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Geothermal Energy for Food Security in the Himalayas

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ABSTRACT

Energy and food are the two essential requirements for national security of any country. India is the third largest consumer of oil, the fourth largest oil refiner and a net exporter of refined products. India is dependent on import of fossil fuel for meeting its energy demands which was 80% in 2018. 60% of the electricity goes to meet the Heating Ventilation Air Conditioning (HVAC) demands of the country. The dependence on fossil fuel can be reduced by using locally available renewable energy sources like wind, solar and geothermal. A solution is also required to the problem of energy access in remote areas where a reliable supply from the national grid is not available. This paper investigates the feasibility of utilizing low enthalpy geothermal energy to provide food security specially in remote areas. A case study of village Chumathang located at 3,950 masl in Union Territory of Ladakh, India, shows the socio-economic impact of geothermal utilization in remote areas by using a low enthalpy geothermal and how it can solve the current problem of food and energy security. A commercial greenhouse of 1,000 m2 would be able to supply year-round fresh vegetables. The case study shows that such projects lead to employment opportunities, prevent migration of people in search of jobs, adds to food security of the region, improves the health of people. This is especially important for women in the region who bear most of the burden of domestic work and are most impacted due to not having access to reliable energy. Such a model can be replicated in any low temperature geothermal remote areas where normally energy supply is not possible.

1. GREENHOUSE VEGETATION (PROTECTED CROP CULTIVATION)

The national highway connecting Ladakh to the rest of India gets blocked from October to May due to snowfall in the high passes. Ladakh has a cold and arid climate with low precipitation (100 mm). Due to the high altitude, only some fruit and vegetables are produced in the region in the summer season. In winter when the temperature goes below - 20°C, it becomes impossible to grow anything in the open air and hence there is no access to fresh fruits and vegetables. According to Dr. Tashi Thinlas, Physician at the Public Hospital, Leh, the absence of fresh fruits and vegetables is one of the reasons for nutrition deficiencies, especially among girls. Greenhouses have been in use in Ladakh since the 1980s with many NonGovernmental Organizations (NGOs) pioneering in introducing the greenhouse vegetation culture. Some of these are the Ladakh Ecological and Development Group (LEDeG), Ladakh Environmental and Health organization (LEHO) (Personal communication, Ishey Tundup, Director, LEDeG, July 2019). Apart from these Government of India provided incentives for the promotion of greenhouse vegetable cultivation through the Department of Horticulture, Ladakh Renewable Energy Development Agency (LREDA). Many schemes were introduced like distributing the polyethylene sheet (silpaulin) for subsidized amount, providing 50% grants for constructing a greenhouse, providing frames and silpaulin, etc. to the farmers (Personal communication, Dr. Tsewang Thinglas, Director, LREDA, July 2019).

Design of greenhouse in Ladakh The most successful commercially available greenhouse has been the one provided by LREDA. Figure 1.1 shows the sections of the greenhouse. The greenhouse is constructed using mud-brick for the walls, talbu (willow twigs), and mud for the roof, husk, or wood chips for insulation between walls. The glazing material is polyethylene sheet of 150 GSM. The greenhouse is oriented in the east-west direction to have maximum sun gain during winters. It has walls on the north, east, and west sides to protect from the wind and heat loss. The location of the door is kept on the east wall as the wind direction is west to east. Ventilators are provided at the west wall and on the roof to get rid of excess heat during daytime (Figure 1.2). For this project, we assume that the size of the greenhouse is 1,000 m2 with the heating pipes laid under the plants. At design conditions the inside temperature is maintained at 20°C.

Material selection for the greenhouse construction The materials considered in the analysis of the greenhouse are mostly available locally. This has been selected to reduce the cost of transportation. Also, by using locally available sustainable materials the project becomes more sustainable. The materials for the walls are mud-brick which is a widely used construction material. The insulation between the walls is straw. Only the glazing material which in this case is polyethylene sheet will be transported from the plains of India.

Weather data Ladakh falls under the cold climate zone as shown in Figure 5.3 (Bureau of Energy Efficiency, Ministry of Power, Government of India, 2017). Weather data is an important factor while calculating heat losses. It was not possible to get the weather data from the Indian metrological department due to privacy issues. The ten-year weather data from World weather online is used which shows the data collected from their station in Hanle which is 80 km from Chumathang. The monthly maximum, minimum, and average temperatures for ten years from 2009 to 2019 are shown in Figure 4.4. The average minimum temperature is -20°C and the average maximum temperature is 15°C.

1.1 Material selection for the greenhouse construction

The materials considered in the analysis of the greenhouse are mostly available locally. This has been selected to reduce the cost of transportation. Also, by using locally available sustainable materials the project becomes more sustainable. The materials for the walls are mud-brick which is a widely used construction material. The insulation between the walls is straw. Only the glazing material which in this case is polyethylene sheet will be transported from the plains of India.

