DESK RESEARCH ON HEATING SYSTEMS FOR APPLICATION IN SCHOOLS

Research & Development Division

Department of Renewable Energy

Ministry of Economic Affairs

June 2018

Executive Summary

With the early resuming of schools in the country, there was an increase in the number of Chilblain cases as reported in the March 22, 2017 issue of the Kuensel. Over 241 students were reported with the cases of chilblain in Thimphu, Paro and Wangdue dzongkhags. With due concern, the Ministry of Education has been making an effort to provide adequate heating facilities the schools in the colder regions. With directives from the Department, the Research & Development Division undertook the activity to conduct research of providing heating facility using renewable energy sources. This desk study is a preliminary research which has been conducted, explores the feasibility of introducing three technologies namely geothermal heat pump, air source heat pump and solar water heating systems.

The Country has 575 schools (as per the Annual Education Statistics 2017[1], Ministry of Education, Bhutan), which includes only primary, lower, middle, higher and central schools in the 20 districts. About 4% of the schools are located in regions where the winter sets in for longer duration and they are listed as priority by the Ministry of Education to address the heating requirements. In 2017, due to the change in the timings of academic sessions from February 5 by the Ministry of Education, the schools have to reopen while the winter cold is still at the peak in some areas of the country resulting in the outbreak of chilblain and has led the concerned authorities to look into alternative solutions to provide/improve the heating systems.

This desk research is aimed understand the geothermal heat pump, air source heat pump and solar water heating systems and to see the applicability of it in the schools of Bhutan to address the chilblain.

[1] *http://www.education.gov.bt/documents/10180/317343/17th_AEC.pdf/55d1c8c1-9aa6-43f9-b208-b9a72076c0d8?version=1.0*

LIST OF ACRONYMS

ACCA	Air Conditioning Contractors of America
ASHP	Air Source Heat Pump
BTU	British Thermal Unit
CoP	Coefficient of Performance
DRE	Department of Renewable Energy
ft	Feet
^{o}C	Degree Celsius
GHP	Geothermal Heat Pump
kW	Kilo Watt
kWh/yr	Kilo Watt Hour per year
M	Million
masl	Meters above sea level
MPH	Multi-purpose Hall
Nu.	Ngultrum
sq. ft	Square feet
Sq.m	Square meter
SWH	Solar Water Heaters

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1. INTRODUCTION

1.1 BACKGROUND

Bhutan is a small, mountainous country with altitude ranging from 160 meters to more than 7000 meters above mean sea level. Temperatures vary accordingly with the elevation. The climate is humid and subtropical in the southern plains and foothills, temperate in the inner Himalayan valleys of the central regions, cold in the north, with year-round snow on the main Himalayan range. From late November to March, winter sets in with frost throughout most parts of the country often with multiple snowfalls leading to a high energy demand for heating requirements. It is also around this time that the electricity demand is at its peak while the generation capacity drops to its lowest levels due to reduced discharge in the river system. Therefore, introduction of energy efficient heating system is expected to contribute in meeting the energy demand and lower the peak electricity demand during the lean season.

Over the time, the Country has seen an increase in number of cases of chilblain outbreaks in schools of colder regions[2]. Chilblains are lumps on the skin, which come up as an abnormal reaction caused due to exposure in sustained cold conditions[3]. The academic session for the schools starts by 1st week of February where the winter is still at its peak and the prevalence of chilblain cases in the schools has been reported due to lack of adequate heating systems. Currently, the measures taken by the schools include providing electric room heaters in the classrooms and carrying out classes outside during sunny days. The outbreak of chilblain in schools has become a serious concern, which led the concerned authorities to look into alternative solutions to provide/improve the heating systems.

The Department of Renewable Energy (DRE) as a nodal agency for the promotion of renewable energy and energy efficiency measures is looking into addressing the cold and inadequacy of the heating systems in the schools primarily through introduction of renewable energy technologies. This study provides the various heating systems and its applicability in schools.

