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Financial Analysis of Solar Underfloor Heating System and Variable Refrigerant Flow (VRF) System for Space Heating: A Case Study of Resort

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Abstract: The need of thermal comfort is one of the major topic of energy consumption in building. Alternative means for space heating are required for reducing building energy consumption and also reduce its carbon footprint. Solar thermal systems are matured technology in field of hot water and space heating. Though solar water heater has flourished in Nepal, space heating system is less popular. With an objective to assess the less popularity of such system in Nepal, financial comparison of solar underfloor heating system against commonly used VRF system designed to meet heating requirements of a particular site is done. The selected site is a resort in *Nagarkot*, Nepal. The selected site has minimum temperature of 3 ºC which is to be maintained at 20 **ºC** of which the total heating load is 10.527 kW. From the financial analysis, it is seen that though installation cost of solar powered system is more, in long run it turns out to be economic and in this case the system is technically and financially viable. For solar underfloor heating, the levelized cost of energy when subsidized with 3.5 % interest rate is NRs. 13.18 which is slightly more than current rate of electrical energy. The solar powered heating system has very high footprint because of which this type of system is less employed in urban areas and high rise buildings.

Keywords: Space heating, heat loss, levelized cost of energy, footprint analysis

1. Introduction

All over the globe, people and industry consume massive quantity of energy to power their homes and offices, travel across the world and operate factories that produce billions of dollars of goods. Fossil fuels, nuclear and renewable are the fuel sources that satiate the global thirst for energy. The buildings sector is being a leading energy consumer [16]. Buildings account for about 40 % of the global energy consumption and contribute over 30 % of the CO_2 emissions [9]. Despite the worldwide energy crisis, a considerable amount of energy is consumed every year due to thermal comfort considerations [6]. In case of Nepal, 4 % of total energy consumed in an urban house is for purpose of space heating [13].

Thermal comfort is that condition of mind that expresses satisfaction with the thermal environment. Because there are large variations, both physiologically and psychologically, from person to person, it is difficult to satisfy everyone in a space [3]. The need for heating has originated from the necessity to create a temperature change balance between the human body and the environment and the need to provide thermal comfort. Providing for indoor thermal comfort and reducing energy use in buildings is becoming increasingly difficult and this has called for new ways of thinking and re-evaluation of the existing methods of tackling this problem [1].

Accelerated prices of secondary energy sources like petroleum, electricity will of course effect the annual operating cost of conventional space heating systems that are powered by them. The use of alternative energy sources such as solar energy, geothermal energy and waste heat, are very promising sources to cover partially or totally the energy demands of buildings. Solar energy utilization for space heating consist of an efficient and simple way to cover the building loads in a high fraction [15]

Solar thermal systems (STS) collect energy from the sun and transform it into heat used to raise the temperature of a heat transfer fluid. The fluid that can be air, water or a specially designed fluid can be used directly for hot water or space heating/cooling needs. The heat generated can also be stored in a proper storage tank for use in the hours when the sun is not available. In all cases, thermal energy can be transferred by means of heat exchangers designed according to the final energy application. Solar thermal technologies are also used to heat swimming pools and to provide hot water for commercial buildings and industrial processes [7].

A theoretical and experimental study is made for underfloor heating system using solar collectors. In addition, a study for a similar system using solar ponds is made under the same local conditions. Results obtained show that the solar collector system is 7 % more efficient than the solar pond system. Economic analysis show that the Solar Collector System (SCS) will break even earlier than the Solar Pond System (SPS) but practical considerations show that the SCS requires less operation and maintenance [4].

A significant number of works are dedicated to study about underfloor heating systems. With recent trends being application of commercial CFD codes to simulate temperature distribution so that no temperature gradients are formed in heated space, some researches are dedicated for comparative study with other heating system as well [14].

