Application of low enthalpy geothermal resource in the built environment

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ABSTRACT

Over 50% of the world's population lives in cities today based on estimations by the World Bank and the United Nations. This migration of people is driving an increase in urban energy demands and greenhouse gas emissions associated with the energy demand of acclimatizing buildings. This trend is reflected in Jakarta, one of the most populated cities in the world; however, some leaders such as Pertamina Energy Company are aiming to create a new paradigm of sustainable buildings. Their proposed headquarters is being designed to include a super-tall tower that consumes all of its power from clean onsite sources. Current renewable application under investigation for the tower includes a low enthalpy geothermal system in a combined heat and power scheme using binary cycle technology as primary source of energy. Geothermal has the highest energy density (kWh/m^2) compared to other renewable energy sources and thus is more efficient. Further, the waste heat recovered from the organic vapor turbine will feed absorption chillers and satisfy much of the site's cooling demands. This paper will study the integration of low temperature, compact geothermal plants into an urban environment. As people continue to migrate into cities, geothermal energy will prove to be a viable option that reduces greenhouse gases and makes a more livable city.

1. INTRODUCTION

The unprecedented growth of Urbanization since the late 18th century is mainly due to the agricultural and industrial revolution. It started in the western world and rapidly expanded globally. By 2050, it is estimated that 75% of the world's population will live in cities. Until then, there will be one million people added to our cities every week. In Indonesia,, this rural-urban migration urbanization, has significantly increased since the 1970s. In 2010, 44% of the country's population lived in cities. According to the Central Statistic Agency, Jakarta's average population density exceeds 14,400 people per square meter. In 2020, the same source estimates 11 million people to live in this city unless measures are taken to control the population.

World urbanization comes at a high environmental cost, stressing valuable resources if not planned for appropriately. Lack of transit systems and proliferation of power plants to provide for the increased energy demands has resulted in poor air quality impacting human health. The level of particulate matter (PM 2.5), a dangerous pollutant for human health, is a good representation of the severity of air pollution. Cities where fossil fuel power plants dominate the energy generation mix have a very high and sometimes unsafe concentration of PM 2.5. Therefore, it is crucial to promote cleaner fuel such as renewable energy as a way to reduce and control pollution. Some forms of renewable energy do not have to be built far from cities. For instance, geothermal energy plants can easily be located in city centers or on its perimeter. Current projects in or near city centers are located in such diverse locations as Reno, NV-USA; Boise, Idaho-USA; Paris, France; Munich, Germany; Reykjavik, Iceland. Clean energy generation follows energy reduction at the building level. Solar panels and wind turbines can easily be integrated to buildings, but may require large area uptake. Geothermal energy offers cities the opportunity to become greener and allow building to approach net zero energy while maintaining density This paper focuses on how the new Pertamina Energy headquarters aspires to become the world's first net positive super tall building campus that potentially will offset both operational and embodied carbon.

2. PERTAMINA ENERGY TOWER CAMPUS

In 2011, Pertamina decided to reflect its transformation from an oil and gas company to a "world class national energy company". its vision includes a consistent development of renewable energy sources. Today, Pertamina is focusing its effort on the development of geothermal energy as a potential alternative energy source. In order to reinforce this move forward, this national energy company has set an important objective to have 25% of its energy supply coming from new and renewable energy by 2020. Pertamina is also committed to achieve a greenhouse gas emission reduction target of 26% by 2020. Additionally, it is studying the utilization of wind energy, solar, algae as bi-ethanol feedstock and biomass energy [2].

Figure 1, Pertamina Energy Tower Campus architectural impression

Pertamina's new headquarters and campus at Rasuna Epicentrum Kuningan is a mixed use development in Jakarta, Indonesia, consisting of the Pertamina Energy Tower for 20,000 employees, the Pertamina Pavilion containing an exhibition hall and auditorium, the Mosque, the Visitor's Center and Sports Field House, a Café. A Central Energy Plant will potentially utilize geothermal energy to help the campus attain the highest sustainability ratings. As an energy company, Pertamina has high goals for environmental stewardship, so the architecture features many elements to mitigate the tropical climate and serve as an example of green design. Further, the campus grounds are designed with sensitivity and reference to the Indonesian landscape. Integrated into the green spaces is a continuous pedestrian walkway and bridge system, the "Energy Ribbon," which provides a pleasant pedestrian experience between buildings while the roof harvests energy from the high equatorial sun. By the time of completion the campus will be well served by various mass transit routes and will be accessible by private vehicles.

