	0.00	0.00
9	9:00 AM	10:00 AM	39.14 kWh	39.14	0.00	0.00	0.00	0.00
10	10:00 AM	11:00 AM	41.58 kWh	41.58	0.00	0.00	0.00	0.00
11	11:00 AM	12:00 PM	44.03 kWh	44.03	0.00	0.00	0.00	0.00
12	12:00 PM	1:00 PM	46.97 kWh	46.97	0.00	0.00	0.00	0.00
13	1:00 PM	2:00 PM	47.94 kWh	47.94	0.00	0.00	0.00	0.00
14	2:00 PM	3:00 PM	46.48 kWh	46.48	0.00	0.00	0.00	0.00
15	3:00 PM	4:00 PM	45.50 kWh	45.50	0.00	0.00	0.00	0.00
16	4:00 PM	5:00 PM	39.14 kWh	39.14	0.00	0.00	0.00	0.00
17	5:00 PM	6:00 PM	19.57 kWh	19.57	0.00	0.00	0.00	0.00
18	6:00 PM	7:00 PM	0.00 kWh	0.00	0.00	0.00	0.00	0.00
19	7:00 PM	8:00 PM	0.00 kWh	0.00	0.00	0.00	0.00	0.00
20	8:00 PM	9:00 PM	0.00 kWh	0.00	0.00	0.00	0.00	0.00
21	9:00 PM	10:00 PM	0.00 kWh	0.00	0.00	0.00	0.00	0.00
22	10:00 PM	11:00 PM	0.00 kWh	0.00	0.00	0.00	0.00	0.00
23	11:00 PM	12:00 AM	0.00 kWh	0.00	0.00	0.00	0.00	0.00

OK			
Solar PV			Daily
Time	From	To	Solar production
0	12:00 AM	1:00 AM	0.00 kWh
1	1:00 AM	2:00 AM	0.00 kWh
2	2:00 AM	3:00 AM	0.00 kWh
3	3:00 AM	4:00 AM	0.00 kWh
4	4:00 AM	5:00 AM	0.00 kWh
5	5:00 AM	6:00 AM	0.00 kWh
6	6:00 AM	7:00 AM	0.00 kWh
7	7:00 AM	8:00 AM	1.63 kWh
8	8:00 AM	9:00 AM	3.26 kWh
9	9:00 AM	10:00 AM	6.52 kWh
10	10:00 AM	11:00 AM	6.92 kWh
11	11:00 AM	12:00 PM	7.33 kWh
12	12:00 PM	1:00 PM	7.82 kWh
13	1:00 PM	2:00 PM	7.98 kWh
14	2:00 PM	3:00 PM	7.74 kWh
15	3:00 PM	4:00 PM	7.58 kWh
16	4:00 PM	5:00 PM	6.52 kWh
17	5:00 PM	6:00 PM	3.26 kWh
18	6:00 PM	7:00 PM	0.00 kWh
19	7:00 PM	8:00 PM	0.00 kWh
20	8:00 PM	9:00 PM	0.00 kWh
21	9:00 PM	10:00 PM	0.00 kWh
22	10:00 PM	11:00 PM	0.00 kWh
23	11:00 PM	12:00 AM	0.00 kWh

No actions require for the solar applications part

9) Efficiency calculations and output results $\xrightarrow{\text{TAB}}$ Efficiency

	Check	Safety factor	Efficiency
Country	OK		
Cooling load			
Specification	OK		
Heat_Source	OK		
Strat	OK		
Cooling demand Peak/Off-peak Hours	OK		
Solar Thermal	OK		
Solar Photovoltaic	OK		
Single-effect absorption Chiller (thermal)	OK	0%	9.69 kW(heat)/RT
Single-effect absorption Chiller (elec)		0%	0.035 kWh/RT
Cooling tower	OK	0%	0.152 kWh/RT
Condenser pumps	OK	0%	0.356 kWh/RT
Primary pumps	OK	0%	0.139 kWh/RT
Hot water pumps	OK	0%	0.063 kWh/RT
Solar pumps	OK	0%	0.001 kWh/RT
Total ancillaries	OK		0.746 kWh/RT

Contract capacity	33.55 kW	% consumption
Annual electricity consumption - Peak hours	96.61 MWh	56%
Annual electricity consumption - Off-Peak hours	75.88 MWh	44%

ⓘ To remind the previous errors check.