In [8], different heating source are studied and are compared for comfortable room temperature. Underfloor heating was found to be best for comfortable room temperature. Risberg, 2015, performed CFD simulation of indoor climate in low energy buildings by varying the pipe spacing as well as the material. The study also shows that for low climates, PEX-AL-PEX pipes can be used to heat the house in sub-arctic region. Thus, generally for better room air temperature, underfloor heating with PEX type piping of tube diameter 16 mm was used [14].

2. Background and Methodology

2.1 Site Plan and Considerations

In this case, we have considered heating of ground floor of the building for which the indoor design temperature is 20 ºC and the Outdoor temperature is 3 ºC. Fig. 1 shows the ground layout of building with design consideration. The indoor temperature is so chosen for thermal comfort and outdoor temperature is average minimum temperature in dry season referenced from annual temperature data by NASA. Also, the hot area and the glass house are excluded from the design. However, heat loss to these areas when they are not in use is considered.

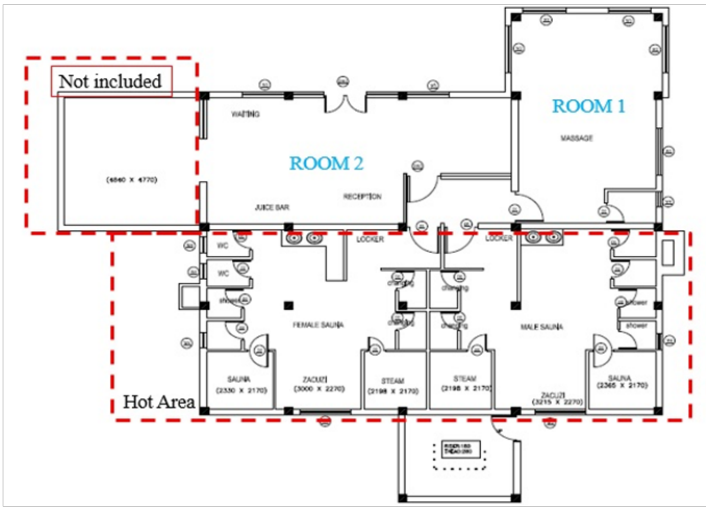

Fig. 1 : Site Plan with Design Considerations

Avatar Resort is situated in *Naldum, Nagarkot*. The resort has total land area of 8139.84 m^2. The designed building is oriented towards north consisting three storey with total building area of 218.51 m^2. Main entrance gate is facing towards north in between two large windows and the ground floor consists of reception, massage, sauna and jacuzzi. Bedrooms and living rooms are in first floor. It is required to design solar underfloor heating for ground floor in reception and massage room area that has total area of 89.76 m^2 and height 3.27 m with eight windows.

2.2 Thermal Properties of Site Considered

In most steady state heat transfer problems, more than one heat transfer mode is involved. The various heat transfer coefficients may be combined into an overall coefficient so that the total heat transfer can be calculated from the terminal temperatures. The solution to this problem is much simpler if the concept of a thermal circuit is employed [2]. Table 1 details the calculated U value for various building components.

Table 1 : Calculation of Overall Heat Transfer Coefficients

U value of components		
S.N.	**Component**	**U Value, W/m^2K**
1	Outside Wall	2.1509
2	Ceiling	2.0287
3	Floor	5.5571
4	Partition	2.3939
5	Door	0.6380
6	Window	5.9402

Total heat loss is calculated by summation of heat loss through various heat loss mechanisms.

2.3 Summary of Heat Loss

2.3.1 Transmission heat loss

Steady state heat loss by conduction and convection heat transfer through any surface is

$$q = U * A * (t_i - t_o) \tag{1}$$

where,

q = heat transfer through wall, glass, roof, ceiling, floor or other exposed surface, W
A = area of surface, m^2
U = air to air heat transfer coefficient, W/ (m^2. K)
t_i = indoor air designed temperature, K
t_o = outdoor air temperature, K [2]

Employing this equation, the calculated value of heat loss obtained from Room 1 and Room 2 is 10191.59 W. Details of which are presented in table 2 and 3.

