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COMPREHENSIVE STUDY ON HYBRID GEOTHERMAL-SOLAR COOLING SYSTEMS WITH SPECIAL FOCUS ON GUJARAT, WESTERN INDIA

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ABSTRACT

To utilize the resources at hand and for solving the issue of energy security in India, focus on various ways of using the naturally available unconventional energies has been intensifying for last couple of decades. This is fuelled by the augmenting awareness about Global Warming and hazards of pollution. Renewable energies like wind power, solar energy, nuclear energy, geothermal energy, biomass and hydro energy need to be given the upper hand. This paper discusses the integrated systems of solar and geothermal energies and proposes design for heating, ventilation and air cooling system for use in Gujarat on commercial basis for domestic and commercial buildings. Winters in Gujarat see an average of about 22^oC while in summers, temperatures peak to around 42^oC. The average ground temperature remains constant at around 30^oC all around the year being warmer than atmosphere in winter and cooler in summer by around 10^oC. Thus, ground can be used as a heat source or sink respectively. Power from solar collectors can be used to run the electrical components of the system like pumps and the rest of the power can directly be added to the power supply of the building. This proves economical than conventional cooling systems working on electrical energy as it makes use of both the accumulation and loss of heat simultaneously at two different places for heating and cooling respectively..

1. INTRODUCTION

The heat energy from the time of formation of the Earth and radioactive decay of materials in the core of the earth are the sources of geothermal energy of the Earth's crust. It is a clean and sustainable source of energy. Resources of geothermal energy range from the moderate-to-low temperature hot spring systems to hot rock found a few miles beneath the earth’s surface, and down even deeper to the extremely high temperatures of molten rocks. The temperature of the geothermal reserves depends on the local geothermal gradient and the depth (Oschner, 2007; Chua et al., 2010).

The subsurface zone of the depth ranging from 10 m to 100 m is called as the undisturbed zone of the earth (Haehnlein et al., 2010). The average temperature of this zone remains constant throughout the year irrespective of the diurnal changes or seasonal changes in solar radiation and the temperature of the atmosphere and surface of the Earth. However, the temperature of the undisturbed zone varies from place to place depending on the local geothermal gradient affected by presence of subduction zones, mantle plumes or rift zones.

Geothermal resources have been classified into low, medium and high enthalpy resources based on their temperature. Muffler and Cataldi classified resources having temperature <90 ^0C and >150 ^0C as low and high enthalpy resources respectively.

Steam from high grade heat sources is directly used for driving a turbine resulting in production of electricity from whereas the use of low grade heat source varies from use in fish farming,drying fruits, wood to extracting gold and silver from ore (Blum et al., 2010). Mushroom culture, pulp and paper processing, capsicum and tomato cultivation, concrete block curing and fabric dyeing also use this natural resource. It is also used for milk pasteurization. Geothermal power plants are also a good electricity generator. Organic Rankine Cycle coupled with GSHP is used for these plants where low enthalpy geothermal resources are available. Additionally, tourists are also attracted by hot water sprigs and for spa (Bayer et al., 2010).

Low enthalpy geothermal resources are used for heating, cooling of space and water and ventilation for domestic and industrial buildings and complexes.Ground Source Heat Pumps (GSHPs) are utilized to absorb low enthalpy heat energy from a domestic or commercial building (heat source), transport and concentrate it and then release it into the ground in summer and thus, it can be used for space or water cooling (Lund, 2001). A reverse process can be used for space or water heating in winters. GSHPs are explained in more detail at a later stage in this paper.

2. CLIMATIC CONDITIONS OF GUJARAT

Gujarat is Western most state of India, surrounded by the Arabian ocean on western part of Gujarat with a coastline of 1600 km^2. Tropic of Cancer passes through the Northern part of Gujarat. This causes extreme climatic conditions in Gujarat. Summers in Gujarat lasts from March to June and are extremely hot and dry. Temperature in summers usually is 40-44^oC during daytime and no less than 28-30^oC during night. Gujarat (particularly Ahmedabad city) has observed record breaking heat wave with the temperature of 50^oC on 16th May, 2016. Winter temperature ranges from 29-30^oC during day to 10-12^oC during night. Thus along with extreme temperature, Gujarat also experiences humid climate due to long coastline and cross country winds.