This project will implement clear and responsible strategies to minimize the buildings' environmental impact. For example, treatment facilities are designed to manage all its waste and rain water reuse. The ventilation and air conditioning (VAC) system is designed to maintain indoor human comfort and improve indoor air quality. The use of a mix of renewable energy (wind, solar, and geothermal) is clean and hence does not have adverse air quality impacts. Most importantly, the high performance and sustainable design of this campus is consistent with Pertamina's objectives.

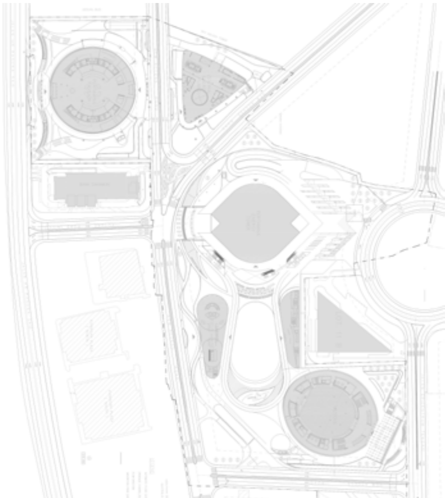

Figure 2, Pertamina Energy Tower Campus

3. ENERGY REDUCTION TO MINIMIZE SUPPLY

Energy reductions come from a variety of places, at a variety of scales. Designers play an important role in achieving reductions through design responsibilities. However, owners and end users are critical to achieve these projections and improve upon them during operation throughout the building life span.

A poorly designed building with a very well educated facilities management staff and knowledgeable and committed occupants can see far better energy reductions than the most exemplar building design in the world that show energy reductions in design models but are not operated and maintained as assumed or expected. The steps in figure 3 explain the methodology the architectural and engineering designers have followed to achieve the High Performance Design (HPD) for the Pertamina Energy Tower project.

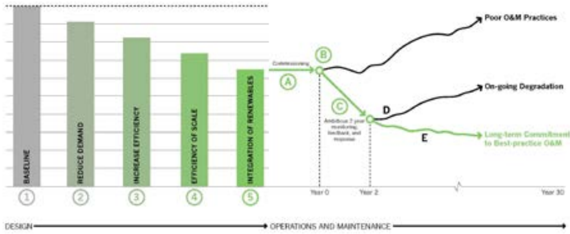

Figure 3, High Performance Design methodology

For the design phase (figure 3), step 1 is to create baseline energy demand using established benchmarking tools, such as ASHRAE 90.1-2007 Energy Standard. Step 2 is to integrate passive strategies and solutions to reduce the energy demand of the project. Step 3 is to increase efficiency and reduce energy demands by integrating active strategies. Step 4 is to incorporate central energy plant strategies to gain efficiency of scale. Step 5 is to integrate on-site renewables. The operation and maintenance phase starts with the commissioning process followed by a post-occupancy evaluation and on-going operation and maintenance to increase the building's lifespan and further reduce energy demand. The building operation becomes a constant optimization process.

The PET project will utilize Indonesia's GREENSHIP rating systems as a measure of the building's environmental performance. The project is designed to meet and exceed the minimum energy, water and environmental requirements to achieve Platinum level required by Pertamina and thus will incorporate a series of passive and active strategies.

Some examples of energy reduction strategies on this project are:

<u>Passive strategies</u>

High performance façade allows increased transparency and daylight penetration while minimizing cooling loads in the building by the combination of selected glazing and external shading.

Daylight penetration maximizes natural ambient light in lieu of artificial light.

High efficiency LED lighting fixtures

<u>Active strategies:</u>

Occupancy sensors reduce lighting energy consumption by automatically dimming or switching off luminaries.

Demand controlled ventilation by treating and supplying the required ventilation rates to the building based on occupants needs.

Regenerative braking will recapture energy during the braking cycle of conventional elevators, which is typically dissipated as heat, and convert it into electricity.

Exhaust relief air energy recovery with the implementation of double enthalpy wheels in outside air handling units, systems used to pre-cool outdoor make-up air and passively dehumidify the entry outdoor air.

High efficiency VAC system provide greater efficiency over code minimum requirements.

The application of these strategies along with other site specific ones will result in significant energy reduction from baseline for the Pertamina Energy Tower campus, estimated to be at some 60% from Jakarta typical office energy demand of 250kWh/m²/annum. This allows optimizing energy supply or generation concepts in order to achieve a net positive energy super tall tower.