Table 2 : Transmission heat loss from room 1

S.N.	Component	Total Heat Loss Area, m^2	Heat Loss, W
1	Window	9.72	980.86
2	Outside Wall	41.90	1532.43
3	Ceiling	38.40	1324.31
4	Partition	15.72	639.93
	Total		4477.55

Table 3: Transmission heat Loss from room 2

S.N.	Component	Total Heat Loss Area, m^2	Heat Loss, W
1	Door 1 (Main Door) North Side	3.37	123.40
2	Window	11.70	1181.50
3	Door 2 (South Side)	5.40	219.75
4	Door 3 (East Side)	3.66	39.70
5	Outside Wall (East Side)	12.06	441.12
6	Outside Wall (North Side)	19.98	730.50
7	Partition	29.65	1206.76
8	Ceiling	51.36	1771.27
	Total		5714.04

2.3.2 Infiltration Heat Loss

The energy required to warm outdoor air entering by infiltration to the temperature of room is given by

$$q_s = C_P * Q * P * (ti\text{-}to) \tag{2}$$

where

q_s = heat flow required to raise temperature of air leaking into building from t_o to t_i, W
c_p = specific heat of air at constant pressure, kJ/ (kg. K)
Q = volumetric flow of outdoor air entering building, L/s
ρ = density of air at temperature t_o, kg/m^3 [2]

Table 4: Details the calculation of infiltration losses in selected site from both room 1 and 2.

S.N.	Items	Unit	Value
1	Hourly Air Change Rate		0.20
2	Air Density	Kg/m^3	1.20
3	Specific heat of Air at Constant Pressure	kJ/kg.K	1.005
4	Total Space Volume	m^3	294.04
	Total Sensible Heat Loss, W		336.32

Upon summing the transmission and infiltration losses thereby neglecting other minor losses, the total heat loss in the building is 10.527 kW. Designed space heating system must be able to supply heat energy at this rate to maintain the heated zone at required temperature of 20 ºC.

2.4 Financial Analysis

After all the designs and component selection were finalized, cost of each equipment of both system was determined from market by preparing the Bill of Quantities (BoQ). Cost includes labor cost and transportation charge during installation. Thus, initial investment cost of the system was obtained. In addition, total operation and maintenance cost were also calculated. Then, cost of solar underfloor heating system was compared with VRF system. For this system, initial investment cost is very low but annual operating cost is high compared to the solar underfloor heating system. So the difference in saving of annual operating and maintenance cost is taken as revenue, based on which payback period, NPV and IRR is calculated.

Cost analysis based on levelized cost of energy is a wide spray method to compare different energy generation technologies. Main concept behind is to compare the total cost in reference to energy supply system with the energy supplied by this system over its lifetime.

LCOE measures lifetime costs divided by energy production. It calculates present value of the total cost of the system and operating cost over an assumed service life.

$$\frac{\sum_{t=1}^{n} \frac{I_t+M_t+F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \tag{3}$$

where

I_t = Investment expenditures in year t
M_t = Operations and maintenance cost in year t
F_t = Fuel expenditure in year t
r = Discount rate
n = Life of the system

3. System Description and Cost Calculation

3.1 Solar Underfloor Heating System

To obtain uniform temperature distribution with 13 mm (ID) PEX pipe, tubes were spaced at 150 mm center to center. Seven pipe loops are employed to heat the space with mass flow rate of water at 3.59 gpm and eighteen collectors each of area 1.86 m^2. Collectors are paired in two, and the pairs are then connected in parallel to get the output temperature of 50 ºC with inlet temperature 43 ºC. The collectors are placed with adjacent gaping of 100 mm in column and 320 mm in adjacent rows of collector. The total area required for placement of collector is 46.31 m^2. Which implies that per unit area of collector required to heat unit area of floor is 0.51 m^2. Two insulated tanks of capacity 3000 L and 3500 L are used which occupy floor area of 13.35 m^2. As adopted from design guideline to reduce losses in fluid flow, one inch PEX pipe insulated from outside is employed in collector side and supply line up to manifold and 0.5 inch PEX pipe is used in loops. Manifold in the system is selected with inbuilt thermostat and thermometers to control the temperature of water flowing in the loop. Also, the manifold will be equipped with air vents. Thermostats is fitted in the heated space to control the temperature of the room; their output is used as feedback to shut off water flow to the loop when temperature in heated space just exceeds 20 ºC. Two pumps of capacity 114 W and 45 W are employed in room side and collector side respectively to circulate water in the loops. The basic layout is presented in Fig. 2.

