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Evaluation of a Proposed Scheme with Shallow Geothermal for Sub-Cooling in Cooling Systems as an Application

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Abstract

Lately, the growth in less costly energy generation from solar and wind renewable resources has lead to new methods of system design objectives and approaches. In parallel, energy extraction from additional non-traditional fossil-based resources have contributed to stabilizing energy supplies and cost. Hence, the focus for system design and approach should be on the utilization of mix-energy resources which include both traditional fossil-based fuel and renewable resource, in addition to enhancing system efficiency to further endure and maintain the stability of energy and consequently resulting in less release of harmful pollutants to the fragile environment.

In this article an evaluation of a proposed scheme to use shallow geothermal resource to sub-cool refrigerant in cooling systems; as an application. As it is known sub-cooling is the reduction of refrigerant temperature below saturation. The required heat exchange for sub-cool is relatively small which is compatible with shallow geothermal resource. Because of the significant consumption of energy by cooling systems and their wide-spread use, any improvement in their efficiencies would have substantial stabilization of energy supplies. A proposed cooling system is coupled with near ground-surface geothermal resource to reduce the sub-cooled refrigerant temperature significantly, and consequently resulted in tangible reducing energy consumption. The entropy generation and energy requirements for the proposed method were evaluated and are compared against a typical arrangement for cooling cycle. It was demonstrated that the power requirement for the scheme is about 10% less as well as the heat dissipation from the system is also about 10% less. Efficient systems with less energy consumption contribute to conserving non-renewable energy resources and reducing emission of harmful gases to the environment.

Keywords: shallow geothermal, geothermal subcooling, ground coupled heat pump (GCHP), horizontal ground heat exchanger, near-surface ground geothermal.

1. Introduction

Recently, there have been a significant rapid increase in energy extraction from wind and solar resources which have contributed to stabilizing energy supplies and cost even in the face of increase demand on energy where the latter is attributed to population growth and improvement in the standard of livings across the globe. Undoubtedly, this is reflected on the approach of engineering design and objectives of systems.

The importance of energy-efficient systems evidently play a key role in economic decisions and in combating the deterioration of the fragile environment due to the emission of harmful pollutants. According to the International Energy Agency (IEA), cooling of homes and buildings constitute about 10% of the global electrical demand [1]. Also, it is reported that the energy consumption in 2021 was about 161.1 tera kWh, hence the energy requirement for buildings is quite significant, 16.1 tera kWh which is more than 800 times the annual consumption of total energy by the country Jordan [2]. Furthermore, according to the International Institute for Environment and Development (IIED) that air-conditioning and refrigeration demand for energy could increase up to 20% by year 2050 of total energy demand unless more efficient systems are used [3]. They emphasized the importance of improving efficiency of energy-consuming systems in slowing down the growth in demand of energy by air-conditioning and refrigeration. The projection for this increase is mainly attributed to the significant rising in emerging economies like India and China.

A significant portion of these air-conditioning and refrigeration systems employ the vapor compression cycle (VCC) to meet the cooling and heating demands. Much progress has been made to improve the efficiency of these systems whether be it at the component level; e.g., improving the effectiveness of the evaporator, condenser and selecting better-performing compressor, or by employing what has become known as "inverter" air

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conditioning where a control of the compressor speed is used to match the cooling load.

Refrigerant subcooling is a well-known method used to reduce energy consumption required by the VCC compressor; however, it is limited in typical systems by the way of its architecture. In some systems, the return pipe from the evaporator that carries the cool vapor is placed in-contact with the pipe that is coming out from the condenser which carries the hot liquid. In this method, the liquid refrigerant is cooled at the expense of heating the vapor returning to the compressor. Although sub-cooling is achieved with its all benefits in reducing energy consumption; however, at the same time it results in superheating the vapor leaving the evaporator although it is beneficial to the compressor since it ensures no liquid droplets enter it, nonetheless excessive superheating leads to more energy consumption since the compressor is inducing warmer vapor. In other systems, sub-cooling is achieved at the condenser outlet through additional cooling by the ambient air beyond change of phase, thus the drop in the sub-cool temperature is limited by the temperature of the ambient air and the effectiveness of the condenser.