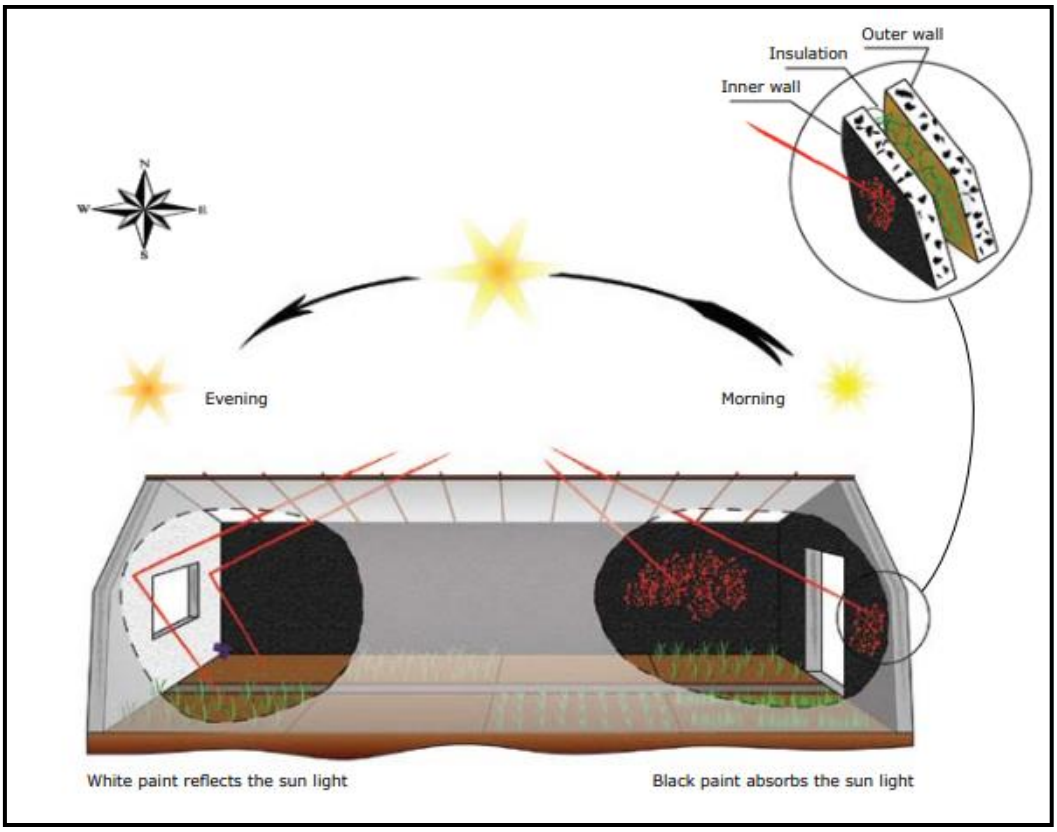

Figure 1.1: Front view of the LREDA commercial greenhouse. The wall is a double-layered mud-brick wall with insulation in between to protect against heat loss. The walls are painted black to absorb the heat during daytime and reflect at nighttime.