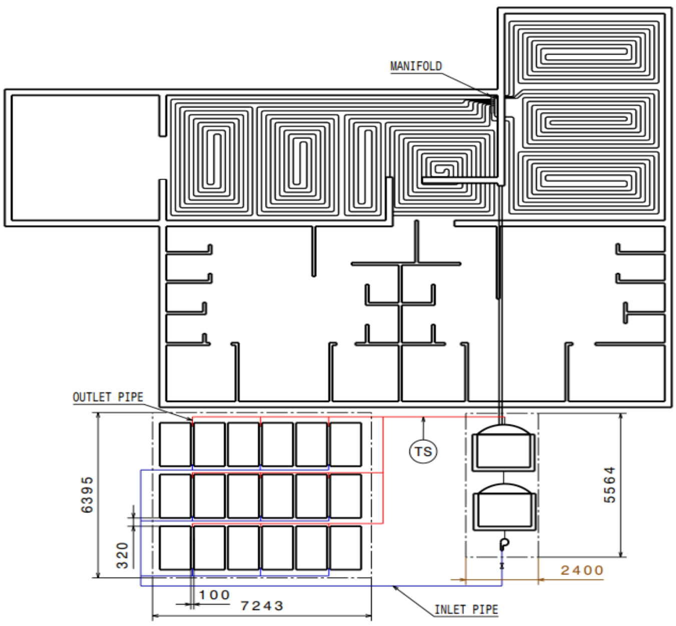

Fig. 2 : Planned Layout of Solar Underfloor Heating System

3.2 Variable Refrigerant Flow System

The VRF system will have two wall mounted indoor units of 8 kW capacity for room 2, 5 kW capacity for room 1 and one outdoor unit of capacity 15.5 kW.

The planned layout for installation of VRF system is shown in Fig. 3.

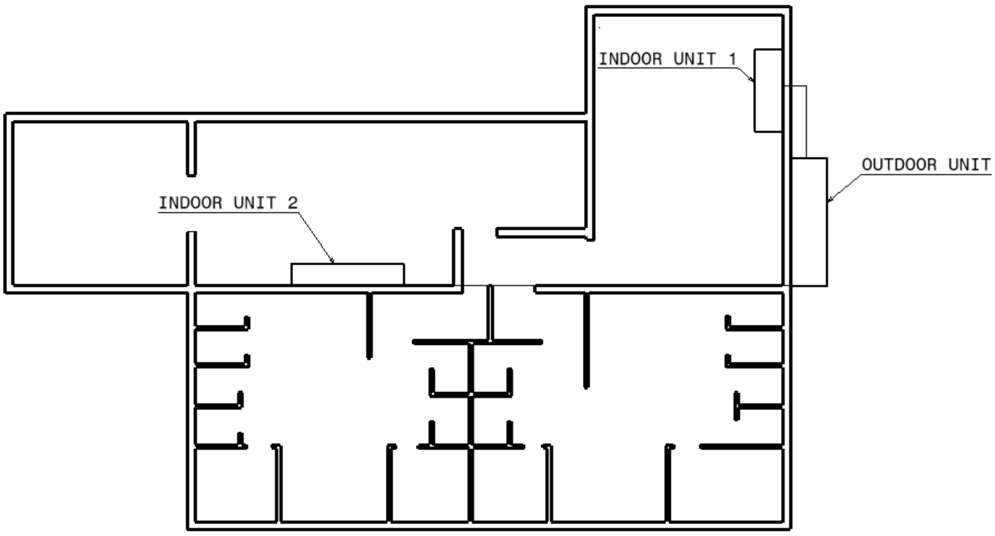

Fig. 3: Planned Layout of VRF System

3.3 Capital Costs

3.3.1 Solar Underfloor Heating System

The capital cost for the system were collected from local suppliers who import and distribute system components from international market. The capital cost of solar underfloor heating system is presented in table 5.