ⓘ Errors check for this “Efficiency” sheet.

Input the tolerances of the efficiency coefficients (optional)

Hours	N°Day in year	N° Day in month	N° Day in week	N° Week	N° Month	Day hour	Week hour	Type of day	DBT (°C)	Relative Humidity %	WBT (°C)	Peak/Off-Peak	Cooling load demand	Cooling load @ Chiller Plant	Check Load demand = Load Plant	Solar Thermal production	Solar Electricity production
												OK			OK	OK	OK
													74 RTh	74 RTh		57 kWh	9 kWh
													231 kRTh	231 kRTh		150 MWh	25 MWh
1	1	1	3	1	1	0	49	PH	22.1	71	18.4	O	0 RTh	0 RTh	OK	0.00 kWh	0.00 kWh
2	1	1	3	1	1	1	50	PH	24.85	66.5	20.3	O	0 RTh	0 RTh	OK	0.00 kWh	0.00 kWh
3	1	1	3	1	1	2	51	PH	27.45	61.5	21.9	O	0 RTh	0 RTh	OK	0.00 kWh	0.00 kWh
4	1	1	3	1	1	3	52	PH	27.1	62	21.7	O	0 RTh	0 RTh	OK	0.00 kWh	0.00 kWh
5	1	1	3	1	1	4	53	PH	26.85	63.5	21.7	O	0 RTh	0 RTh	OK	0.00 kWh	0.00 kWh
6	1	1	3	1	1	5	54	PH	26.7	63.5	21.6	O	0 RTh	0 RTh	OK	0.00 kWh	0.00 kWh
7	1	1	3	1	1	6	55	PH	26.55	63	21.3	O	0 RTh	0 RTh	OK	0.00 kWh	0.00 kWh
8	1	1	3	1	1	7	56	PH	26.5	64	21.5	O	0 RTh	0 RTh	OK	9.78 kWh	1.63 kWh
9	1	1	3	1	1	8	57	PH	26.9	65.5	22.0	O	20 RTh	20 RTh	OK	19.57 kWh	3.26 kWh
10	1	1	3	1	1	9	58	PH	27.95	64.5	22.9	O	38 RTh	38 RTh	OK	39.14 kWh	6.52 kWh
11	1	1	3	1	1	10	59	PH	29.3	60	23.4	O	47 RTh	47 RTh	OK	41.58 kWh	6.92 kWh
12	1	1	3	1	1	11	60	PH	30.7	55	23.8	O	55 RTh	55 RTh	OK	44.03 kWh	7.33 kWh
13	1	1	3	1	1	12	61	PH	31.95	51.5	24.2	O	66 RTh	66 RTh	OK	46.97 kWh	7.82 kWh
14	1	1	3	1	1	13	62	PH	32.8	49.5	24.6	O	63 RTh	63 RTh	OK	47.94 kWh	7.98 kWh
15	1	1	3	1	1	14	63	PH	33.3	48.5	24.8	O	57 RTh	57 RTh	OK	46.48 kWh	7.74 kWh
16	1	1	3	1	1	15	64	PH	33.55	49	25.2	O	51 RTh	51 RTh	OK	45.50 kWh	7.58 kWh
17	1	1	3	1	1	16	65	PH	33.5	51	25.5	O	46 RTh	46 RTh	OK	39.14 kWh	6.52 kWh
18	1	1	3	1	1	17	66	PH	33.1	52.5	25.4	O	41 RTh	41 RTh	OK	19.57 kWh	3.26 kWh
19	1	1	3	1	1	18	67	PH	32.35	56	25.4	O	38 RTh	38 RTh	OK	0.00 kWh	0.00 kWh