1.2 RESEARCH OBJECTIVES

- To understand the applicability and relevance of various space heating technologies that are available in the market in Bhutanese context,
- Recommend various energy efficient heating technologies to address the chilblain outbreak in the schools.
- To provide energy efficient heating systems in the schools with due consideration for availability of space, heating requirements and environmental and social impacts.

[2] *Source: Kuensel dated 22 March and 10 April 2017.*
[3] *Source: Kuensel, 12 April 2017*

2. METHODOLOGY AND APPROACH

The study focuses on the literature review (desktop study). Visits to four schools were carried out to study the heating requirements and feasibility of various heating systems in the schools. Basic merits and demerits were studied and the environmental impact has been researched. The research also presents estimated cost of various systems based on the information acquired from the Internet as per the executed projects in other parts of the world.

2.1 LITERATURE REVIEW

Due to the insufficient thermal protection in the majority of buildings, space heating is the major energy consuming activity in the building sector. The fact combined with the limited market availability of the newest technology and the growing electricity rate has caused concerns with the high expenses required for the purpose of heating. Nowadays a variety of technologies are available, with each heating system having distinct advantages and disadvantages, therefore it is necessary to examine various alternatives before the final selection and installation.

While no screening tool has been applied to derive the following technologies, the desktop study selected Ground Source Heat Pump (GSHP), Air Source Heat Pump (ASHP) and Solar Water Heating for the following reasons:

1. Heat pumps are being widely used in other countries and are highly recommended by most studies, therefore in order to study the applicability and pilot the heat pumps (in future) in Bhutan; the desktop research includes two heat pumps, GSHP and ASHP.
2. Solar water heating system has been installed in a lot of places in the country for hot water. The system, however, has never been used for space heating. With this desktop research and future piloting perspective, it was a good opportunity to explore the possibilities of using solar water heating system for space heating along with hot water.

In general, a heating system must ensure the following:

1. The operative temperature within the thermal comfort zone must be as uniform as possible, in the range of 20 to 23°C
2. Indoor air quality must be maintained in acceptable levels. The system must neither release dust, harmful gases and odors nor create air draughts or noise.
3. The use of the system must be easy and the maintenance simple.
4. The operation of the system must not put in danger the building and its occupants, even in the most adverse conditions.
5. The investment and operation costs should be low and the lifetime of the equipment satisfactory.

The three technologies used for the desktop studies fulfils the above general requirement

2.1.1 GEOTHERMAL HEAT PUMPS

Generally a heat pump is a device, which runs on electricity that transfers heat from a source of heat to a destination mostly called "heat sink". A heat pump transfers heat from warmer place to colder place and vice versa. A heat source can be a heater when the objective is to warm the heat sink and it can be an air conditioner when the objective is to cool the heat source.

Geothermal heat pump uses the earth's heat and simply transfers the heat from and to the earth. As the season changes, the outside temperature on the surface also changes accordingly, but four to six feet below ground, temperatures remain relatively constant year-round due to the insulating properties of the earth. A geothermal heat pump uses the same principle as that of a refrigerator, and transfers heat from the ground to the house (or vice versa). It does this through long loops of underground pipes filled with liquid (water or an antifreeze solution). The loops are hooked up to a geothermal heat pump in the home, which acts as both a furnace and an air conditioner.

