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Research paper

FC Geo-cool: earth coupled solar assisted hybrid heat pump energy efficient cooling system

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Abstract

This applied research topic addresses the potential of integrating a Solar Power Assisted Ground Source Heat Pump, for the purpose of space cooling at HCT Fujairah Women's and Fujairah Men's College building(s), United Arab Emirates (UAE). The proposed model is designed such to provide sustainable cooling. A ground source heat pump dependent upon a heat transfer grid of four vertical drilled boreholes of 360-400 feet depth (100-125m) with closed vertical loop constructed of saltwater resistant polyethylene tubing, with thermally enhanced, Bentonite grouted construction, to protect from groundwater contamination, while promoting effective heat transfer between the earth and closed-loop tubes. The system will deploy thermoelectric generators and a nocturnal cooling radiator to dissipate heat from the closed loop. The system is expected to produce a cooling power of about 12 kW at an approximate cost of a solar assisted ground source cooling system of AED 80,000, about $22,000 USD, equipment only, system with cost-benefit analysis improved by a diligent administration, negotiation, management, and design; the system will be able to accomplish this target.

Keywords: *Sustainable Cooling; Geo-Cooling; Hybrid Heat Pump; Earth Heat Sink; Nocturnal Cooling Radiator; Thermoelectric Generator; Ground Source Heat Pump; Solar Assisted.*

1. Introduction

This proposal addresses the potential of integrating the Solar Power Assisted Ground Source Heat Pump for the purpose of space cooling an HCT Fujairah Women's or Fujairah Men's College building(s), United Arab Emirates (UAE) [1]; [2]. The proposed model is designed such to provide continuous cooling. Thermal performance of the proposed system shall be mechanically engineered, and a feasibility study conducted in terms of the size of the system, given the budget, in order to assess the system's installation costs as well as economic and environmental impacts [3].

2. Main body

2.1. Background of research

The proposed model was implemented on a known case in the United States, where such systems are widespread [4]; [5]; [6]. The target application is provides supplemental cooling to an institutional application, namely a college building in Fujairah of approximately 85 square meters (sqm) or 915 (sq. ft) square feet size, with a net cooling load supplement of 12-15 kilowatts (kW). The obtained results from the actual installation will be analyzed for a larger-scale deployment through a critical analysis upon completion of the project, in comparison to pre-project estimates. This is to identify the optimum configuration, and if Geo-Cool's successful deployment was achieved in terms of feasibility and potential long term energy savings.
Previous studies have found that a comparable hybrid system with 30% solar contribution achieved the lowest cost per efficiencies performance. The proposed system targets Annual Energy Consumption (AEC) savings of about 17,000 kWh, and net contribution of the system by replacement yielding a reduction by 65% in the annual operating costs [7]. The payback period of the proposed system will be determined upon installation, but is estimated to approach a best case scenario of only 2.5 years. The proposed system is expected to also contribute towards greenhouse reduction, by reducing carbon-dioxide emissions by 10 tons per year [8].

2.2. Project objectives

2.2.1. Benefits of system

Near future applications of this piloted study, will meet the commercial, cooling needs, of green-focused developments in hot desert regions, such as HCT-Fujairah Colleges in UAE. While installation costs can run up to double of what a traditional HVAC system costs, energy consumption can be one half or better, on a per annum basis with a 400% efficiency gain [9]. Advances in energy utilization aligns with the UAE development strategy.

2.2.2. Pilot project

HCT-Fujairah Colleges Geo-Cool system; a proposal for a novel approach utilizing ground source heat pumps hybridized with solar and thermoelectric technologies as a sustainable cooling system. This project aims to create a proprietary application, designed, created and deployed by the Higher Colleges of Technology (HCT)—HCT is UAE's largest public university, and presently operates 17 college campuses across the country—and shared jointly with a select industry partner. This project will develop student's mechanical engineering, and commercial business skills through experiential and applied learning. Faculty resources and industry collaboration in these same areas are required, and therefore, are expected to bring additional benefits e.g., leveraging of resources, technology transfer, project management know-how, and spinoffs.
The project uses borehole-based vertical, hybrid ground coupled heat pump systems to cut energy consumption costs, by utilizing the Earth as a heat sink. Usable lifecycle is estimated at over 50 years plus for the subsurface components such as boreholes [10], and heat exchange loops and manifolds, and 25 years for above ground components such as air handlers, nocturnal cooling radiators, and thermoelectric generators—a proven technology in organic cycle waste heat recovery for commercial applications by Seimens AG [11]. A group of Venture capitalists evaluated the concept at the Pitch-in-Paris event, and recommended inclusion of a metered computer application to measure and communicate in real time, the actual energy savings being provided by the FC Geo-Cool system (Personal Communication, Jack Russo, November 21, 2018).