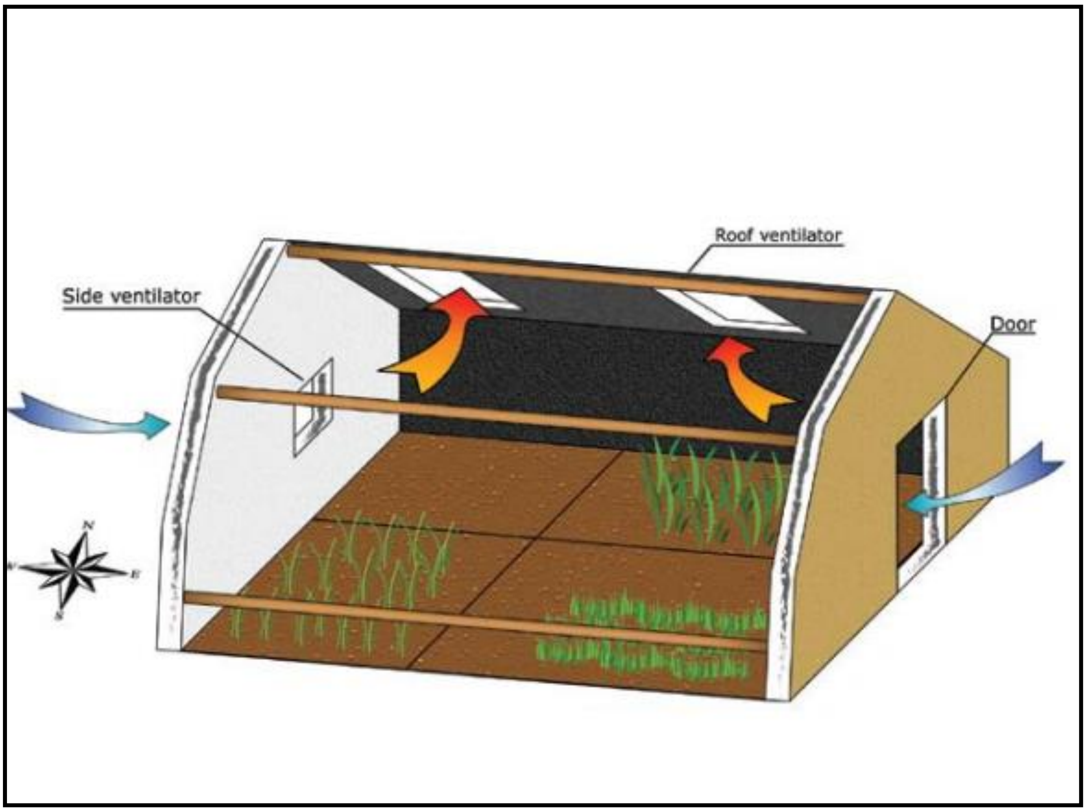

Figure 1.2: Heat convection in the LREDA greenhouse.

1.2 Weather data

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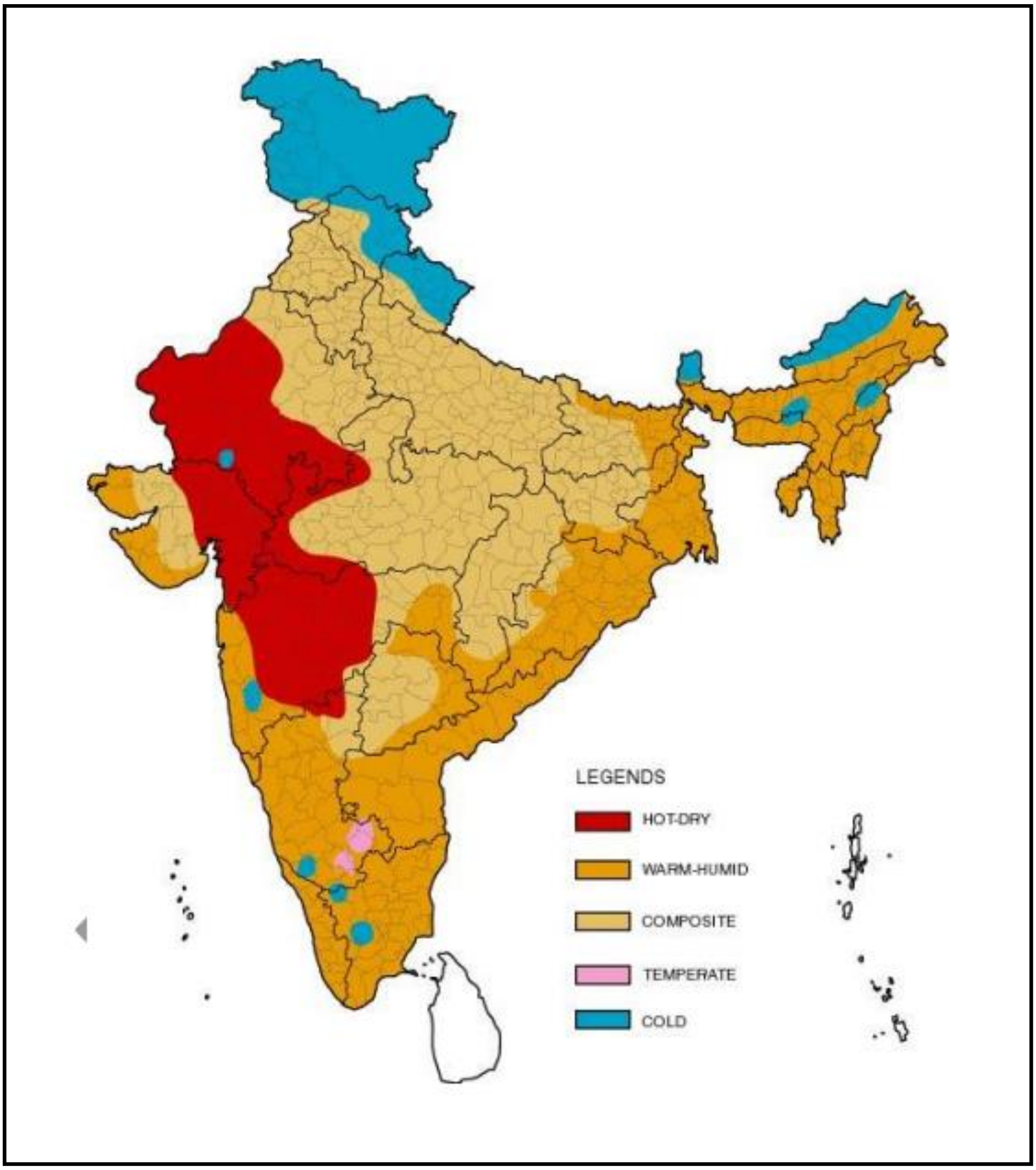

Figure 1.3: Climate zones of India (Bureau of Energy Efficiency, Ministry of Power, Government of India, 2017).