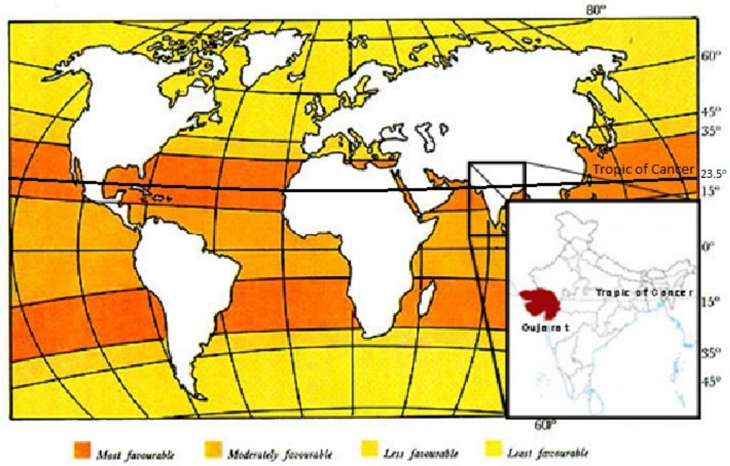

Figure 1 : World map with regions favorable for Solar Power Generation, Inbox: Map of India with State of Gujarat and Tropic of Cancer passing through it (http://almashriq.hiof.no/lebanon/600/610/614/solar-water/unesco/24-26.html)

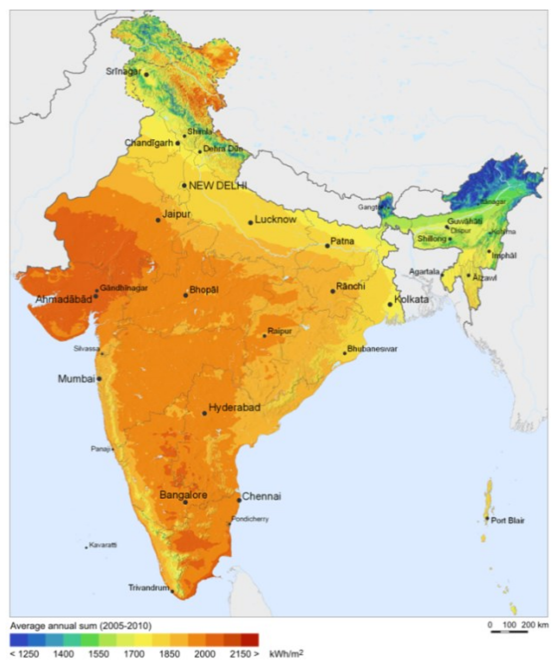

Figure 2: Direct Solar Irradiance (kWh/m^2) distribution across India (SolarGIS, 2011)

3. BACKGROUND WITH RESPECT TO GUJARAT

With increasing volatile temperature conditions, there is increased need in artificial cooling and heating systems (mostly cooling in Gujarat). The air conditioning devices drain a lot of electricity. In fact, they contribute the largest share in domestic and commercial electrical consumption (almost 40% as per survey by TOI in Mumbai, Dec. 2009). In conventional air conditioning (AC) systems, the power consumption is mostly due to work done by compressor working between temperature of heat source and heat sink. Due to high heat sink temperature, work to be done is increased and in turn increases electric consumption. Moreover, conventional ACs dump the heat from the domestic/commercial building into the air, adding on to increase the atmospheric temperature even more. So to mitigate these problems, concept of space cooling using hybrid system of geothermal (ground source heat pump) and solar is discussed in the paper. As the ground temperature, below few feet remains constant throughout the year at around 28-30 ^{0}C, problem such as high heat sink temperature and volatile temperatures can be resolved.

4. SET-UP AND WORKING OF A CONVENTIONAL GSHP:

In conventional GSHP, earth is used as heat sink as opposed to the use of atmosphere as heat sink in case of conventional Air Conditioning System (Oschner, 2007). A geothermal heat pump system consists of three main components:

4.1 Ground heat exchanger loop:

A closed or open loop system of pipes set in ground to absorb or reject heat into the ground. A mixture of water and antifreeze chemicals is circulated through heat exchanger loops (Pertzborn et al., 2010).

4.2 Heat Pump:

It is an assembly of heat exchangers, expansion valve, compressors or pumps and other components through which the working fluid flows. The working fluid is required for efficient transfer of heat between fluids circulated through a building by distribution system and that in ground loop. They are used for heating or cooling the building by exchange of heat with ground. The change in the phase of a working fluid occurs as follows:

Working fluid of low boiling point, initially a mixture of liquid and vapour, converts into saturated gas (at same temperature as inlet super cooled stream) by absorbing heat from the room resulting in cooling of the room (Papadopoulos et al., 2010) ((also called evaporator)

The working fluid, now in gas form, is compressed with a compressor to raise its temperature higher than the ground temperature so that efficient transfer of heat can take place from the working fluid to the comparatively cold water being circulated in the ground heat exchanger loop through Condenser and eventually resulting in dumping of heat from the room into the ground (Papadopoulos et al., 2010).