2.3. System specifications

2.3.1. General overview

The vertical loop will use multiple boreholes approximately 200 meters deep, arranged in a grid of 4 boreholes, which is required to meet the cooling capacity.
High-density polyethylene for installed as loop piping inside the boreholes and circulating monopropylene glycol, $C_3H_8O_2$, as a European Union approved refrigerant [12]; otherwise known as MPG, will virtually eliminate the potential for environmental harm, in the event of refrigerant leakage [13]. Site-specific geologic conditions will affect borehole design, and shall be grouted with claylike bentonite, of natural origin, creating a heat exchange medium to surrounding rock and sealing against groundwater contamination.
This Sustainability/Innovation focused-project has value because it will appeal to venture capitalists interested in backing green technologies that deliver a return on investment within a 2 to 5-year time horizon. Earth coupled heat pumps reduce reliance on fossil fuels and annual running costs are half or less than traditional electricity-based systems. The system is expected to combat the negative effects of global warming, ozone depletion, urban air quality and sulfur emissions contributing to acid rain [14].

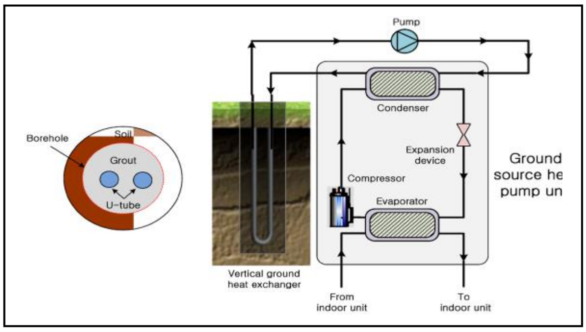

Fig. 1: Ground Source Heat Pump, Source [15].

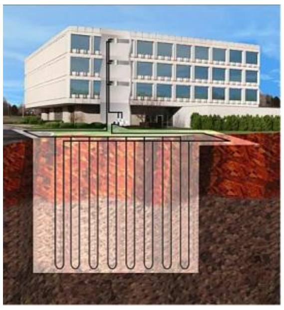

Fig. 2. Schematic of Ground Source Heat Pump System, Source [16].

Estimated installation cost for this capital improvement is 3,268 AED per ton of refrigeration on 50 to 500-ton application which equates to building sizes of 1,400 to 14,000 square meters, typical of commercial structure size variations, and such, as found at HCT-Fujairah Men's College [17].

2.3.2. Overcoming inherent challenges

Hot dry climate installations such as UAE and Saudi Arabia, typically require auxiliary heat exchange. This is because the system primarily operates continuously under high cooling demand [18]; [19]; [20]; and [21]. Rejection of heat from the heat exchange bed surrounding the boreholes if required can be effected by energy stored from the solar assist to counteract the constant effect domination of the cooling cycle and is effective through powering the system as a nocturnal cooling radiator (NCR) [22]. The hybrid system will employ a loop-optimizing methodology [23]. This research will introduce Thermoelectric generators as a means of converting extra heat into useful electric power to reduce the system consumption and improve the thermal cycle efficiency [24].

2.3.3. Project scope

Deployment within the 2-year project window will be enabled by proprietary engineering and business development work performed at the Fujairah Campuses of the Higher Colleges of Technology. Pilot projects of the borehole-based vertical, hybrid ground coupled heat pump systems are potentially extensible for installation on each of the 17 Higher Colleges of Technology College campuses, as part of a hands-on applied research initiative. These will be practical projects engineered, developed, managed and marketed through campus engineering, business incubators, by the students operating with faculty and management support. COMSOL multi-physics software will be used for modeling and simulation of the built environment. Synergies will be achieved between Business and Engineering as part of Applied Research. Successful project outcomes and the project story will be communicated to community stakeholders via effective media communications by HCT.
The pricing has been accurately researched [25] and at a 200,000 AED price point, a minimum 15 KW system can be delivered for ground source cooling with underground components estimated to have a 50-year lifespan and above ground a 25-year lifespan with pay back in reduced energy consumption in a best case scenario of 3-5 years.