The potential of ground heat exchanger (GHE) coupled with heat pump has been known since the mid 20th century where some of the early works as an example found in Hughes, J. E. (1954), who conducted calculations and provided analyses on heat pump systems coupled with ground heat exchanger [4]; in Banks, D. (1978), the focus was on the response of the ground for heat pumps coupled with ground heat exchangers to understand the dynamics of heat extraction and injection rates [5]. More recently, Lund, J. W., & Boyd (2016) surveyed ground-coupled heat exchangers as part of the wider application of geothermal resource for cooling and heating [6]; Sanner, B., & Sved, M. (2000) details an overview of the technologies in ground source heat pump systems which includes the overall system integration. In fact the subject has been fairly dealt with in the literature [7].

Interest in horizontal configuration stems from the fact that its initial investment is low in comparison with vertical ground heat exchangers (GHE), in fact the initial digging cost of 50.0m deep borehole for vertical configuration may cost in the range of USD3000.00 to USD6500.0, depending on the locality. However, in the case of horizontal configuration the initial digging cost is intangible since it involves near-surface trenches. Furthermore, for this article the initial digging is assumed to be zero since the initial digging is made for building foundation, a common practice in country like Jordan. The required components that may have added cost is the LLHX which is normally used by other GHE systems. Widiatmojo et al, conducted experimental work in the country of Thailand to investigate the possible use of horizontal configuration coupled with heat pumps for cooling purposes with different GHE pipe configuration [8]. They reported energy saving of 17.1% and 18.4% for two setups of ground-coupled heat pumps compared to air-cooled heat pump. Further, to show the benefits of these reduction in energy consumption on the environment, they reported that, by surveying the pertinent data base concerning Thailand, in 2015 the total electricity generation was 178 TWh whereby 91.6% came from fossil fuel resources which lead to 96.035 MT of CO2 emission as a result of electricity generation in 2017. Of the total electricity generated, 20.4% was used by homes and of which 46% and 17% for air-conditioning and refrigeration; respectively. Therefore, any efficiency improvement at the system level would in no doubt result in reduction of CO2 emission. Yu Zhou st al; have conducted finite element analysis (FEA) of horizontal GHE using different pipe configurations: straight, slinky loop and dense slinky loop with all located at depth of 1.5m that simulated the NSW Australia region for supplying heat to poultry shed for raising chicken [9]. They also conducted experimental work to validate the FEA simulations. They validated the numerical results against their own experimental work and they reported well agreement. They concluded that trench spacing may be reduced so that heat exchange load may be accommodated. Other work included numerical simulation as seen in [10, 11, 12].

However, from the literature survey that was conducted by the authors no research has focused the attention only on sub-cooling alone using GHE configuration. The advantage of sub-cooling, which is the lowering of the liquid refrigerant temperature below its saturation temperature, is that it requires less heat exchange but it results in significant improvement to the efficiency of the cooling system. This small heat exchange is suitable for applications of horizontal GHE.

The Use of renewable energy resources to advance system design and enhance efficiencies has been addressed in many aspects. For example, Ababneh [13] conducted a theoretical study for use of solar energy along with fossil fuel to drive a cooling system based on a double-effect absorption cycle. The system can be driven day and night; however, since cooling demand increases usually the daytime as a result of solar irradiation, the benefits of using solar assist during daytime is magnified. Also, others have evaluated the feasibility and performance of a solar-assisted ground-coupled heat pump to supply hot water and heating requirements for low level energy needs of residential buildings. They demonstrated that the geothermal can assist with 7.7 kW of heat in addition to solar.