Working fluid, now in liquid state due to cooling in Condenser, is adiabatically expanded leading to super cooled liquid state using expansion valve (Throttle) based on principle of Joule –Thomson Effect (Stijepovic et al., 2012).

4.3 Distribution system:

It consists of a system of ducts or pipes to circulate hot or cold air or water throughout the building and for regulating the level of humidity. Air ducts, baseboard radiator, fan coil unit and under floor circulating pipes are included (Sivasakthivel et al., 2012).

5. COMPARISON: CONVENTIONAAL V/S GEOTHERMAL COOLING SYSTEM

Conditions and Assumptions: The average annual atmospheric temperature is taken as 40^{o}C and average annual subsurface temperature is taken to be 30^{o}C for calculations for comparing the performance of conventional ACs to cooling by GSHPs. The working fluid used for the study is R-134a with flow rate assumed to be 0.05 kg/s. The desired room temperature is taken to be 15^{o}C. The phase of working fluid at the inlet of the evaporator is mixture of liquid and vapours while at the outlet, it is in saturated vapour phase at the same temperature as that of inlet. Thus, cooling in the room is assumed to be proportional to the heat required by refrigerant to change from vapour + liquid phase to saturated vapour phase (Lim et al., 2007).

The summer season lasts for 2.2 months from April 9 to June 14 with an average annual temperature being 40°C.To dump the heat absorbed by the working fluid from evaporator i.e. the room into the atmosphere, the compressor is used to increase the pressure and subsequently the temperature of the refrigerant to such an extent that efficient heat flow from working fluid to atmosphere can be achieved.

Refrigerant Used – R-134a (1,1,1,2-Tetrafluroethane)

Mass flow rate of refrigerant, $\acute{m}_r$= 0.05 kg/s (for Domestic)

Mass flow rate of refrigerant, $\acute{m}_r$= 0.835 kg/s (for Commercial)

Molar mass = 102.03 g/mol

Compressor Work:

$$Wc = \acute{m}_r \times (h_2 - h_1) \tag{1}$$

Refrigeration Capacity

$$Qc = \acute{m}_r \times (h_1 - h_4) \tag{2}$$

Refrigeration Tonnes (RT)

$$RT = \frac{Qc}{3.5168525} (\because 1RT = 3.5168525 \text{ kW}) \tag{3}$$

Coefficient of Performance (COP):