No actions require for this part

Chiller 1	Chiller 2	Chiller 3	Chiller 4	Chiller 5	Part load production	Chiller production	Check Chiller production	Electrical consumption	Thermal consumption	Thermal energy requies from Natural gas	Actual NG for CH 1	Actual NG for CH 2	Actual NG for CH 3	Actual NG for CH 4	Actual NG for CH 5	Actual natural gas demand	Energy Efficient coeff.	Thermal COP of Chiller
							OK									OK	9.69 kW(heat)/RT	0.36
98 RT	0 RT	0 RT	0 RT	0 RT	27%	74 RTh		1.40 kWh	388 kWh	38 kWh						38 kWh	5.21 kW(heat)/RT	0.09
1.40 kW	0.00 kW	0.00 kW	0.00 kW	0.00 kW	76%	234 kRTh		8 MWh	2,268 MWh	224 MWh						97 MWh	39.62 kW(heat)/RT	0.67
0	0	0	0	0	0%	0 RTh	OK	0.00 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0.00 kW(heat)/RT	0.00
0	0	0	0	0	0%	0 RTh	OK	0.00 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0.00 kW(heat)/RT	0.00
0	0	0	0	0	0%	0 RTh	OK	0.00 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0.00 kW(heat)/RT	0.00
0	0	0	0	0	0%	0 RTh	OK	0.00 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0.00 kW(heat)/RT	0.00
0	0	0	0	0	0%	0 RTh	OK	0.00 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0.00 kW(heat)/RT	0.00
0	0	0	0	0	0%	0 RTh	OK	0.00 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0.00 kW(heat)/RT	0.00
0	0	0	0	0	0%	0 RTh	OK	0.00 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0.00 kW(heat)/RT	0.00
0	0	0	0	0	0%	0 RTh	OK	0.00 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0.00 kW(heat)/RT	0.00
1	0	0	0	0	21%	21 RTh	OK	1.40 kWh	388 kWh	38 kWh	19 kWh	0 kWh	0 kWh	0 kWh	0 kWh	19 kWh	18.87 kW(heat)/RT	0.19
1	0	0	0	0	39%	38 RTh	OK	1.40 kWh	388 kWh	38 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	10.16 kW(heat)/RT	0.35
1	0	0	0	0	49%	48 RTh	OK	1.40 kWh	388 kWh	38 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	8.09 kW(heat)/RT	0.43
1	0	0	0	0	56%	55 RTh	OK	1.40 kWh	388 kWh	38 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	7.08 kW(heat)/RT	0.50
1	0	0	0	0	68%	67 RTh	OK	1.40 kWh	388 kWh	38 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	5.83 kW(heat)/RT	0.60
1	0	0	0	0	65%	64 RTh	OK	1.40 kWh	388 kWh	38 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	6.10 kW(heat)/RT	0.58
1	0	0	0	0	58%	57 RTh	OK	1.40 kWh	388 kWh	38 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	6.83 kW(heat)/RT	0.51
1	0	0	0	0	53%	52 RTh	OK	1.40 kWh	388 kWh	38 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	7.48 kW(heat)/RT	0.47
1	0	0	0	0	48%	47 RTh	OK	1.40 kWh	388 kWh	38 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	8.25 kW(heat)/RT	0.43
1	0	0	0	0	43%	42 RTh	OK	1.40 kWh	388 kWh	38 kWh	19 kWh	0 kWh	0 kWh	0 kWh	0 kWh	19 kWh	9.21 kW(heat)/RT	0.38
1	0	0	0	0	39%	38 RTh	OK	1.40 kWh	388 kWh	38 kWh	38 kWh	0 kWh	0 kWh	0 kWh	0 kWh	38 kWh	10.16 kW(heat)/RT	0.35