Al-Smadi et. al. [14] investigated the level of awareness in the Jordanian society about renewable energy and found among 660 surveys that more than 90% are aware of renewable energy benefits contrasted with the environmental impact resulted from using fossilized resources. This indicates the high level of acceptance by the general population. Perhaps this enthusiasm among the Jordan population has prompted researchers to further explore relatively new ideas of extracting water from atmospheric air. Jawarneh et. al. [15] experimentally investigated extracting water from atmospheric air using non-toxic natural and hybrid multi-layer desiccant composite materials. The research has showed promising results.

Geothermal resources are categorized into three groups: 1, high temperature resource for power generation; 2, medium temperature range used for direct heating applications; and 3, shallow geothermal at depth about 3-5 meters below the earth surface where the temperature is low and ranges 15-22ºC, depending on the geographical location. Bansal et al. measured the soil temperature below the ground surface at depth 4 m for the condition of wetted soil and covered by dry black soil with the shaded surface over the year for an area at New Delhi, India [16]. The study found that the maximum soil temperature is 17.5^{o}C. Cui et al. conducted experimental work to measure the soil temperature over a year long from June 2010 to June 2011 for a range of depth 100m below the earth surface in Chongqing, located in southwest China; they found at depth 5m the soil temperature has an annual variation between 19.5 and 21.5C [17]. The relatively low-temperature shallow geothermal resource is basically available worldwide and could have a supplemental source for cooling and heating applications when coupled with a heat pump. The soil temperature becomes constant for depths below 3m and more less depends on the surrounding ambient conditions and solar intensity; in fact it is about the mean average ambient temperature for the specific geographical location.

Regarding the subcooling methods mentioned above, they are not optimal since they are limited by the ambient air temperature, also the superheat maybe excessive which leads to increasing the compressor energy consumption due to the shift of the thermodynamic state of the refrigerant vapor to the right on a temperature-entropy diagram. The proposition herein for this work is to assess the utilization of the shallow geothermal resource in the reduction of the temperature of the liquid refrigerant; specifically increasing the subcool. This scheme of cooling the refrigerant is a hybrid one, through using the ambient air to cool the hot superheated refrigerant by bringing it down to saturated liquid temperature which is slightly above the ambient temperature then followed by geothermal subcooling.

Evidently ,the use of renewable energy resources lessens primary energy consumption which is associated with reduction in CO2 emission to the environment which is becoming more fragile. According to the Environmental Protection Agency (EPA/USA, it is estimated that in year 2018, about 0.8 billion metric tons of CO2 equivalent results from commercial and residential sectors, which is about 12% of the total greenhouse gas emissions (direct/indirect) [EPA]. The US Energy Information Administration (EIA) Residential Energy Consumption Survey (2009) estimated that approximately 41% of residential household energy consumption was due to space heating and is responsible for over 98% of greenhouse gas emissions from the sector. Approximately 50% of US households rely on natural gas as their main source of heat, followed by 30% electricity, 7% fuel oil, and 13% other/none [18]. As it is becoming known the use of renewable energies can significantly reduce harm to the environment in addition to economic benefits that result from reduction in system's energy consumption. According to the National Resource Defense Council (NRDC), it is estimated that the US can cut its greenhouse gas emissions by 80% by 2050 by investing in energy efficiency technology, expanding the country's electricity generating fuel mix to 70% renewables, and building a decarbonized and modernized energy supply [19]. Of the heat pump technologies currently available, ground-source heat pumps (GSHP) are recognized for their high-efficiencies, environmental benefits, and comparatively higher incremental cost [20].