1.3 Heat load calculations

The various parameters that characterize the greenhouse and the operating conditions are shown in 1.

Table 1.

Table 1.1: Design parameters for greenhouse.

Length	125 m

Width	8 m
Height	2.4 m
Floor surface area	1,000 m^2
Volume	2,400 m^3
Greenhouse indoor design temperature	18°C
Outdoor design temperature	-20°C

Figure 1.4 shows the transfer mechanism of energy in a greenhouse.

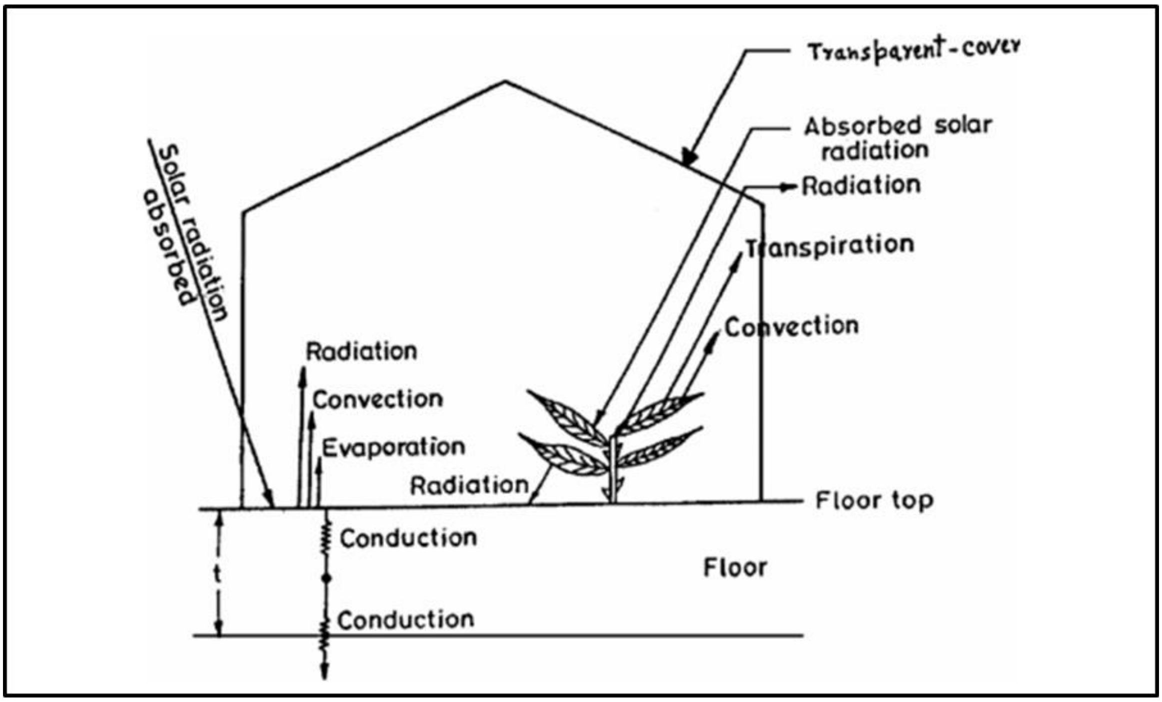

Figure 1.4: Energy transfer mechanism in a greenhouse (Taki et al., 2018).

In the static method, heat loss for a greenhouse is composed of two components:

- Transmission losses through the walls and roof,
- Infiltration and ventilation losses caused by cold outside air.

In the greenhouse that is considered here, there are walls on the north, east and west side of the greenhouse. Each of these walls has three layers. The inner layer wall is made of 0.3 m thick mud-brick, in the middle there is 0.15 m thick straw insulation and then the outermost layer is 0.3 m mud-brick wall. The glazing material, which covers the south side of the greenhouse and for a large part the "roof", is polythene.