Table 5 : Capital Cost of Solar Underfloor heating

S.N.	Component Name	Specification	Quan-tity	Unit	Rate	Total Cost
1	Solar Flat Plate Collectors	BT Collector	18	No.	75,000	1,350,000
2	Collector Support Frame	MS Frame	1	Lot	56,000	56,000
3	PEX Pipe (1 Inch Dia)	For conveying and Col-lecting Heating Water	40	m	450	18,000
4	PEX Pipe (1/2 Inch Dia)	For Circulating Hot Water in Room	550	m	200	110,000
5	3000 L + 3500L Hot Water Storage Tank Insulated, Stainless Steel Tank		1 Each	No.	400,000	400,000
6	Manifold and oth-er accessories	7 Branching (1 to 1/2); Included thermostat and Temperature Gauge	1	Set	25000	25,000
7	Gate Valve	1inch	2	No.	520	1,040
8	Globe Valve	1inch	1	No.	1,100	1,100

9	Floor Insulation	Pre grooved polystyrene 25 mm thickness	90	m^2	800	72,000
10	Pipe Insulation	Elastomer insulation	40	m	150	6,000
11	Circulating Pump 1 (For circulating inside room)	120 watt Davey Company, SS30-25	1	No.	27,000	27,000
12	Circulating Pump 2 (From tank to collector)	45 watt Davey Company, SC 20-25	1	No.	20,000	20,000
13	Auxiliary Heating Device	2 kW electric coil heater with thermostatic sensor	1	No.	6,000	6,000
14	Pipe fittings		1	Lot	20,000	20,000
15	Installation Cost		1	Lot	50,000	50,000
	Total					2,162,140

VRF System

The Table 6 gives the details of the installation expense of VRF system as quoted from local market.

Table 6 : Capital Cost of VRF System

S.N.	Description	Unit	Quantity	Rate	Total
1	Air Cooled Heat Pump VRF Inverter Multi System Out Door Unit	Set	1	132,000	132,000
2	VRF wall mounted Indoor Unit	Set	1	113,000	113,000
3	VRF wall mounted Indoor Unit	Set	1	89,000	89,000
4	Refrigerant Quality Copper Tubes of Following Inner Diameter **(Φ 19.05, Φ 15.88, Φ 9.52)**	m	10	1985	142,975
			45	1585	
			50	1036	
5	Branch set for ref. pipe with insulation	Set	1	10,000	10,000
6	Condensate PPR Drain Pipe	m	20	500	10,000
7	Electrical Cables and conduits for cables	Lot		10,000	10,000
8	Control cables	Lot		20,000	20,000
9	Total				526,975.00
10	VAT				13 %
				Grand Total	595,481.75

3.4 Operation and Maintenance Cost

With operational and regular maintenance cost considered in each year, it is assumed that systems will run for next 25 years after installation without any further investments and major overhaul. Also for VRF system, 25 years is considered.

3.4.1 O&M costs of solar underfloor heating system

Solar thermal is a mature technology, the various components carry long warranties and it is anticipated that with minimal intervention, systems will continue to operate for 15 to 40 years [5]. It is assumed that cleaning is done 3 times in a year auxiliary heating device is assumed to be run half an hour every day. Total operating days is assumed 180 as system will be operating in winter only. The O&M costs are given in detail in table 7.