The focus of this work is to assess using shallow geothermal resource in a closed-loop horizontal ground heat exchanger (GHE) configuration to enhance the performance of heat pumps by increasing the subcooling while maintaining the superheat delta temperature to minimal to avoid unnecessary extra work by the compressor. The ground heat exchanger is presumed to be buried in regular clay (mud sand) without any special treatment; e.g., certain grout, to avoid any extra initial cost. The GHE is coupled with a vapor compression refrigeration cycle to evaluate the effectiveness of the GHE. The potential application of such scheme is in countries like Jordan where many homes are built on land lots of approximately 500m^2 with dimensions equal to 20mx25m. These homes are normally started with digging the ground to more than 4m below surface for structural foundation. Therefore, if the pipes for the ground heat exchangers (GHE) made of relatively inexpensive polyethylene material are laid down at the start of the construction, then the initial cost for the GHE is minute.

The method of evaluation is based on minimum entropy generation coupled with least energy requirement. These methods are outlined herein.

2. System Architect

2.1. Propose System Layout

The proposed system consists of interfacing a vapor compression cooling system with a ground heat exchanger (GHE) via a liquid to liquid heat exchanger (LLHX). A schematic of the proposed system is shown in Figure 2.1. Shallow geothermal resource in a horizontal configuration is used to keep initial cost to minimal. The ground heat exchanger is presumed to be laid horizontally about 5m below the ground surface where the temperature normally follows the annual ambient temperature. For Jordanian localities the temperature is assumed 20^{o}C at depth of about 5m below earth surface. The benefits of the shallow geothermal resource will become apparent in the "Results" section.

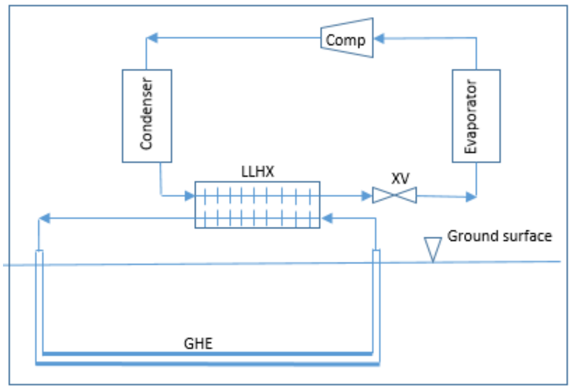

Figure 2.1. Schematic diagram of the system architecture.

2.2. Justification and Assessment of the Proposed System

The method to assess the proposed system is based on comparing the entropy generation in the proposed system against other basic systems. The general second law "balance" equation for flow processes is

$$\left.\frac{dS}{dt}\right|_{sys} = \dot{S}_{in} - \dot{S}_{out} + \dot{S}_{gen} \quad (2.1)$$

Where the entropy flow into and out of the system is due to heat transfer from the system boundaries and mass flow into the control volume. For steady-flow process, the equation can be re-arranged for process entropy generation,

$$\dot{S}_{gen} = \dot{S}_{out} - \dot{S}_{in} \quad (2.2)$$

The entropy generation for each individual process of the cycle is computed and the overall of the entropy generation for the cycle is obtained by adding up the entropy generation for these individual processes. Since entropy generation is directly related to exergy destruction hence the cycle is considered more efficient if it has lower entropy generation and less work for the same cooling load.

The proposed system performance is compared against two typical cycles which are shown on a temperature-entropy diagram in Figure 2.1.The cycle on Figure 2.1a represents the basic vapor compression cycle (VCC) which has slight subcooling effected by the ambient air (cooled from point 3' to point 3 on the diagram) and has no superheat where point 1 is saturated vapor. The cycle on Figure 2.1b represents a more realistic model of many cyclesfound in actual applications where the processes of superheat (the thermodynamic states 1' to 1) and the further subcooling (the thermodynamic states 3" to 3) are basically regeneration processes whereby the pipe carrying the vapor leaving the evaporator is made in contact with the pipe that carries the hot liquid refrigerant coming from the condenser and prior to reaching the expansion valve. The blackened dots on both Figures represent slight subcooling effected by ambient air. This arrangement of the two previous pipes allows heat to be exchanged among the working fluid existing at different locations.