						OK						0.15 kWh/RT
Heat rejected	CT 1	CT 2	CT 3	CT 4	CT 5	Partload CT	Electrical consumption CT 1	Electrical consumption CT 2	Electrical consumption CT 3	Electrical consumption CT 4	Electrical consumption CT 5	Efficiency Cooling towers
190 HRTh	62 HRT	0 HRT	0 HRT	0 HRT	0 HRT	44%						0.12 kWh/RT
590 kHRTh	2.50 kW	-	-	-	-	84%	35 MWh	-	-	-	-	0.27 kWh/RT
0 HRTh	0	0	0	0	0	0%	0.00 kWh	-	-	-	-	0.00 kWh/RT
0 HRTh	0	0	0	0	0	0%	0.00 kWh	-	-	-	-	0.00 kWh/RT
0 HRTh	0	0	0	0	0	0%	0.00 kWh	-	-	-	-	0.00 kWh/RT
0 HRTh	0	0	0	0	0	0%	0.00 kWh	-	-	-	-	0.00 kWh/RT
0 HRTh	0	0	0	0	0	0%	0.00 kWh	-	-	-	-	0.00 kWh/RT
0 HRTh	0	0	0	0	0	0%	0.00 kWh	-	-	-	-	0.00 kWh/RT
0 HRTh	0	0	0	0	0	0%	0.00 kWh	-	-	-	-	0.00 kWh/RT
0 HRTh	0	0	0	0	0	0%	0.00 kWh	-	-	-	-	0.00 kWh/RT
50 HRTh	1	0	0	0	0	81%	2.50 kWh	-	-	-	-	0.13 kWh/RT
97 HRTh	2	0	0	0	0	78%	5.00 kWh	-	-	-	-	0.13 kWh/RT
121 HRTh	3	0	0	0	0	64%	7.50 kWh	-	-	-	-	0.16 kWh/RT
139 HRTh	3	0	0	0	0	74%	7.50 kWh	-	-	-	-	0.14 kWh/RT
168 HRTh	4	0	0	0	0	67%	9.99 kWh	-	-	-	-	0.15 kWh/RT
161 HRTh	4	0	0	0	0	64%	9.99 kWh	-	-	-	-	0.16 kWh/RT
144 HRTh	3	0	0	0	0	77%	7.50 kWh	-	-	-	-	0.13 kWh/RT
131 HRTh	3	0	0	0	0	70%	7.50 kWh	-	-	-	-	0.15 kWh/RT
117 HRTh	3	0	0	0	0	63%	7.50 kWh	-	-	-	-	0.16 kWh/RT
106 HRTh	3	0	0	0	0	56%	7.50 kWh	-	-	-	-	0.18 kWh/RT
96 HRTh	2	0	0	0	0	77%	5.00 kWh	-	-	-	-	0.13 kWh/RT

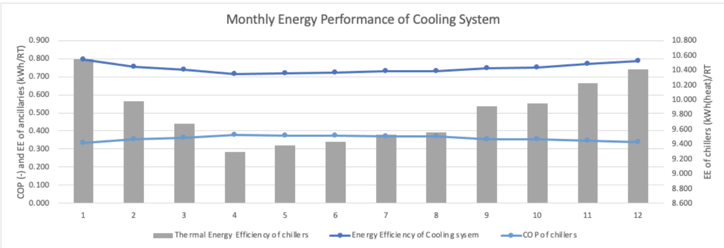
No actions require
for this part

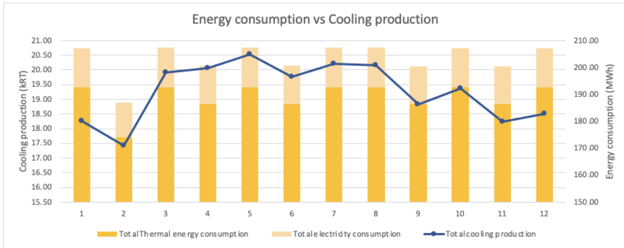
10) Summary output result and efficiency graph TAB → Efficiency_graph