Table 7 : O&M costs of solar underfloor heating system

Particulars	Total kWh	Rate/kWh	Cost (NRs.)
Auxiliary Heating device	180	11.3	2,034
Pump	343	11.3	3,881
Collector Cleaning Cost			2,500
Miscellaneous			2,000
Total			10,415

3.4.2 O&M costs of VRF system

VRF system has high operating cost. It consists of two indoor units and one outdoor unit. Maintenance cost is servicing cost, which is usually done 3 times annually. Table 8 presents the associated O&M cost of VRF system.

Table 8 : O&M costs of VRF system

Item	Cost (NRs.)
Electricity Cost for indoor unit 1	1,855
Electricity Cost for indoor unit 2	488.16
Electricity Cost for outdoor unit	119,111.04
Maintenance cost of VRF system per year	7,500
Total	128,954

4. Results and Discussion

The following assumptions have been made for the financial analysis of the designed system. The assumptions are based on the existing practice in local market. The service life of the whole system has been assumed 25 years, which would require regular and effective maintenance throughout the mentioned period of which cost has been considered as shown in table 8. Two case are taken for analysis one with subsidy and second without subsidy.

Average Yearly Inflation Rate = 4.5 % [11]
Service Life = 25 years

- Tariff Rate for commercial systems:
    - Demand Charge: NRs. 325 /kVA
    - Energy Charge: NRs. 11.2 /kWh [10]

- Discount rate with subsidy: 3.5 % [12]

4.1 Investment Cost

The investment cost of solar components and Variable Refrigerant Flow (VRF) system were taken from supplier in local market. It includes cost price of equipment along with installation cost. Investment cost of solar underfloor heating system with BT collector is quoted at NRs. 21, 64,200. Investment cost of VRF system is quoted at NRs. 595, 481.75. Using BT collector, investment cost of solar underfloor heating system is 3.7 times more than VRF system.

4.2 Operation and Maintenance Cost

The annual O&M costs mainly comprise of the electricity cost for pump operation, cost of cleaning collectors, filter and wire replacement. The annual cost of O&M of solar underfloor heating is only NRs. 10,415 while that of VRF system is NRs. 128,954.21. Annual cost of VRF of system is about $1/5^{th}$ of the installation cost of it. The annual cost of operation and maintenance VRF system is 12.4 times more than solar underfloor heating.

4.3 Savings by use of Solar Underfloor Heating

Considering the installation and operating cost difference between VRF system and solar underfloor heating system, it can be seen that though initial cost is more of solar underfloor heating system, it saves annual cost if used as substitute for VRF system. The comparative cash flow diagram is shown in Fig. 4.