1.4 Calculation of U-Values

U-value stands for the thermal transmittance or overall heat transfer coefficient. U-value of a building component such as a wall, glazing or roof describes how well or badly that component transmits heat from the inside to the outside. The lower the U-value, the better it is for heat retention from escaping heat to the outside (Greenspec, 2020). We can say that the U-value measures the amount of energy (heat) lost through a square metre of that material for every degree (K) difference in temperature between the inside and the outside. Thermal resistance (R) is defined as the reciprocal of the thermal transmittance. The U-value is commonly determined by computation from the thermal resistances of the different building materials between inside and outside (the wall) as well as the convective heat transfer coefficients between the wall surface and the surrounding air on both sides of the wall. Given that the wall consists of three layers of materials the U-value can be calculates from the following equation:

$$U_{wall} = \frac{1}{(\frac{1}{h_i} + R_1 + R_2 + R_3 + \frac{1}{h_0})}$$

Where

U_{wall}	= Thermal transmittance, W/m^2K
h_i	= Heat transfer coefficient at inside of the wall, W/m^2K
h_o	= Heat transfer coefficient at outside of the wall, W/m^2K
R_1, R_2, R_3	= Thermal resistance of the wall layers, m^2K/W

The U-value of the mud-brick wall is calculated using the above equation while the U-value for the polythene glazing is taken from Lund, (1996).

The thermal Resistance is the fight the material puts up against the heat passing through it for a given thickness and area. For a solid layer, the R-value can be calculated using the following equation:

$$R = \frac{t}{\lambda}$$

Where

t	= Thickness of the material, m
λ	= Thermal conductivity, W/(mK)

The λ -value or the thermal conductivity indicates how well a material conducts heat. It is the quantity of heat (W), conducted through 1 m^2 wall, in a thickness of 1 m, when the difference in temperature between the opposite surfaces of this wall equals 1 K. The lower the λ-value, the better the insulation property of the material.

Table 1.2 gives the thermal conductivity of some of the common building materials used as per Energy Conservation Building Code 2017 by Bureau of Energy Efficiency, Ministry of Power, Government of India.

Table 1.2: Building and Insulating materials and their thermal conductivity (Bureau of Energy Efficiency, Ministry of Power, Government of India, 2017)

Material	**Thermal conductivity (λ)(W/(mK))**
Asbestos Cement Board	0.4709
Cement Plaster	1.208
Ceramic Frit Glass	0.6882
Clay Tile	0.6323
Float Glass/ Clear Glass	1.0522
Extruded Polystyrene XPS	0.0321
Fibre Reinforced Plastic (FRP)/Fiberglass	0.2252
Fire Brick	1.2729
Glass wool	0.0351
Plastic Polymer	0.5027
Polyurethane Foam (PUF)	0.0372
Rigid Polyurethane (25 kg/m^3)	0.0384
Tempered Glass	1.0493
Wood	0.2652

The insulation used between the walls is straw, as can be seen in **Figure 1.5**. Straw is an agricultural by-product, the dry stalks of cereal plants after the grain and chaff have been removed. Straw makes up about half of the yield of cereal crops such as barley, oats, rice, rye, and wheat. The thermal conductivity (λ) of straw is 0.08 W/mK (Greenspec, 2020).

Figure 1.5: Straw insulation used between the walls at North, East, and West of Greenhouse.

Since the mud-brick walls are insulated the convective thermal resistance at the inside and outside of the wall is relatively small and can be neglected. However, it is important to include the thermal convective resistance in the calculations of the heat loss through the polythene glazing, both because it is a relatively large part of the thermal resistance per unit area for this part of the construction and also because the polythene covers a dominating part of the total surface area of the greenhouse. The convective thermal resistance depends strongly on the wind speed.

Table 1.3 shows the thickness and thermal conductivity of the main materials that are used in greenhouse construction.

Table 1.3: Thickness and thermal conductivity of materials used in greenhouse construction.

Material	**Thickness (m)**	**λ-value (W/mK)**
Mud-brick	0.3 x 2 layers	1.28
Straw (insulation)	0.15	0.08
Polythene	0.006	0.5

Table 1. shows the thickness, total surface area, and the thermal transmittance of the two types of walls/glazing used in greenhouse construction.

Table 1.4 also shows the results of the heat loss calculations based on the following equation:

$$Q_t = U \cdot A \cdot (T_i - T_o)$$

where

Q_t = Total heat transmission losses through walls and roof (W)

U = Overall heat transfer coefficient or thermal transmittance (W/m2 °C)

A = Surface area of the greenhouse (walls and glazing material) (m^2)

T_i = Indoor design temperature (°C)

T_o = Outdoor design temperature (°C)

As shown in Table 1.4 the total heat loss is estimated to be 317 kW at design conditions when the outdoor temperature is -20°C.

Table 1.4: Heat loss from different construction components of the greenhouse.

Construction part	Thickness (m)	Surface area (m)	U-value (W/m^{2}K	Heat loss (kW)
Mud-brick wall	0.75	338.4	0.43	5.5
Polythene glazing	0.006	1,175	6.98	311.5
Total		1,513		317

1.5 Infiltration Heat Losses

The air change method is the general method for the calculation of infiltration heat losses. The method is based upon the number of times per hour (ACH) that the air in the greenhouse is replaced by cold air leaking from outside. The number of air changes, which occur, is a function of wind speed, greenhouse construction, and inside and outside temperatures. **Table 1.**5 outlines general ACH values for different types of greenhouse constructions, which can be used by the designers.