No actions require for this part

Energy performance of cooling plant

No.	Month	Total cooling production	Total Thermal energy consumption	Available waste heat	Outsource thermal demand	Actual NG demand	Waste/excess heat consumption	Total electricity consumption	Outsource electricity demand	Electricity consumption - Peak hours	Electricity consumption - Off-peak hours	Energy Efficiency of Cooling sysem	Thermal Energy Efficiency of chillers	COP of chillers	Outsource cost	Electricity cost	Total energy cost	Solar thermal production	Solar PV production
		kRT	MWh(heat)	MWh(heat)	MWh(heat)	MWh(heat)	MWh(heat)	MWh	MWh	MWh	MWh	kWh/RT	kWh(heat)/RT	-	kTHB	kTHB	kTHB	MWh(heat)	MWh
1	January	18.27	192.59	173.60	18.99	8.28	173.60	14.54	12.47	8.16	6.38	0.796	10.544	0.334	12,959	65.42	13,024.03	12.39	2.06
2	February	17.43	173.95	156.80	17.15	7.37	156.80	13.14	11.10	7.77	5.37	0.754	9.981	0.352	11,705	59.14	11,763.70	12.27	2.04
3	March	19.91	192.59	173.60	18.99	8.12	173.60	14.69	12.36	8.26	6.43	0.738	9.673	0.364	12,959	66.12	13,024.73	14.03	2.34
4	April	20.06	186.38	168.00	18.38	7.79	168.00	14.36	11.98	7.52	6.84	0.716	9.292	0.378	12,541	64.61	12,605.21	14.27	2.38
5	May	20.52	192.59	173.60	18.99	8.19	173.60	14.75	12.53	7.87	6.89	0.719	9.385	0.375	12,959	66.40	13,025.01	13.34	2.22
6	June	19.76	186.38	168.00	18.38	7.97	168.00	14.26	12.18	8.26	6.00	0.722	9.434	0.373	12,541	64.16	12,604.76	12.48	2.08
7	July	20.21	192.59	173.60	18.99	8.29	173.60	14.73	12.68	8.66	6.07	0.729	9.528	0.369	12,959	66.28	13,024.90	12.29	2.05
8	August	20.15	192.59	173.60	18.99	8.32	173.60	14.75	12.74	7.87	6.89	0.732	9.556	0.368	12,959	66.40	13,025.01	12.09	2.01
9	September	18.82	186.38	168.00	18.38	8.07	168.00	14.08	12.14	8.55	5.53	0.748	9.906	0.355	12,541	63.34	12,603.94	11.62	1.93
10	October	19.36	192.59	173.60	18.99	8.42	173.60	14.56	12.61	8.16	6.41	0.752	9.947	0.354	12,959	65.53	13,024.15	11.74	1.96
11	November	18.23	186.38	168.00	18.38	8.10	168.00	14.07	12.15	7.77	6.30	0.772	10.226	0.344	12,541	63.32	12,603.91	11.53	1.92
12	December	18.50	192.59	173.60	18.99	8.39	173.60	14.55	12.59	7.77	6.78	0.786	10.408	0.338	12,959	65.45	13,024.07	11.83	1.95
Average		19.27	188.97	170.33	18.63	8.11	170.33	14.37	12.30	8.05	6.32	0.747	9.823	0.359	12,714.77	64.68	12,779.45	12.49	2.08
Total		231.21	2,267.58	2,044.00	223.58	97.31	2,044.00	172.48	147.55	96.61	75.88	0.746	9.807	0.359	152,577.24	776.18	153,353.42	149.87	24.94