4. ENERGY SUPPLY

Energy supply comes in different forms such as extraction, transmission, generation, distribution and storage. For the PET project, energy generation is introduced once all active and passive strategies define the energy demand. It is indispensable to generate power onsite using renewable sources to aim for a sustainable site and a net zero energy supertall office tower. PET campus designers are proposing the use of locally available renewable energy resources for the project. Figure 3 describes Indonesia's vast renewable energy potential. The country has committed to allocating 20% of its energy mix for renewable resources by 2025 [5].

Renewable Energy Source	Potential	Installed Capacity (MW)	Installed to Potential Ratio (%)
Wind Power	3 to 6 m/s	1.4	0.015
Solar Power	4.8 kWh/m^2/d	14.1	--
Geothermal	28.53 GW	1,190	4.2
Hydro Power	75.67 GW	4,200	5.55
Biomass	49.81 GW	445	0.89

Figure 4, Indonesia renewable energy potential.
Source: Ministry of Energy and Mineral

Photovoltaic and Wind Energy

Jakarta's location on the equator provides a very good opportunity for generating power using photovoltaic (PV) panels that converts solar radiation to electric energy. GREENSHIP proposes 2.5% of the total site electrical energy needs to come from renewables to obtain maximum allowable points in this scoring system. The designers decided to cover roughly 1,750 m^2 of the pavilion roof with 20% efficient monocrystalline PV panels in order to satisfy 2% of the total site electrical energy needs. Using an annual solar radiation simulation, the pavilion rooftop was assessed to be ideal location on site to install PVs for optimum power generation.

The remaining 0.5% of the GREENSHIP energy requirement comes from vertical axis wind turbines integrated into the tower's crown (see figure 4). The latter is located at a 530m height and the crown design of the tower has been designed to take advantage of the Venturi effect. Several weather data sources have been used and extrapolated at the crown height to provide the most accurate prediction of the local wind resources expected at the PET project site. Since all sources converge on easterly and westerly wind directions, the tower has been optimized for these directions. Furthermore, a comprehensive computational fluid dynamics (CFD) study comparing fifteen tower forms has been used to inform the most optimum crown design and respective wind accelerations. A rendering that represents the integration of these wind turbines into its environment is shown in figure 4.

Figure 5, Pertamina Energy Tower sky lobby

Geothermal Energy

Indonesia is located on a highly active volcanic geology, making geothermal energy a viable option to generate electric and thermal energy. Due to the merit and potential of this onsite resource, PET designers recommend a desk study and exploration bore holes to determine the actual geothermal resource available for the Pertamina Energy Tower site and the application of a low enthalpy binary cycle scheme. The result of these studies will determine geological layers and if the project needs are met; The estimated design team assumption is a minimum a resource of 150^{o}C with a flow rate of 160 kg/s. PET will potentially be the first net-positive supertall building campus that will offset both operational and embodied carbon in the world. If achieved, the new Pertamina's headquarters building will be the tallest net-positive building in the world

The designers are currently exploring different energy generation alternates to provide onsite power and cooling. The final choice is dependent on the design progress and the findings of the desk and bore hole studies. The first two options utilize the geothermal binary cycle concept, however the third one utilizes a gas fired turbine as a backup option

Option 1

The geothermal binary cycle power plant in PET, recommended to be implemented, will utilize a combined heat and power unit with the following components (figure 6): a 4.2 MW organic vapor turbine that will satisfy 100% of the site's electricity annual energy needs and a heat exchanger in series to feed single stage absorption chillers. The absorption chillers provide cooling for the site and will "charge" a thermal storage tank during low cooling demand hours. The thermal energy storage tank is designed to provide supplemental capacity when the absorption chillers cannot meet load on peak cooling demand hour. There will also be secondary backup electric chillers that will be activated if required.