2.3.4. Impact on students

Overriding emphasis in on delivering applied education opportunities for a range of student final projects. This GHSP project will directly involve students in the following areas:
Business Division: Integrative Final Project

- Pursuit of sustainable ecosystems and innovation clusters, demonstrating practices and skills for formation of effective teams, and cultural development–respecting diversity and deploying design thinking, innovation and entrepreneurship.
- Principles of responsible management education, (PRME) while scaling organizational innovation, and change management, to benefit organizations and society and help develop their own careers.

Mechanical Engineering Division: A wide range of Senior Design Projects.

- Solar assisted ground source heat pump-based as a climate control solution for UAE
- Developing a sustainable cooling system for UAE using Thermoelectric generators, nocturnal cooling radiators and Ground Source heat pumps for the built environment of the college.
- Development of sustainable solutions to control temperature inside the greenhouses.

Student/Faculty Roles: Senior design project "Modeling Thermo-Electric Generation in Ground Source Cooling System Using Constant Temperature Calculations", to include Mechanical Engineering system design, modeling, analysis, evaluation of performance, and project management. Business Division, marketing including concept of sustainability, sourcing, solicit and evaluate bids, and both for procurement, management of external contractors, cost and managerial accounting, project management, selection of contractors, evaluation of bids, interactions with government on licensing and compliance inspections.
Delivered Research Output: The student produced promotional video; and a version of this proposal was bid, and resulted in this concept winning entry to the Art of Building Entrepreneurial leaders, and the Pitch in Paris competition.
Proposed Research Output: The scholarly research potential of this project is contemplated at three or more papers suitable for Scopus-indexed publication standards. One with a general focus, two or more papers with an engineering focus, and another on business aspects.
Future Research: This project lends itself for additional future applied and scholarly research, as the positive effects of the Geo-Cool system may be evaluated and deployed in combination with other cooling interventions. As part of continuous improvement, and as part of Stage II of this undertaking, deployment of Geo-Cool in additional HCT Campuses. Plans include ideas to augment Geo-Cool technology with additional cooling techniques for maximum results and savings. It is hoped that learning from the Pilot Project at HCT's Fujairah Campuses, future proposed Geo-Cool systems will bring measurable improvements for the structures Geo-Cool is deployed in combination with improvements in additional elements within these structures. For example, in future Geo-Cool deployments a redesign of systems can be undertaken based on a number of variables. Researchers can also influence and control for retrofitting of older structures, or for new construction. Some of these variables and determinants could factor in to the Geo-Cool System design, include a building's (a) design; (b) height (single story vs. multi-story buildings); (c) insulation and R values; (d) passive solar orientation design and to the extent to which this produces cooling efficiencies (aperture; absorber; thermal mass; distribution; control; etc.); and other considerations.

2.3.5. Timeline

The project time horizon is in Table 1. Completion at the campus level two years with design start expected over Summer 2019; drilling of the vertical boreholes and loop installation, leading to project completion in Fall 2020; and no later than Spring 2021. Principals to disseminate project successes to the commercial market and can take place concurrently following successful pilot completion and with the first commercial installations. Summer 2019 will utilize two engineering student research assistants operating under a SURF Grant over seen by Co and Principal Investigators, to investigate sizing, pricing, vendors, senior design project "Modeling Thermo-Electric Generation in Ground Source Cooling System Using Constant Temperature Calculations".

Table 1: The Project Lifetime

Milestones/Deliverables	Summer 2019	Fall 2019	Spring 2020	Fall 2020
Literature Review	■			
Modeling and Simulation		■		
Tender Bids, Sourcing		■	■	
Building Model		■	■	
Patent Application*		■	■	
Testing and Analysis		■	■	■
Marketing and Promotion	■	■	■	■
Economic Study			■	
Outcomes Reporting				■

*Note: Patent Application Can Occur at Any Time to Protect Intellectual Property Rights.