Observe that the required refrigerant mass flow rate in Figure 2.1b is less than that of Figure 2.1a when are subjected to the same cooling load since the enthalpy at the thermodynamic state of point 4 is less in (b) than in that of (a) which consequently results in accordingly larger difference in enthalpies. Furthermore, the difference in enthalpies between the thermodynamic states (2) and (1) is larger with the superheat compared to no superheat since the constant pressure lines are diverging in the vapor region. It is apparent from the last arguments that sub-cooling is desirable in reducing the refrigerant mass flow rate while superheat unfortunately increases the difference in enthalpies across the compressor as a consequence to the shifting of the inlet thermodynamic state to the compressor (state 1) to the right; therefore, offsetting some of the sub-cooling benefits, nonetheless, the cycle with superheat is more effective. Therefore, it is desirable to have sub-cooling with zero superheat. Observe that superheating means the increase of the vapor temperature at constant pressure which is equal to that of the evaporator's pressure and hence result in increasing the compression work; recall the reversible work definition as found in any thermodynamic textbook. However, an apparent advantage of superheating is ensuring that no liquid droplet enter the compressor which could cause mechanical damages.

Therein lies the basic concept of the shallow geothermal sub-cooling where the hot liquid refrigerant coming from the condenser (the thermodynamic state 3 in Figure 2.2a) is further cooled employing the cool ground-heat transfer fluid (GHTF) coming from the geothermal heat exchanger (GHE) and at the same time not requiring any superheating of the vapor coming from the evaporator. In this study the GHTF was assumed to be water although it is normally a mixture of water and antifreeze in real practice. In this technique the full advantage of sub-cooling is realized without impacting the inlet/exit thermodynamic states of the compressor; specifically, maintaining them as in Figure 2.2a. For the purpose of preventing any liquid droplets seeping into the compressor, an accumulator-separator may be used at the inlet of the compressor.

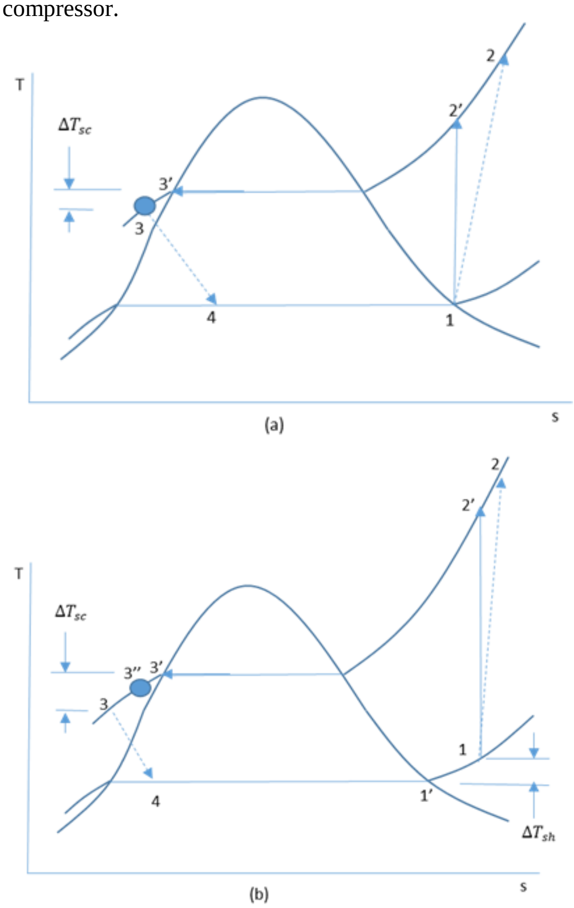

Figure 2.2. Temperature-entropy diagrams for: a) zero-superheat; b) with superheat, $\Delta T_{su} = 15^oC$.