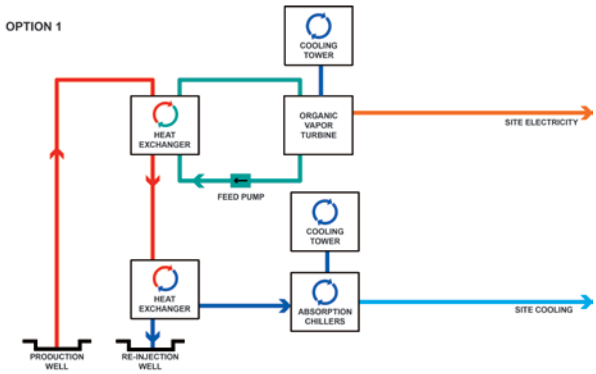

Figure 6, geothermal binary cycle cogeneration plant

Option 2

This options also employs a geothermal binary cycle power plant, but without utilizing the organic vapor turbine's waste heat. While this turbine provides an additional 1.3 MW of electricity (total capacity 5.5 MW), its waste heat will not meet the single stage absorption chillers' heat requirements. As a result, high-efficiency centrifugal chillers with variable frequency drives will provide the project required cooling demand. As the electric chillers are the sole source of cooling in this option, the plant must be sequenced properly to minimize the chiller energy consumption. If the chillers cannot meet site demand, the thermal storage tank will discharge similarly to option 1.

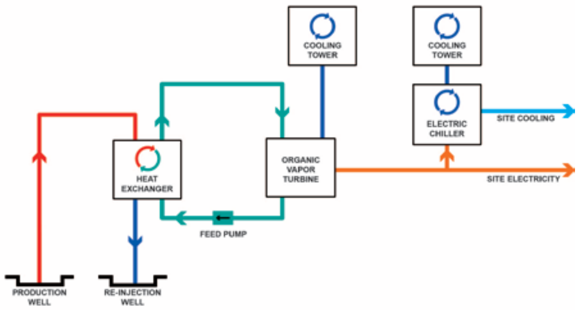

Figure 7, geothermal binary cycle power plant

Option 3

If the results of the geothermal desk study and bore holes exploration are not in favor of the implementation of the proposed binary concept, then this option will be pursued. It utilizes an 8 MW dual fuel gas turbine - that can use both natural gas or diesel in its combustion chamber - to provide 100% of site's annual electrical energy needs. The waste heat of this type of turbine is of high calorific value and thus can directly feed double stage absorption chillers which perform better than single stage chillers. As in all options, the thermal energy storage tank will provide supplemental capacity when the absorption chillers cannot meet the load. In case of an event when the thermal storage tank is depleted and additional cooling capacity is still required, secondary electric chillers will activate and run to satisfy the load.

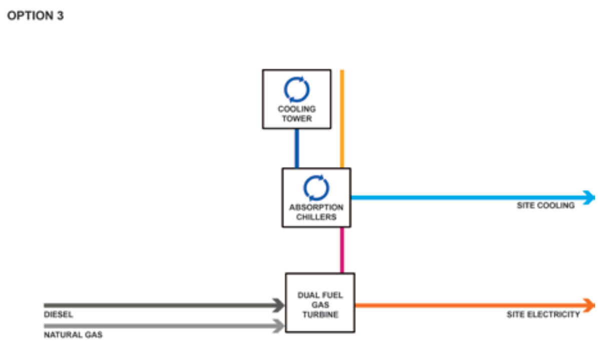

Figure 8, Dual fuel gas turbine cogeneration plant

PET project designers recommend Pertamina to reach out to their own internal resources or third party experts in order to assess the feasibility of a geothermal binary cycle scheme. Economically, this is a viable solution that will show a real commitment and support to sustainable energy. Many cities have dug wells deeper than 2,000 / 3,000 meters to tap geothermal resources for district heating or power generation. For example Paris-Orly airport has a 1,700m well that feeds a local district heating geothermal plant. In a Munich suburb, a binary cycle plant with wells around 5,000 m deep has been in operation since 2013. By doing similar practice in Jakarta, Pertamina will be at the forefront of the renewable energy world, potentially establishing the world's first net zero energy super-tall building with no carbon emissions. Pertamina can be an indispensable part of a greener Jakarta, providing state of the art facilities that use renewable energy, promoting sustainability and cleaner air.

This project can be a catalyst to educate the mainstream population about tools for different clean energy sources at the heart of Jakarta.

5. ENERGY BALANCE

To achieve net-zero or the more challenging net-positive operation, all calculations must balance different sources and meet energy demand.. The PET campus will have different source of renewable energy that cover different aspects of its demand. The dominant renewable source will be geothermal cogeneration. The biggest energy demand is cooling and therefore, the primary task for the design team has been in supplying the cooling load for the whole campus. By implementing the geothermal cogeneration plant, all cooling generated will be carbon free. Due to the non-intermittent aspect of geothermal energy, electricity will always be generated by the binary plant and thus may produce more electricity than will be consumed on campus (valley). There will be times when there will be a deficit of energy supply from renewable sources (peak). The balancing of peaks and valleys on the energy demand / supply or, even better, the surplus of valleys will allow the PET campus to become what is known in the built environment industry as a net-positive project.