Table 1.5: Air Change per Hour (ACH) values for glazing/ cover materials (Lund, (1996))

Greenhouse cover material	Air Change per Hour (ACH)
Single glass	2.5-3.5
Double Glass	1.0-1.5
Fiberglass	2.1-3.1
Single Polythene	0.5-1.0
Double Polythene	0.0-1.0

After selecting the appropriate number from Table 1.5, the following equation is used to calculate the infiltration heat losses.

$$Q_i = V \cdot ACH \cdot c_p \cdot \rho \cdot (T_i - T_o)/3600$$

where

Q_i = Infiltration heat loss (W)

V = Volume of greenhouse (m^3)

ACH = Air change per hour

c_p = Specific heat capacity of air (J/kg °C)

P = Density of air (kg/m^3)

The Infiltration heat loss for the greenhouse is calculated as 30 kW.

The total heat load, Q, for the greenhouse can be calculated as the sum of the transmission heat losses and the infiltration heat losses as follows:

$$Q = Q_t + Q_i$$

The total heating load for the greenhouse is calculated as 347 kW.

The mass flow of geothermal water required to heat the greenhouse is given by the following equation

$$\dot{m} = \frac{Q}{C_p \cdot (T_i - T_o)}$$

For this greenhouse, the mass flow of geothermal fluid required at the design conditions is 2.2 kg/s.

The monthly heating requirement for the greenhouse is shown in **Figure 1.6**.

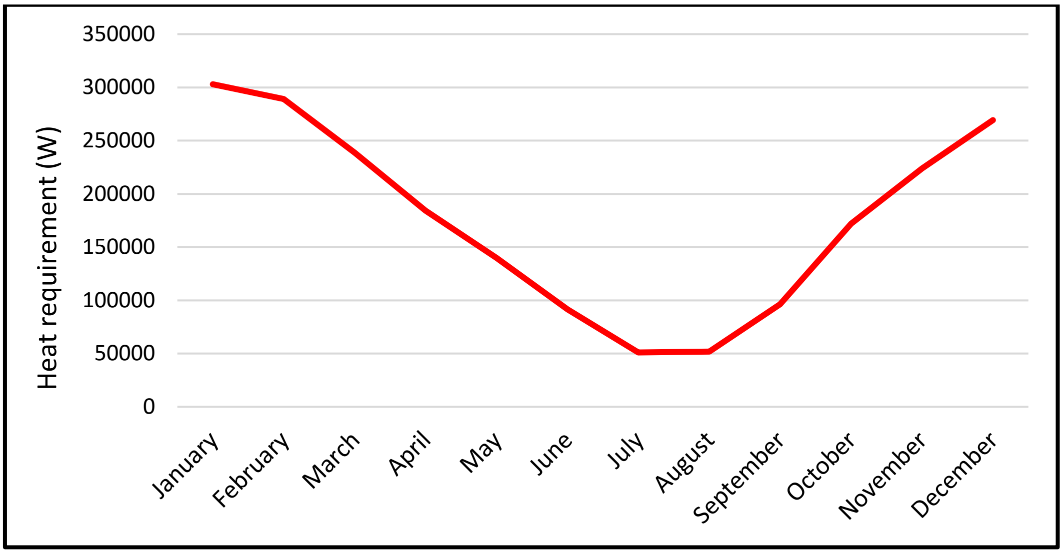

Figure 1.6: Monthly heating requirement for the greenhouse.

1.6 Heating systems

The heating systems can be classified according to the position of the heating installation as shown in **Figure 1.7**. The categories are the following:

- Heating systems in the soil.
- Heating systems laid on the soil surface or the benches.
- Aerial heating systems.
- Cascading.
- Combinations of the above

For the heating of this greenhouse pipes will be laid at the bottom of the bench, on the side walls and above the plant table like shown in Figure 1.7.