2.3.6. Abbreviations and acronyms

MPG	$C_3H_8O_2$, Monopropylene Glycol
T	System Temperature
T_0	Reference Temperature (outside system)
Q	Thermal Energy
$-Q^*$	Lack of Thermal Energy
BHE	Borehole Heat Exchanger
Q_g	Thermal Energy Exchanged with Ground
m_b	Mass Flow Rate
c_b	Heat Capacity
$T_{w,re}$	Inlet
T_w	Outlet
$X_{w,re}$	Exergy of Heat Carrier Fluid Return Flow
X_g	Cool Exergy
T_g	Internal Subsystem Temperature
X_{gex}	Exergy Consumption During Heat Exchange with Ground
X_w	Output Exergy

2.3.7. Equations

Exergy analysis uses a set of equations (1-4b) to determine thermodynamic energy dispersion potential of a given system. While entropy is a measurement of the actual energy dispersion. Exergy potential can be warm or cool, and depends on the differential between system temperature T and reference temperature T0, while it moves ultimately toward equilibrium. Using the inlet temperature (ground), the hot stream and cold stream temperatures, and assuming a high performance heat transfer fluid such as MPG or C3H8O2 [24], corresponding equations can be defined for the heat carrier fluid in the BHE and the ground. Equation 5 defines the positive exchange of energy with the ground i.e. heat carrier fluid (MPG) from the ground. The heat carrier mass flow rate in the BHE, mb, was set to 0.6 kg/s with a heat capacity cb of 4.27 kJ/(kg K). This value is set according to the system's design specifications. Equation 6 represents the exergy extracted from the ground Xg where comprises cool exergy. The internal sub-system temperature Tg is lower than the reference temperature of T0 outside of the system. Ambient or reference temperature, can be defined according to Equation 7. Xw,re is the available exergy of the heat carrier fluid return flow, and shown as Equation 8. Xgex is exergy consumed during the heat exchange with the ground, with Xw being the output exergy comprised in the BHE outlet flow and shown as Equation 9. See table 2. Below for exergy calculations.

Table 2: Equations for Exergy Calculations

$$X_{warm} = (1 - \frac{T_0}{T})\, Q, for\ T > T_0 \quad (1)$$

$$X_{cool} = (1 - \frac{T_0}{T})\, (-Q^*), for\ T_0 > T \quad (2)$$

$$[energy\ input] = [energy\ stored] + [energy\ output] \quad (3)$$

$$exergy = energy - entropy \cdot T_0 \quad (4a)$$

$$[exergy\ input] - [exergy\ consumed] = [exergy\ stored] + [exergy\ output] \quad (4b)$$

$$c_b m_b (T_{w,re} - T_0) + (-Q_g) = c_b m_b (T_w - T_0) \quad (5)$$

$$X_{w,re} + X_g - X_{gex} = X_w \quad (6)$$

$$X_g = \left(1 - \frac{T_0}{T_g}\right)(-Q_g) \quad (7)$$

$$X_{w,re} = c_b m_b \left\{(T_{w,re} - T_0) - T_0 \ln \frac{T_{w,re}}{T_0}\right\} \quad (8)$$