11) Absorption list tab $\xrightarrow{\text{TAB}}$ Absorption list

No actions require for this part

Absorption Chiller specification list

Index	Name	brand	Nber. of effect	Cooling capacity RT	Cooling capacity kW	Chilled Water: Inlet temp	Chilled Water: Outlet temp	Chilled Water: Flow rate (m3/h)	Chilled Water: Friction loss (mWC)	Chilled Water: Connection Diameter (mmNB)	Cooling water: Inlet Temp. (ºC)	Cooling water: Outlet Temp. (ºC)	Cooling water: Flow rate (m3/h)	Cooling water: Friction loss (mWC)	Cooling water: Connection Diameter (mmNB)	Hot water / steam: Inlet temp	Hot water / steam: Outlet temp	Hot water / steam: Steam Consumption (kg/h)	Hot water / steam: Standard steam pressure (kg/cm2 (g))	Hot water / steam: Max pressure (kg/cm2 (g))	Hot water / steam: Connection Diameter (steam) (mmNB)
1	SS20AC	THERMAX	single-effect	98	345	-	-	53.7	3.8	100	29.4	36.7	98	2.9	150	-	-	746	1.5	5	125
2	SS20BC	THERMAX	single-effect	118	415	-	-	64.7	4.7	100	29.4	36.7	118	3	150	-	-	900	1.5	5	125
3	SS20CC	THERMAX	single-effect	148	520	-	-	81.1	5.3	100	29.4	36.7	148	3.7	150	-	-	1120	1.5	5	125
4	SS20DC	THERMAX	single-effect	179	630	-	-	98.1	7	100	29.4	36.7	179	3.9	150	-	-	1354	1.5	5	125
5	SS30AC	THERMAX	single-effect	219	770	-	-	120.1	4.9	150	29.4	36.7	219	3.6	200	-	-	1660	1.5	5	150
6	SS30BC	THERMAX	single-effect	246	865	-	-	134.9	5.6	150	29.4	36.7	246	3.6	200	-	-	1866	1.5	5	150
7	SS30CC	THERMAX	single-effect	293	1,030	-	-	160.7	8.5	150	29.4	36.7	293	5.7	200	-	-	2217	1.5	5	150
8	SS40AC	THERMAX	single-effect	331	1,164	-	-	181.5	6.1	150	29.4	36.7	331	5.4	250	-	-	2507	1.5	5	200
9	SS40BC	THERMAX	single-effect	374	1,315	-	-	205.1	6.4	150	29.4	36.7	374	5.4	250	-	-	2828	1.5	5	200
10	SS40CC	THERMAX	single-effect	410	1,442	-	-	224.8	6.9	150	29.4	36.7	410	5.5	250	-	-	3112	1.5	5	200
11	SS50AC	THERMAX	single-effect	461	1,621	-	-	252.8	6.2	200	29.4	36.7	461	5.8	250	-	-	3493	1.5	5	200
12	SS50BC	THERMAX	single-effect	506	1,780	-	-	277.4	6.4	200	29.4	36.7	506	5.9	250	-	-	3831	1.5	5	200
13	SS60AC	THERMAX	single-effect	592	2,082	-	-	324.6	6	250	29.4	36.7	592	7.1	300	-	-	4487	1.5	5	250
14	SS60BC	THERMAX	single-effect	654	2,300	-	-	358.6	6.3	250	29.4	36.7	654	7.2	300	-	-	4954	1.5	5	250
15	SS60CC	THERMAX	single-effect	736	2,588	-	-	403.5	4.1	250	29.4	36.7	736	11.9	300	-	-	5574	1.5	5	250
16	SS60DC	THERMAX	single-effect	817	2,873	-	-	448	4.4	250	29.4	36.7	817	12.1	300	-	-	6187	1.5	5	250
17	SS70AC	THERMAX	single-effect	921	3,239	-	-	505	4.4	250	29.4	36.7	921	11.5	350	-	-	6993	1.5	5	300
18	SS70BC	THERMAX	single-effect	1029	3,619	-	-	564.2	4.9	250	29.4	36.7	1029	12.4	350	-	-	7802	1.5	5	300
19	SS80AC	THERMAX	single-effect	1142	4,016	-	-	626.2	8.9	300	29.4	36.7	1142	9.5	400	-	-	8653	1.5	5	350
20	SS80BC	THERMAX	single-effect	1250	4,396	-	-	685.4	9.5	300	29.4	36.7	1250	10.2	400	-	-	9467	1.5	5	350
21	SS80CC	THERMAX	single-effect	1440	5,064	-	-	789.5	6.1	300	29.4	36.7	1440	15.6	400	-	-	10946	1.5	5	350
22	SS80DC	THERMAX	single-effect	1569	5,518	-	-	860.3	6.5	300	29.4	36.7	1569	7.5	400	-	-	11907	1.5	5	350