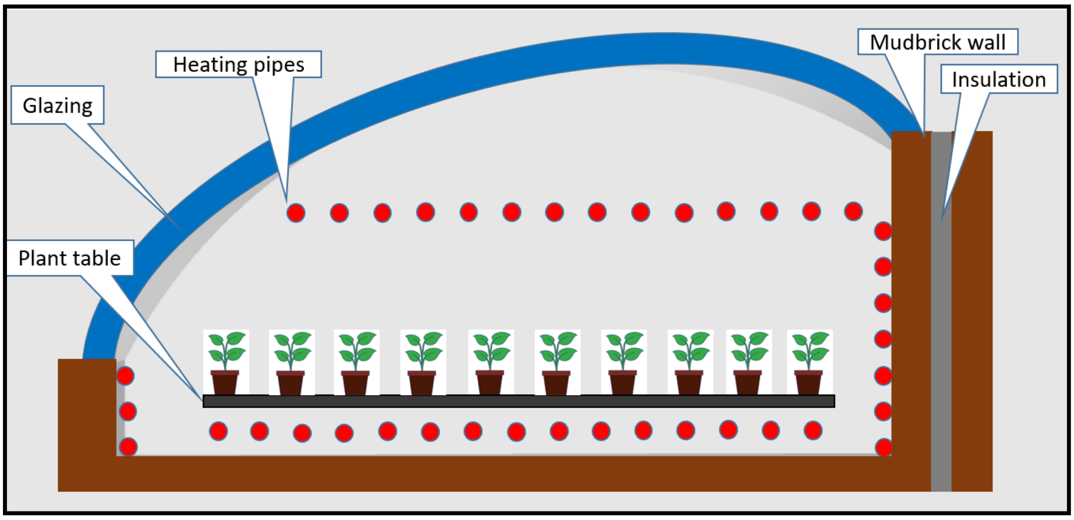

Figure 1.7: Heating pipes layout in the greenhouse.

Pipes will be of steel and 0.05 m diameter. This is selected due to its easy availability in the local market. This size of pipe is also used widely in the greenhouses in Iceland as found during the site visits, see Figure 1.8

Figure 1.8: Heating pipes under the plant benches, on the side of walls in an Icelandic greenhouse.

The length of the heating pipes required is calculated using equation from Lund, 1996, given by the following equation:

$$L = \frac{3.6 \cdot Q}{\left[4.422 \cdot \left(\frac{1}{D}\right)^{0.2} \cdot \left(\frac{1}{1.8 \cdot T_{ave} + 32}\right)^{0.181} \cdot (\Delta T)^{1.266} + 15.7 \cdot 10^{-10}\left[(1.8 \cdot T_1 + 32)^4 - (1.8 \cdot T_2 + 32)^4\right]\right] \cdot 11.345 \cdot A}$$

Where:

L	= Pipe Length (m)
Q	= Total Heating Load (W)
D	= Outside pipe diameter (mm)
T_{ave}	= 255.6 + (AWT + T_{air})/2 (°C)
AWT	= T_{wi} - ΔT/2 (°C)
T_{wi}	= Heating water supply temperature (°C)
T_{air}	= Greenhouse design inside air temperature (°C)
T_1	= 255.6 + AWT (°C)
T_2	= 255.6 + T_3 (°C)
T_3	= (AUST + T_{air})/2 (°C)
AUST	= Average temperature of unheated surfaces in the greenhouse (°C)
A	= Outside surface area of pipe /unit length (m^2/m)

Based on the above equation, the total length of pipe required to heat the greenhouse of 1,000 m^2 is 5,235 m.

Heat load analysis was done on greenhouse of size 1,000 m^2. It was assumed that the construction materials used will be available locally to make it more sustainable as well as economical. Table 1.6 Gives the summary of results of the greenhouse calculation.

Table 1.6: Summary of the results of greenhouse.

Greenhouse parameters	Symbol	Values	Unit
T inside,	T_i	18	°C
T outside,	T_o	-20	°C
Length, m	L	125	m
Width, m	W	8	m
Height, m	H	2,4	m

Area,	A	1,000	m^2
Volume, m3	V	2,400	m^3
Transmission heat loss	Q_t	313,825	W
Infiltration heat loss	Q_i	30,266	W
Total heat load	Q	344,091	W
Mass flow of geofluid	$\dot{m}$	2,163,168	kg/s
Length of pipe for heating	L	5,235	m

1.7 Cost analysis for Local greenhouse with heating

The LREDA commercial greenhouse design used in this project gives a positive NPV of 347276 USD as seen in **Figure 1.**9. This is mainly since the construction materials used are all locally available except for the glazing material and the piping materials which are transported from the plains of India. For the revenue, per unit cost of 1.5 USD is used. The breakeven point is achieved in the first year of operation. The CAPEX in this case is 0.0303 MUSD and the OPEX is 2121 USD per year.