Figure 8 shows a comparison of energy use intensities by program type found on the Pertamina Energy Tower campus and the reduction currently estimated from ASHRAE 90.1-2007 standard baseline. For the buildings and areas that have not being dynamically modeled yet, a conservative reduction of 20% has been assumed from baseline.

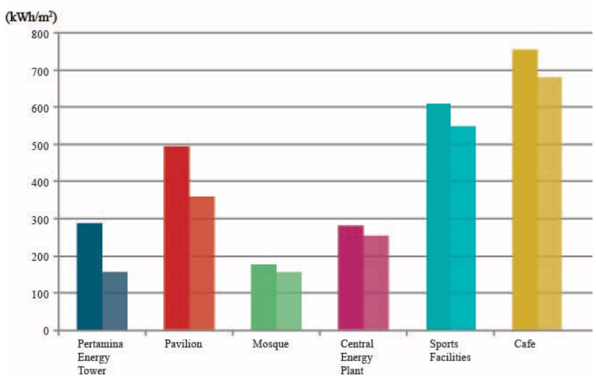

Figure 9, EUI comparison (ASHRAE vs. Design)

In order to operate and claim a net-zero building, all the energy demands need to be covered from renewable sources. Using Option 1 or 2, electricity is generated by a geothermal binary cycle plant, photovoltaic panels and building integrated wind turbines. For these same options, cooling is generated via renewable energy whether absorption or electric chillers are used, free of carbon emissions. It is important to note that thermal systems are designed to meet the demand as much as possible without excess. Current energy conservation measures and Pertamina's commitment to innovation can showcase the application of renewable energy. A net-zero, and perhaps net-positive, super tall tower is within reach—and might encourage other projects to follow Pertamina's lead.

Figure 9 shows the CO_2 emission comparison between the three different options. The grey bars represent the amount of CO_2 emissions the project is offsetting by *not* being connected to the Jakarta electric grid. The green bars represent the amount of CO_2 emissions not emitted by the proposed renewable energy systems. The carbon offset is translated to the number of cars taken off Jakarta's road. The CO_2 estimate was calculated according to the Carbon Trust emissions per kWh, according to the fuel mix existing in Indonesia, in combination with the values indicated by Greenship Indonesian Standard.

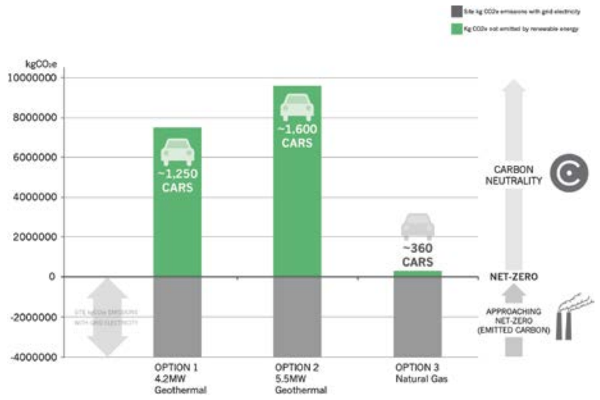

Figure 10, kg of CO_2e emissions offset between different options

6. CONCLUSION

This paper presents active, passive and energy generating strategies that will define a possible net positive energy design for the Pertamina Energy Tower project, located in one of the most urbanized city in the world. The principal strategy that defies conventional projects in urban areas is the geothermal binary cycle plant. This will be a turning point for engineering design, as it will elevate the standards for onsite power generation.

Anywhere in the world where there are not known geothermal resources will show an average temperature gradient of 30°C/km depth. This means that a binary plant may be feasible anywhere. The question is how deep should you go? The city of Munich was willing to go 5,000 m deep to install a geothermal district heating plant in its suburbs. Pertamina hired a third party to execute desk studies to determine the geological layers and depth necessary in Jakarta for a binary cycle. As the PET is awaiting its results, every stakeholder is convinced about the importance and indispensable role this geothermal binary cycle plant will play for this project, for Pertamina, for Jakarta and for the inspiration of future projects.

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