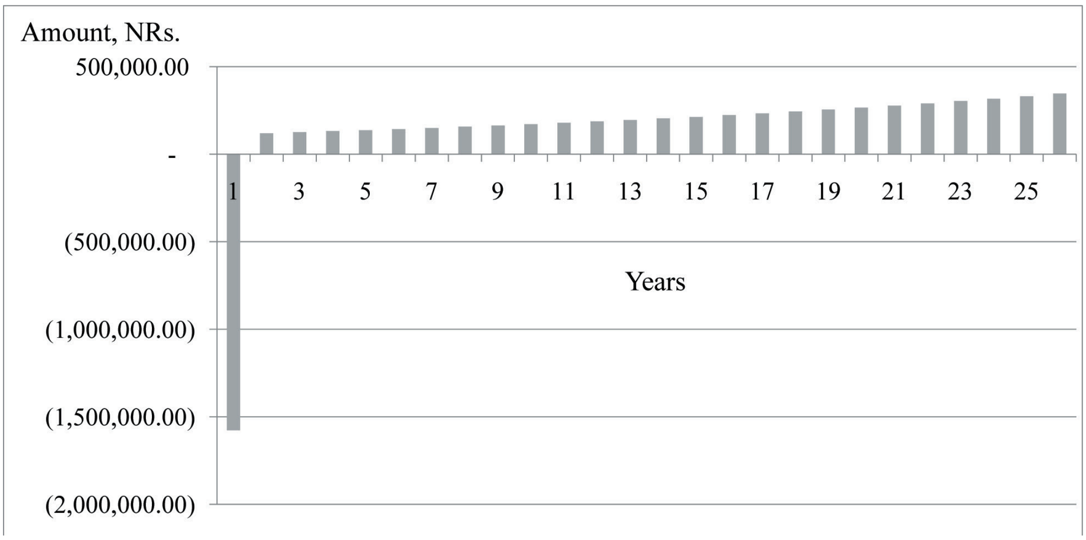

Fig. 4: Yearly Savings Presented as Cash Flow Diagram

4.3.1 Payback period profile

With cash flow diagram being drawn, the next interest was to find the payback period of solar underfloor heating system with savings considered as revenue. Fig. 5 shows that the payback period without interest rate is around 11 years. With discount rate being 3.5 %, the payback occurs around 13 years which is around half of the recommended life of the system.

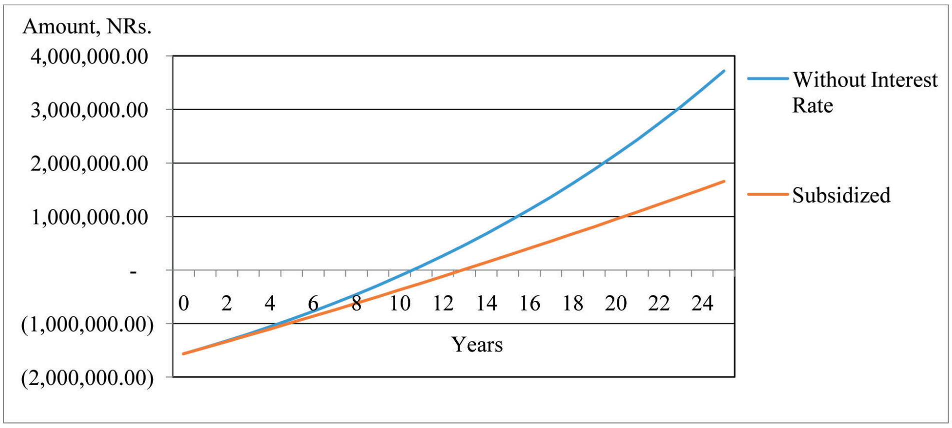

Fig. 5 : Payback Profile with Annual Savings Considered as Revenue

4.3.2 NPV Profile

NPV profile for 25 years was drawn by increasing rate of return in Fig. 6. It can be seen that if rate discount rate is less than IRR i.e. 9.94 % NPV is positive, if discount rate is equal to IRR than NPV is equals to zero and if discount rate is greater than 9.94 % than NPV is negative and project may not be financially viable. Study shows that solar system does not seem to be much financially attractive if subsidy is not provided.