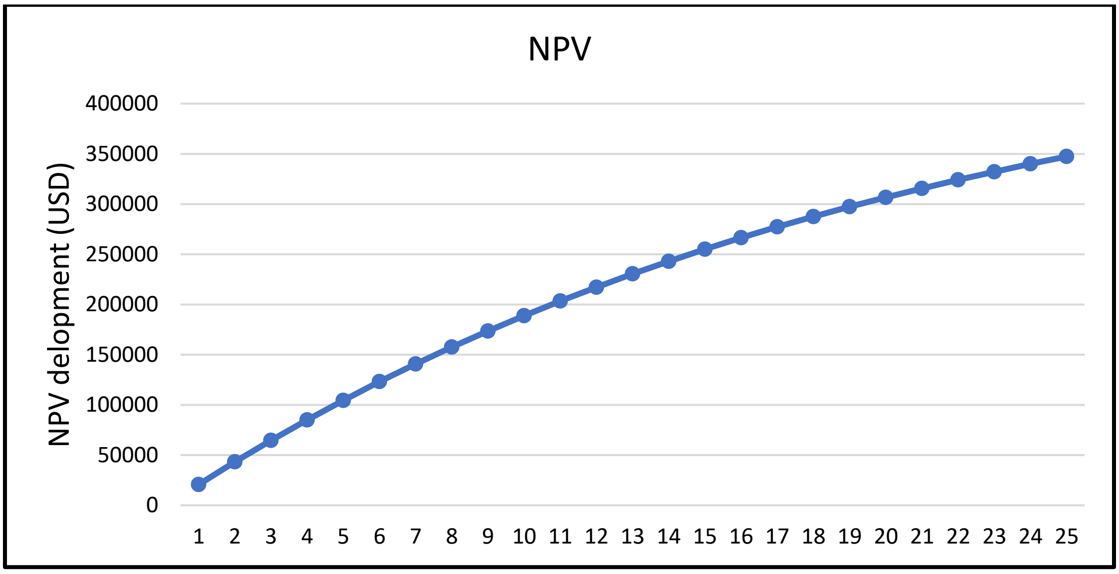

Figure 1.9: Development of NPV during the operation of the greenhouse.

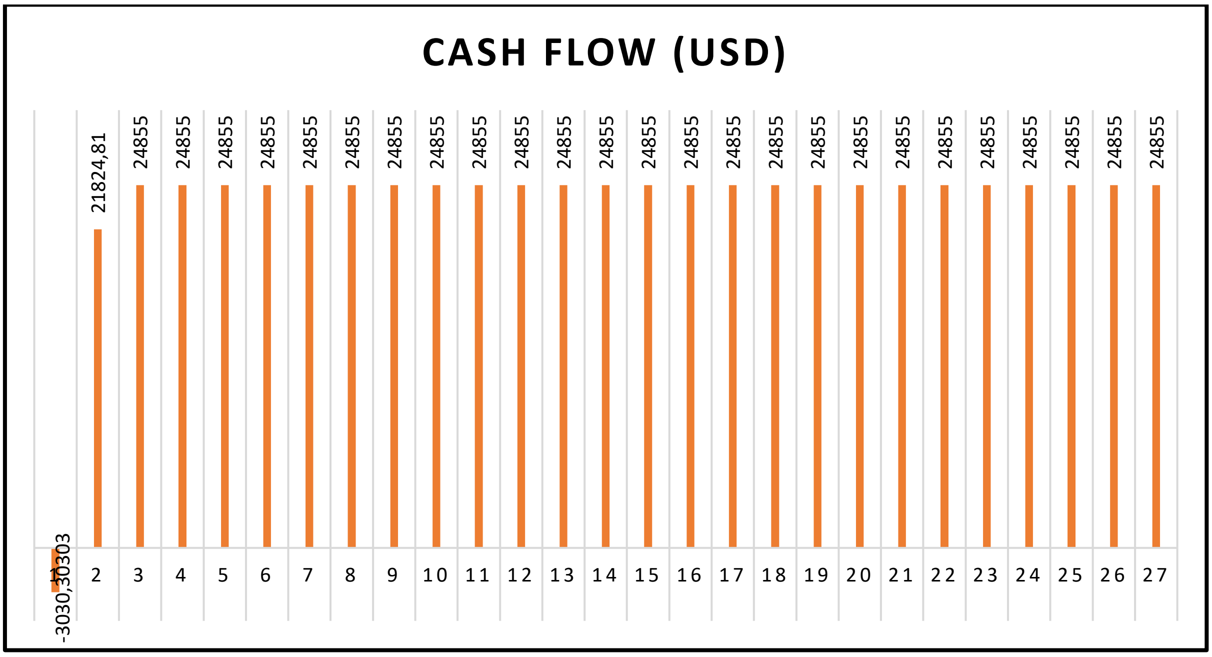

Figure 1.10: Cash flow during the operation of the Greenhouse in USD.

CONCLUSION

Table 1.7 gives the conclusion of the paper in terms of fulfilment of the United Nations Sustainable Development Goals (UNSDGs).

Table 0.1: United Nations Sustainability Development Goals (UNSDs) met through this project

United Nations Sustainability Development Goals (UNSDGs)	How is it met
SDG 2 (Zero hunger)	By having fresh vegetable supply through the greenhouse
SDG 5 (Gender equality)	Women will get a much better quality of life due to access to clean energy.
SDG 7 (Affordable and clean energy)	By having access to clean energy
SDG 9 (Industry, innovation, and infrastructure)	Having 24-hour access to reliable energy will lead to setting up of industries leading to more employment opportunities
SDG 13 (Climate change)	Geothermal is a clean and reliable source of energy compared to fossil fuels and has much fewer emissions hence helping fight climate change.

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