$$COP = \frac{Q_l}{W_c} \tag{4}$$

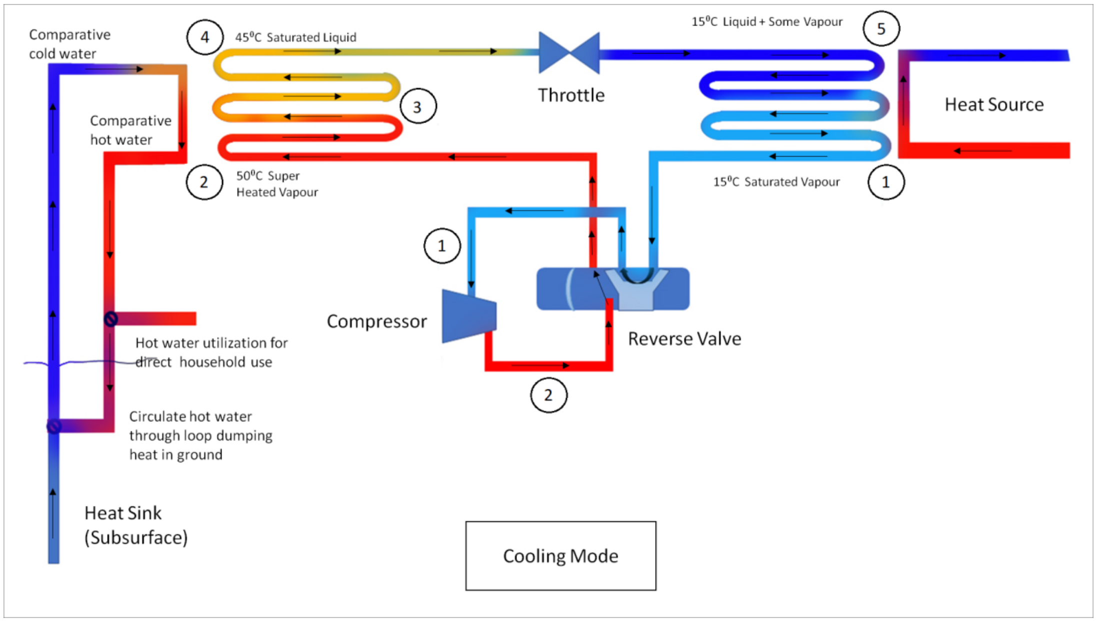

Figure 3. Working of a GSHP in Cooling Mode

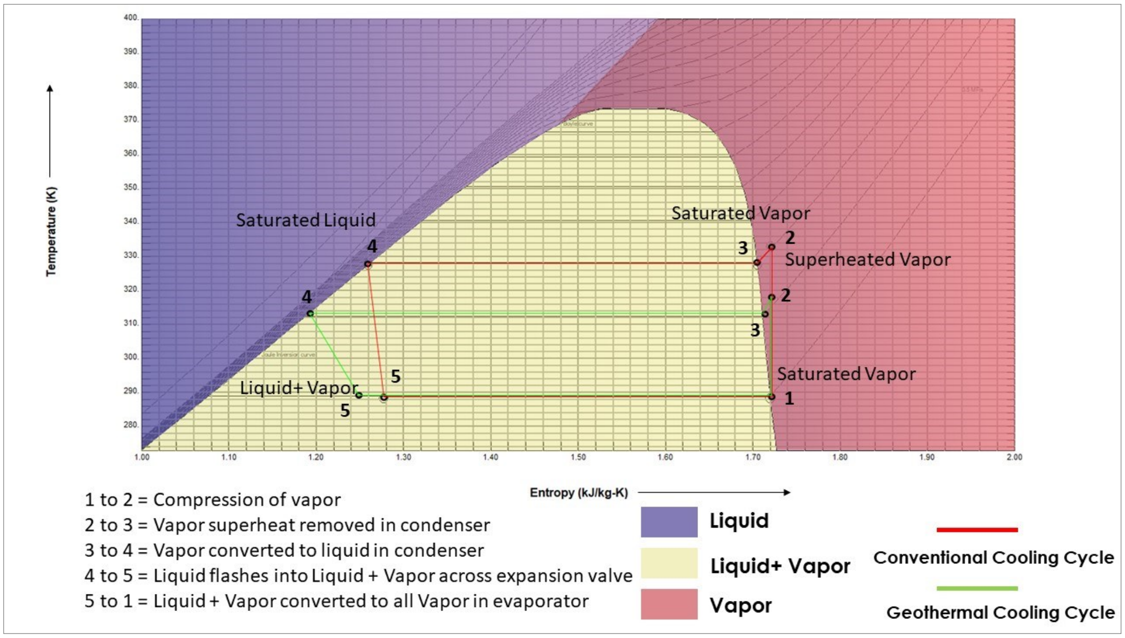

Figure 4. Thermodynamic cycle for working fluid R-134a in GSHP

Table 1. COMPARISION OF CONVENTIONAL COOLING SYSTEM VS GEOTHERMAL COOLING SYSTEM AT NORMAL OUTSIDE TEMPERATURE

	DOMESTIC COOLING SYSTEM		COMMERCIAL COOLING SYSTEM	
Parameters	**Conventional cooling system**	**Geothermal cooling system**	**Conventional Cooling System**	**Geothermal cooling system**
Heat sink Temperature(oC)	40°C	30°C	40°C	30°C
Mass Flow rate(kg/s)	0.05	0.05	0.835	0.835
Compressor Work(kW)	1.181 kW	0.826 kW	19.7227 kW	13.7942 kW
Refrigeration Capacity(Tons)	1.813 **tons**	2.14**tons**	30.276**tons**	35.752 **tons**
COP	5.3988	9.115	5.3988	9.115

(Calculation done based on saturation data for R-134a from software mini-REFPROP)

From the above table, it can be observed that work done by compressor in case of geothermal cooling is less than that of conventional AC, resulting in reduced electricity consumption. Moreover the life span of geothermal system (typically 20 years) is found to be better in comparison to split air conditioners used in houses (typically 7-8 years). The initial upfront cost of geothermal system is found very high as compared to conventional AC so the typical payback period of the system is 7-8 years in case of domestic purpose. In commercial basis, like cooling systems in multi-storey building and for cold storages, Geothermal cooling system turns out to be much more beneficial and payback year turns out to be ~3 years (for refrigeration capacity of around 32 TR) (Staffel et al., 2012).