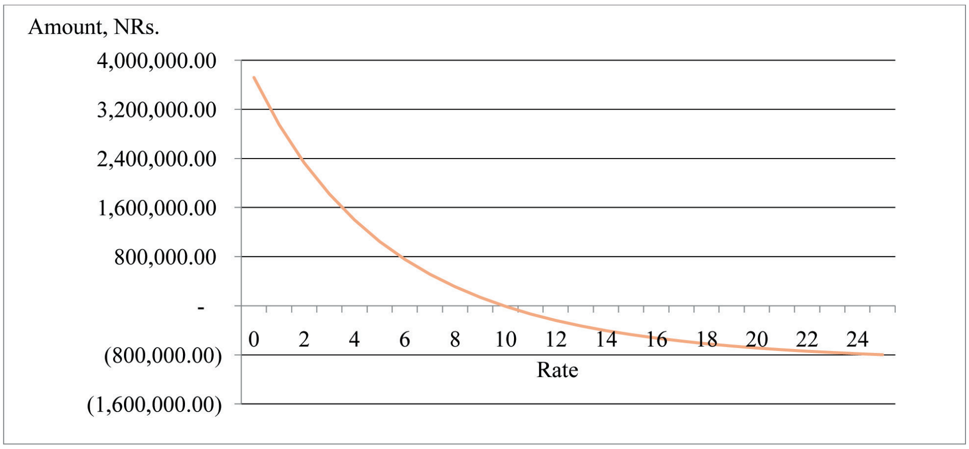

Fig. 6 : NPV Profile with Annual Savings as Revenue

4.4 Levelized Cost Calculation

The Levelized Cost of Energy (LCOE) is one of the residential solar industry's most commonly used metrics. With discount rate of 3.5 % and the system life of 25 years, the levelized cost of the system is calculated to be NRs. 13.18 per kWh. This Fig. is just greater than prevailing rate of electricity for commercial sector, which is NRs. 11.31 per kWh for our case. With price increase of 14.18 %, the levelized cost would breakeven with the electricity cost. Thus, with system performing on long run, the solar system is found to be cost effective than the VRF system if subsidy is provided. Table 9 summarizes the results of the financial analysis of the designed solar underfloor heating system. It can be seen from the table that the financial indicators are quite attractive to the investor. Hence, the investment on solar thermal system for underfloor heating for this case seems justified.

Table 9 : Summary of financial analysis

S.N.	Parameter	Unit	Value with subsidy (3.5 %)
1.	Payback period	Years	12.91
2.	Net Present Value (NPV)	NRs.	1,654,536.09
3.	Internal Rate of Return (IRR)		9.94 %

4.5 Footprint Analysis

In design and component selection, it is very important that the selected component fulfill the desired purpose with minimum equipment spacing. Any increase in size directly alters the budgeting by increased cost of transportation as well as cost of space.

Equipment footprint refers to the physical space, especially the width and depth combination an equipment requires when being placed or deployed within a space such as a home, or an office. It is generally equated in terms of size in square feet / meters of area that the device will occupy in a location and its impact on the overall space. For heating ground floor of the resort, the total footprint required by the solar collector is around 46 m^2 whereas the footprint require by VRF system to heat same area is only 0.44 m^2. Footprint of VRF system is very low compared to that of solar underfloor heating system.

5. Conclusion

Avatar resort in *Nagarkot* was selected as suitable site being cooler place nearby Kathmandu valley, populated with commercial systems like hotel and resorts. Total heating load was estimated to be 10.527 kW. To meet this heating load, total collector area of 33.13 m^2 for solar system was calculated. Financial aspects of solar underfloor heating system were compared against VRF system. Installation cost of the solar underfloor heating system is 3.7 times more than VRF system but the annual operating cost is 12.4 times less. With annual savings considered as revenue, installation of solar underfloor heating system from financial viewpoint in this case seems to be feasible with an IRR of 9.94 % and payback period of 12.91 years. Most of the components in the designed system namely, collectors, pump and piping material were quoted from international market. If locally made collectors could verify their performance and efficiency claims, they could substitute the BT collectors thus lowering the overall installation cost of the system. This would make it much more attractive from financial viewpoint.

The levelized cost of energy from solar system was found to be NRs.13.18 with subsidy and NRs. 27.47 without subsidy. Levelized cost of solar powered system when subsidized is slightly more than the rate of electricity for the system which will be charged at rate of NRs. 11.31 as per electricity rate published by Nepal Electricity Authority in fiscal year 2073/74. If the tariff rate increases more than 15 %, then the solar system would be cheaper than system powered with electricity. Hence, subsidy as loan would be necessary for promotion and implementation of such projects.

The major disadvantage of solar underfloor heating system is its very high footprint. To heat area of unit square meter, we need 0.51 m^2 of open space for collector placement. In urban areas of Nepal with already developed settlements, spacing factor might be a major cause, which is responsible to hold back the system from flourishing. It can be inferred that in mountain areas where barren lands are available and cold climate is experienced throughout the year, solar underfloor system would be a good choice for space heating. For commercial complex in urban areas where space is limited VRF system could be the choice as it has very low footprint and it can be used for both heating and cooling. Furthermore, in high rise buildings where thermal load would be high, the area required for solar collector placement would be very high.

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