3. Validation of the Proposed System Effectiveness

For validating the conceptual design presented herein, energy consumption and entropy generation analysis is conducted for the two cycles described above and compared against the proposed system. The system that consumes least power and has least entropy generation is considered superior. The thermodynamic states which represent an actual-life situation that may exit at nominal high-temperature weather conditions, are shown in Table 3.1.

The energy consumption by the cycle is due to the compressor which is determined from the basic thermal equation with negligible potential and kinetic energy from the following,

$$\dot{W} = \dot{m}(h_2 - h_1) \quad (3.1)$$

The reason for neglecting potential energy is that the elevation distances are small for the refrigeration cycle and for GHE the two vertical pipes effect cancel each other. Because the velocities involved are small, then their contribution as kinetic energy is very small.

The refrigerant mass flow rate is determined from,

$$\dot{m} = \frac{20.0}{(h_1 - h_4)} \quad (3.2a)$$

Table 3.1. Thermodynamic states for VCC* and components design parameters**.

Component	Effectiveness	Fluid	Saturation Temperature, ºC	Delta Sub-Cool, ºC	Delta Superheat, ºC
Evaporator	0.80	Refrigerant R134ain evaporator	2.67	----	0/15
Condenser	0.80	Refrigerant R134a in condenser	39.0	3+	----
Compressor	0.85	Refrigerant R134a	Inlet: 2.67/17.67	----	-----
LLHX*	0.90	GHTF/Liquid R134a	23/36.0	----	-----

* The cycles are shown in Figure 2.1a, b.

* The marks "??" indicate the return temperature of the GHTF depends on GHE performance.

** Ambient air temperature is set at nominally high 34ºC.

\+ Sub-cooling due to ambient air.

with no superheating being present, or

$$\dot{m} = \frac{20.0}{(h_{1'} - h_4)} \quad (3.2b)$$

when there is superheating. Note that the cooling load on the system is assumed to be 20.0 kW and also observe that the refrigerant mass flow rate is determined based on the saturated vapor enthalpy leaving the evaporator in both cases with and without superheating, while superheating for the second case is assumed to occur outside the evaporator as described above.

The entropy for the R134a at each particular state is obtained from the thermodynamic tables which are available mainly in all basic thermodynamic textbooks [21, 22].The entropy generation for adiabatic processes; i.e., compressor and expansion valve, are obtained as follows,

$$\dot{S}_{gen} = \dot{m}(s_{out} - s_{in}) \quad (3.3)$$

Where the lower case s is the specific entropy obtained from the thermodynamic tables. For the case of non-adiabatic processes more details are required to accurately compute the entropy generation. For the condenser, there are three phases involved; de-superheat, phase change and sub-cooling. For the phase change in the condenser, the entropy generation is,

$$\dot{S}_{gen} = \dot{m}(s_{3'} - s_{2''}) + \frac{\dot{Q}_{c,ph}}{T_{c,sat}} \quad (3.4)$$

where here the entropy generation excludes those that are generated outside the refrigerant; specifically, excluding those in the ambient air boundary layer. Mainly, the interest is the refrigerant R134a. Also note that the heat transfer $\dot{Q}_{c,ph}$ is the positive rate of heat leaving the refrigerant during phase change which is computed from the basic equation,

$$\dot{Q}_{c,ph} = \dot{m} h_{c,fg} \quad (3.5)$$

However, the entropy generation in the condenser may be simplified by considering it as adiabatic which including the effect of the ambient air. The contribution of the ambient are is computed from,

$$\Delta S_{air} = \dot{m}_{air} c_{p,air} ln\left(\frac{T_{e,air}}{T_{in,air}}\right) \quad (3.5)$$

Where temperature are in units of kelvin and the air pressure is assumed constant as it flows through the condenser. Similar treatment was made for the evaporator.

To obtain the GHTF return temperature from the GHE, a solution for the mass and energy equations governing the flow of the GHTF through the GHE was obtained and presented in a separate article [20].