$$X_w = c_b m_b \left\{(T_w - T_0) - T_0 \ln \frac{T_w}{T_0}\right\} \quad (9)$$

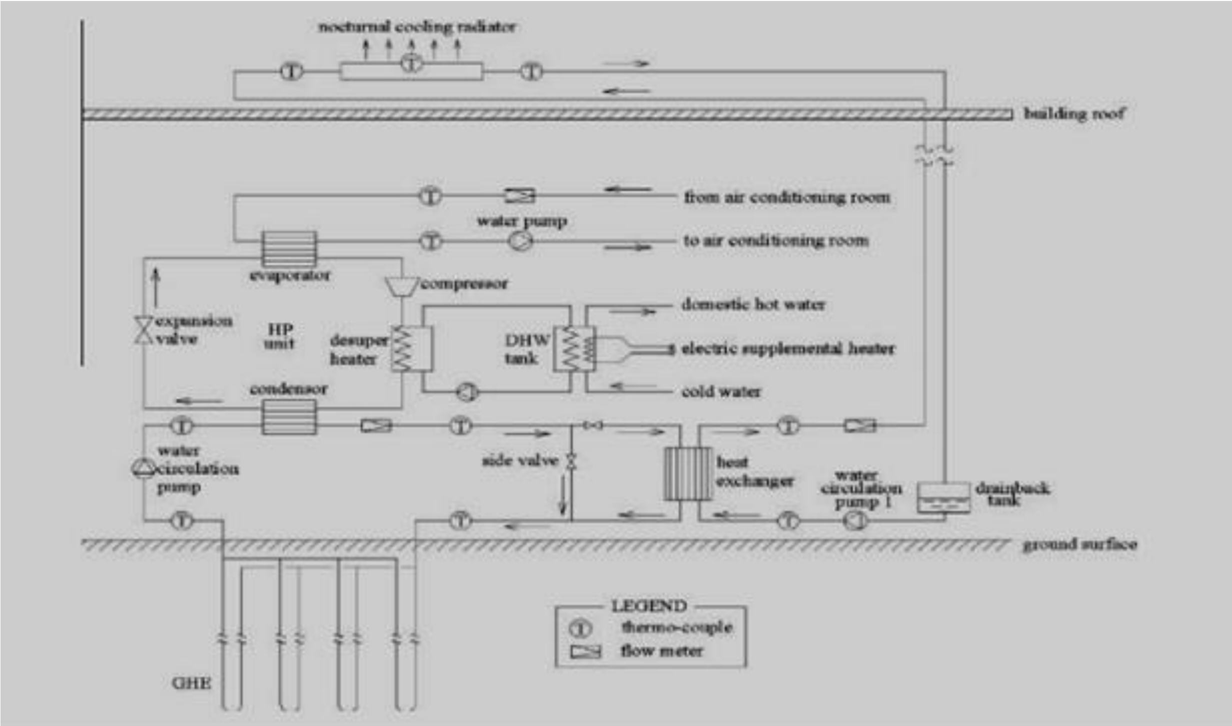

Fig. 3: Schematic Diagram of Novel HCCHP System with NCR, Source [11] P 4162.

Figure 3, previous page, includes the nocturnal heating radiator or NCR which source [11] found necessary in the Saudi Arabia and UAE climate type to counteract saturation of the BHE bed. The NCR operates at night to evacuate heat and renew the differential. Energy demand of the NCR can be met by a solar panel recharged battery [19], [22].

Figure 4 below, shows the available temperature differential between max ambient air temperature and at 5 m depth below grade. As a relatively deeper depth below grade is achieved, moving toward 15 to 20 m depth the line describing this temperature is expected to take on an even more horizontal configuration. With a 150 m forecasted depth of the boreholes, a 20-degree temperature differential, is forecasted to be available for cooling purposes during the hotter months.

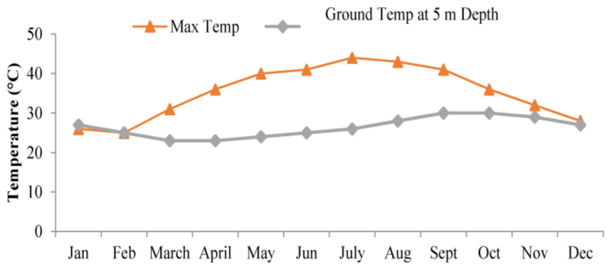

Fig. 4: Subsurface Temperature Gradient in UAE, Source [26].

3. Outcomes

In Spring 2019, the proposed hybrid system attracted a SURF Grant submission to the Higher Colleges of Technology. The SURF Grant was awarded June 9, 2019. The SURF Grant provides funding and allows us to implement Summer Undergraduate Research Fellowships. Letters of interest and support were secured from external industry partners, Chiva Som International and Royal Rotary Club of Thailand, in recognizing the potential to provide a novel method to sustainably, utilize the renewable energy potential of equatorial regions.

The economic benefits are long term energy savings and reduction in the carbon footprint. The major challenge for this project is overcoming the temperature gradient trend, through an engineered application of a nocturnal cooling radiator. Venture Capitalists positively evaluated the project at the Pitch-in Paris event in November 2018, and recommended deploying an app that will track actual energy savings in real time, communicating the efficacy of the FC GeoCool System. Continued college collaboration with the Federal Electricity and Water Authority (FEWA), and industry partners to market this system to the community is proposed.

Acknowledgement

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