12) Solar list & inverter tab $\xrightarrow{\text{TAB}}$ Solar list

1. Thermal collector specification list

Index	Model	Brand	Solar	Gross collector area (m2)	Aperture area (m2)	Absorber area (m2)	Efficiency coefficient	Heat loss coefficient (W/m2K)	Dimensions (mm) Width	Dimensions (mm) height	Dimensions (mm) Depth	Empty collector mass (kg)	Agent flux through collector (L/min)
1	WATT 2020 S	eSens	Thermal	2.04	-	1.88	0.756	3.545	2018	1018	90	33.8	1
2	WATT 2251 S	eSens	Thermal	2.57	-	2.39	0.753	3.396	2167	1187	90	41.8	1
3	WATT 3020 S	eSens	Thermal	2.054	-	1.873	0.784	3.64	2018	1018	90	39	1
4	WATT 3025 S	eSens	Thermal	2.556	-	2.354	0.785	3.66	2518	1018	90	45	1.5
5	WATT 4020 S	eSens	Thermal	2.054	-	1.873	0.845	4.1	2018	1018	90	39	1.5
6	WATT 5020 S	eSens	Thermal	2.05	-	1.9	0.816	4.203	2018	1018	90	47.5	2
7	WATT 5025 S	eSens	Thermal	2.56	-	2.36	0.83	3.933	2518	1018	90	57	2
8	WATT 7020 S	eSens	Thermal	2.057	-	1.852	0.755	3.38	2018	1018	90	36.6	1.1

No actions require for this part

2. Solar PV specification list

Index	Model	Brand	Solar	Max. Power (Wp)	Dimensions (mm) Width	Dimensions (mm) Length	Dimensions (mm) Depth	Number of cell (Pcs)	Max. Power Voltage (V)	Max. Power Current (A)	Open circuit Voltage (V)	Short circuit Current (A)	Max. system Voltage (V)	Operation Temperature range (◦C) min	Operation Temperature range (◦C) max	Tolerance Wattage (+/-)	Surface Max. Load Capacity (m/s)	Weight per piece (kg)	Length of cables (mm)	Cell Efficiency	Module Efficiency	Output Tolerance (+/-)	Frame (Material)
1	525	LONGI	PV	525	2256	1133	35	144	41.20	12.75	49.05	13.65	1500	-40	85	3%	-	27.2	-	-	20.5%	0-5 W	Aluminum
2	530	LONGI	PV	530	2256	1133	35	144	41.35	12.82	49.20	13.71	1500	-40	85	3%	-	27.2	-	-	20.7%	0-5 W	Aluminum
3	535	LONGI	PV	535	2256	1133	35	144	41.50	12.90	49.35	13.78	1500	-40	85	3%	-	27.2	-	-	20.9%	0-5 W	Aluminum
4	540	LONGI	PV	540	2256	1133	35	144	41.65	12.97	49.50	13.85	1500	-40	85	3%	-	27.2	-	-	21.1%	0-5 W	Aluminum
5	545	LONGI	PV	545	2256	1133	35	144	41.80	13.04	49.65	13.92	1500	-40	85	3%	-	27.2	-	-	21.3%	0-5 W	Aluminum
6	550	LONGI	PV	550	2256	1133	35	144	41.95	13.12	49.80	13.98	1500	-40	85	3%	-	27.2	-	-	21.5%	0-5 W	Aluminum

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