4. Results

The effectiveness of shallow geothermal for cooling the GHTF was demonstrated in earlier work by solving the mass and energy equation of the GHE numerically. The advantage of such solution is that it provides the temperature of the GHTF returning from the GHE which is used to cool the liquid refrigerant through the LLHX. For example, Figure 4.1 shows the GHTF temperature distribution along a pipe length of 10m with various inlet temperatures at GHTF flow rate 7 kg/min. For this solution, the GHE was assumed to be buried horizontally at 5m depth from the surface of the ground where the temperature is approximately equals to 20ºC; which is the annual average local ambient temperature. It was determined that the GHTF temperature can reach 23ºC with an 75mm-diameter single-pipeloop that has a length of 125m or more. Knowing this return GHTF temperature to the LLHX, then the temperature of liquid refrigerant supplied to the expansion valve is determined given the LLHX effectiveness and consequently the inlet enthalpy to the evaporator. The mass of refrigerant is then determined for the given cooling load which is used for the evaluation of entropy generation and power requirement for the three cases selected for this study.

Upon the determination of the refrigerant mass flow rate and given the thermodynamic states, the entropy generation for each component of the cycle is assessed. The results of this assessment is given in Table 4.1 which summarizes the entropy generation for each component of the cycle for the three considered cases. Also shown in the Table 4.1 the total entropy generated for the cycle. The energy consumption by the condenser and the compressor are shown in Table 4.2 where the power requirement for the condenser is in the form of fan power needed to drive the ambient air through it. It is to be emphasized that these results are consequence of the assumed thermodynamic states for each cycle where; for example, if the superheat is assumed to occur entirely in the evaporator then this would be reflected on the results. It is seen that the entropy generation in the heat exchanger SuHt-SuCl used for regeneration of the refrigerant by sub cooling it at the expense of superheating is zero for case 1 and case 3 since it is not used in either of those two cases. Similarly, for the heat exchanger LLHX the entropy generation is zero for case 1 and case 2 since this heat exchanger is only used to sub-cool the refrigerant when using cool geothermal GHTF. It is to be observed that when cases 1 and 2 are compared with each other, the benefit of superheating for this kind of cooling system design is that the entropy generated is slightly less for the entire cycle, but more for the condenser; which is a consequence of the higher inlet conditions that results from the shifting to the right on the entropy-temperature diagram. Also, part of it results from using the heat exchanger SuHt-SuCl. This in actuality a benefit of cycle regeneration. Furthermore, it is to be observed that for case 2, the energy requirement for the compressor is less about 0.5% while the heat dissipation by the condenser is less than 0.1% less compared to case 1. The diminishing advantage of sub-cooling at the expense of superheating is a consequence of the shifting to the right of the refrigerant thermodynamic state at the compressor inlet on the entropy-temperature diagram which results in larger delta enthalpy across the compressor with more shifting since the constant pressure line are diverging with entropy increase. Again, this is reflected on the requirement of heat dissipation by the condenser.

However, for case 3 when using geothermal source for sub-cooling it is seen that the entropy generation for all component (except for the compressor) is less when compared with the other two cases; however, there is the added entropy generation due to the LLHX; nonetheless, it is minute that the total of entropy generation for the cycle is still the least. Also, hand in hand the power requirement by the compressor and the heat dissipation by the condenser are least compared with the other two cases; for the compressor power it is 10.1% less than case 1 and 9.6% less than case 2, while for the condenser heat dissipation it is 10.2% than case 1 and 10.1% less than case 2. Less heat dissipation at the condenser implies less power requirement by the fan. This clearly demonstrate the superiority of the method of geothermal sub-cooling.

More importantly, the initial and operational cost for such scheme of using geothermal sub-cooling are anticipated to be minimal. In one hand, in typical building construction in Jordan earth digging is performed for structure foundation hence no added cost. The cost of plastic pipe and pump are usually negligible. For the operational cost which is related to running the pump is far less that required by the compressor.