Gujarat being on the Tropic of Cancer, falls in the region of maximum DNI (Direct Normal Irradiance). Thus, along with extreme temperature conditions throughout the year, it provides opportunity to harvest the solar energy at maximum capacity. Thus, integrating geothermal cooling system with solar power generation system using photo voltaic (PV), results in providing required electricity for compressors and pump of the system. In turn, it decreases consumption of conventional electricity generated by fossil fuels. Moreover, the payback period of the integrated system is decreased along with net-zero or nearly net zero energy cooling system. Capital expenditure in case of geothermal system and solar power system is subsidized by the government to incentivize the increase in utilization of such Green technologies Hepbasli and Kalinci, 2009).

Dumping waste heat in the ground helps in preventing increasing atmospheric temperature mitigating increasing global warming issues.

As shown in **Figure 3**, heat can be dumped in the subsurface by water circulation in a loop or if there is facility of self flowing artesian well, hot water can be used in the household purposes adding extra benefit in terms of cost saving by reducing electricity consumption for heating water (heating water through electrical coils). As heating water and cooling space are the two major utility operations used daily and are major contributors in overall share of electricity consumption. Geothermal-Solar hybrid system can provide benefit of handling both the major household demand in a cost effective way with minimal carbon footprints.

6. ECONOMIC FEASIBILITY

The net present value (NPV) of a project is sum of present values which accounts for net incomes for each period. It is used to evaluate the project while considering long term value of money. The more positive the net present value is more value the project would add to the investment.

Payback time is the duration which the costs incurred for the project are recovered. It is expected that payback time be as low as possible. It is the ratio between initial investment and annual revenue.

Internal Rate of Return (IRR) is used to evaluate the profitability of the project. Internal rate of return is a discount rate that makes the net present value (NPV) of all cash flows from a particular project equal to zero at time equal to payback time Benderitter et al., 1990).

Economic viability of the geothermal system, geothermal system at subsidized rate and solar-geothermal hybrid has been compared on the basis of their NPV and IRR of all three systems. Accurate economic analysis can be done when working setup has been installed considering the design of surface facilities. Ideal comparison of the systems has been done taking into account following assumptions:

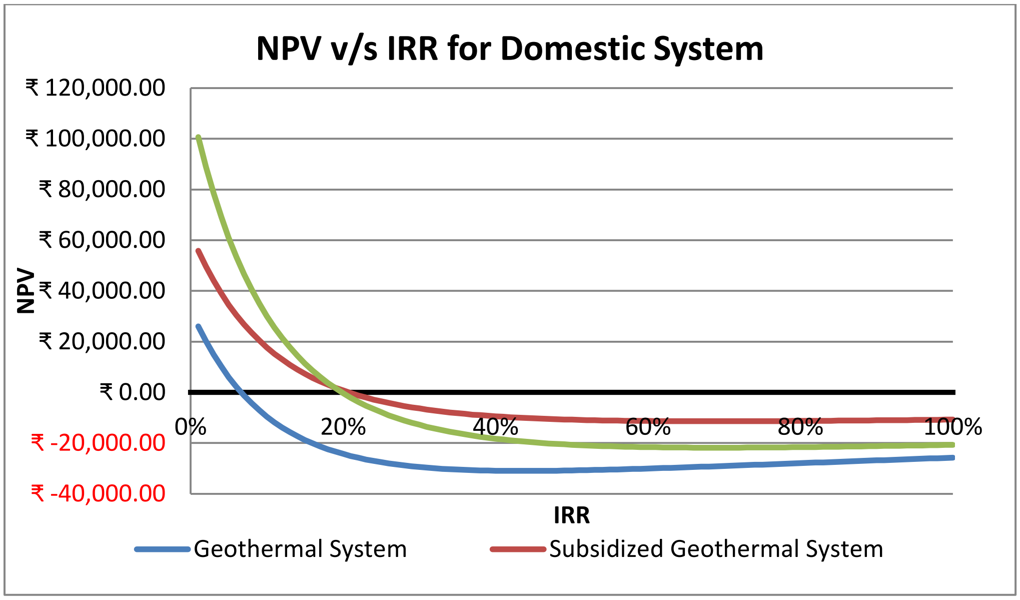

Figure 5: NPVv/s IRR for Domestic System

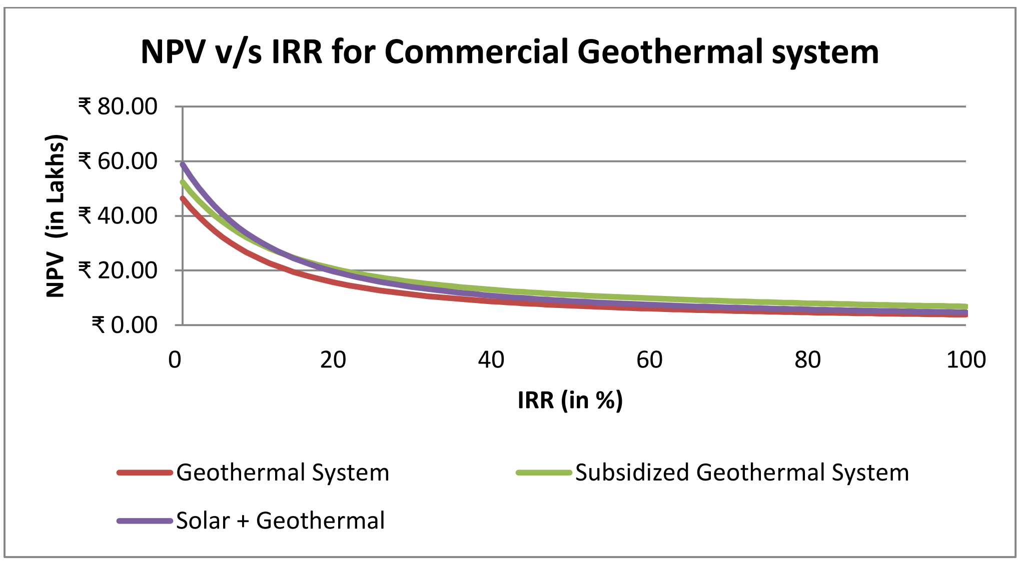

Figure 6: NPV v/s IRR for Commercial Geothermal system

All the systems are compared with 3 star conventional AC unit. For domestic system, cooling load considered is 1.8 TR while that for commercial load consideration is for 32 TR. Life of conventional AC unit is considered as 8 years, while that of geothermal system as 20 years. Subsidized rate is taken as 30% of the initial Capital Expenditure (CAPEX). In case of solar geothermal hybrid system, Levelized Cost of Electricity is considered as ₹3/ unit as compared to ₹5/ unit as of conventional (Schuster et al., 2009).

From the NPV v/s IRR curve for domestic systems, it is evident that as compared to simply geothermal cooling systems, solar and geothermal integrated systems have higher IRR. Thus, even though they necessitate large initial capital investments, the cost recovery is faster making the payback time smaller. Thus, economic advantages can be obtained sooner. This is owing to the Levelized cost of electricity which comes out to be ~ ₹3/unit of electricity instead of ₹5/unit for conventional electricity cost (MPCEA, 2014).

On comparing the graphs for domestic and commercial systems, it can be seen that IRRs for commercial system are not obtained since at 100% IRR they are showing positive NPV. Thus, it can be concluded that higher the cooling load, better is the economic feasibility for installing geothermal cooling system rather than conventional (Sreejith et al., 2014). Moreover, the geothermal system at subsidized rate and Solar- geothermal hybrid proves to be better in terms of NPV at any IRR as can be inferred from **Figure6**.

7. CONCLUSION

In the era of dynamic climate and extreme conditions, issues of global warming is emerging as most concerned issue posing a potential threat for sustainable survival. The paper focuses on the regions which have higher temperature throughout the year leading to increased atmospheric temperature of that region. Ever increasing population ultimately raises the utilization of artificial cooling systems to maintain the comfort temperature. In conventional air conditioning systems, work done by compressors increases to raise the temperature higher than that of heat sink (atmospheric temperature). Moreover, heat is also dumped in atmosphere adding to increasing temperature. Effective, cleaner and greener approach to this is use of geothermal space cooling system which relies on subsurface as heat sink. It provide benefit of dumping heat into earth which diffuses in this infinite reservoir and work done by compressor decreases as temperature of sink is less than that of ambient air temperature (particularly in summers) and moreover constant throughout the year. Regions with high solar irradiance can instead take advantage of opportunity to design net zero system, wherein the energy required can be satisfied by solar itself. Geothermal cooling systems have high upfront cost but are proved highly economical at commercial scale. This technology can find its best potential in commercial multi storey building and even in cold storages where high energy is consumed for sake of high refrigeration tons of cooling.

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