The advantage to the environment is significant when resulting in less emission of harmful gases as a consequence of less energy consumption by both the compressor and the condenser fan.

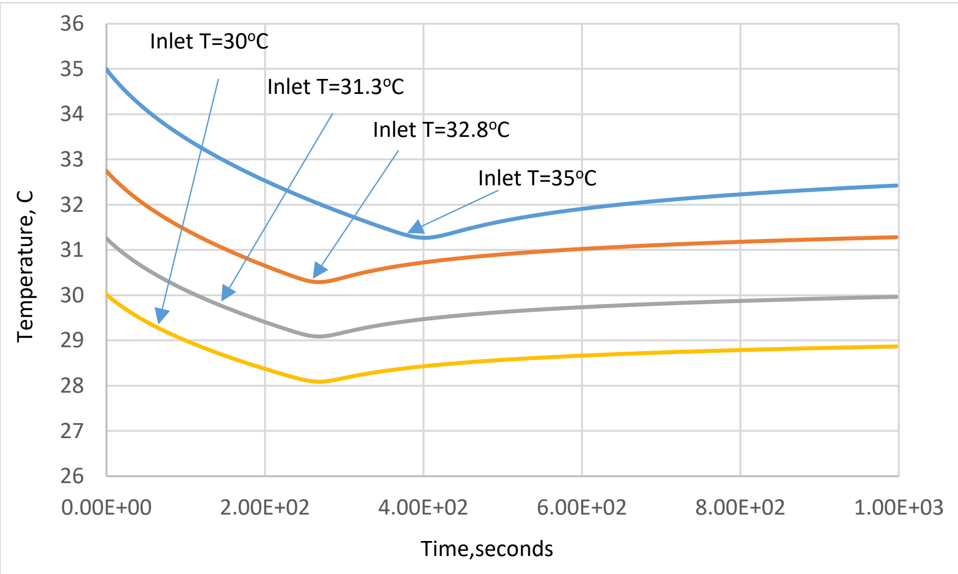

Figure 4.1. GHTF temperature variation along the lengths of 10m-pipe.

Table 4.1 Entropy generation, $\dot{S}_{ref}$, kW/**K**

Case Study	$\dot{m}_{ref}$	**Condenser**	**TXV**	**Evaporator**	**Compressor**	**SuHt-SuCl**	**LLHX**	**Cycle** $\dot{S}_{ref}$
No superheat	0.1336	0.000861	0.00149	0.02419	0.00173	0.0	0.0	0.02827
With Superheat	0.12265	0.002109	0.000751	0.02419	0.000671	0.00051	0.0	0.02823
Geothermal	0.12001	0.000774	0.000600	0.02419	0.00155	0.0	0.00020	0.02731

Table 4.2. Energy consumption.

Case Study	$\dot{m}_{ref}$, kg/s	$\dot{m}_{air}$, kg/s	$\dot{Q}_{cond}$, kW	$\dot{W}$, kW
No superheat	0.1336	5.888	23.668	3.67
With Superheat	0.12265	5.884	23.653	3.65
Geothermal	0.12001	5.289	21.262	3.30

5. Conclusions

Assessment of shallow geothermal in horizontal pipe layout was conducted for the purpose of supplying substantial subcooling in air-conditioning systems while maintaining the refrigerant inlet state to compressor close to saturated vapor. In this proposed scheme of geothermal sub-cooling, it is evident that it has about 10% less of compressor power requirement and about 10% less heat dissipation at the condenser. The horizontal pipe layout is considerably less costly compared to vertical arrangement and is usually laid under the ground surface at modest depth. The initial ground digging is required in many homes that are built in Jordan thus requires no added cost for land preparation. Furthermore, the added cost of the material implement for the geothermal sub-cooling is minute.

The calculated improvement in performance is 10% if implemented globally, when possible, it may also contribute to offsetting the anticipated increase in energy demand by the cooling and refrigeration sector in the near future as projected by the IIED.

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