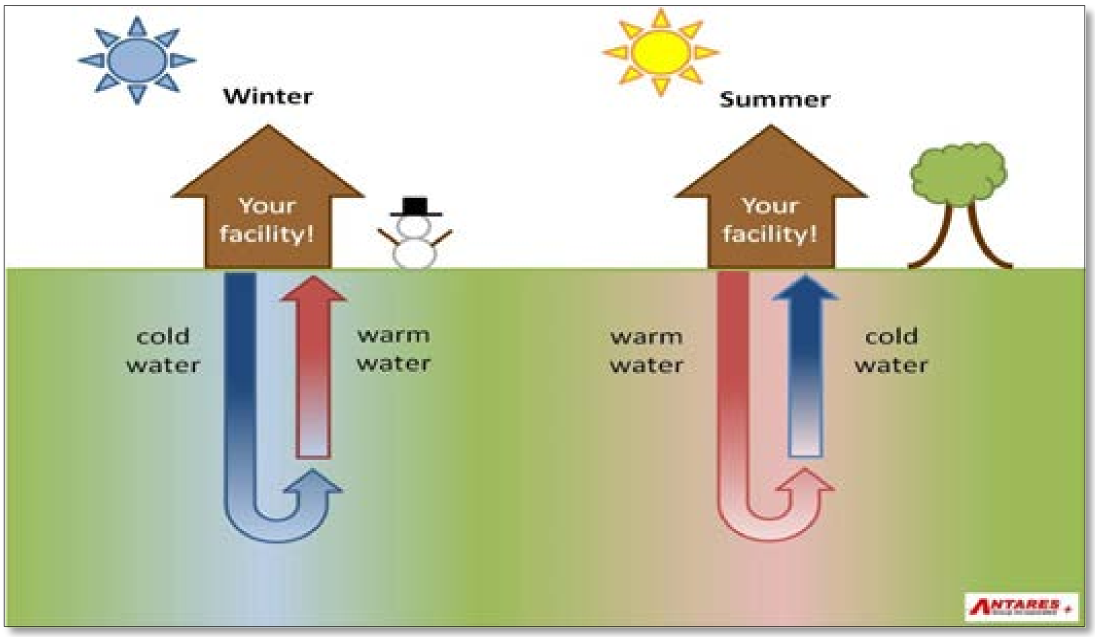


Figure a: Basic working of geothermal energy for heating and cooling[4]

Geothermal heat pump have some major advantages, it can reduce energy use by 30%-60%, control humidity, are sturdy and reliable, and fit in a wide variety of homes.
The geothermal heat pump consists of following components

1. Heat exchanger (evaporator)
2. Compressor
3. Heat exchanger (condenser)
4. Expansion valve

[4] *https://coopermech.com/geothermal-heating-and-cooling/*

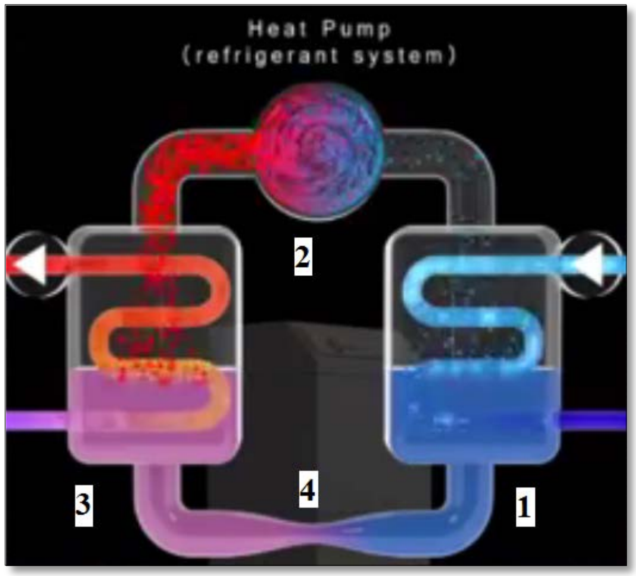


Figure b: Working principle of ground source heat pump[5]

Cold water with antifreeze agent is sent through the ground loop, the constant low grade heat of the ground increases the water temperature. This water is then fed to a heat exchanger called the evaporator. Evaporator contains refrigerant which is a heat transfer fluid. When the water enters the refrigerant the refrigerant boils due to the heat from the water loop and turns into gas. The gas rises to the compressor where the pressure is increased which in turn increases the temperature of the vaporized refrigerant. The high temperature vaporized refrigerant then flows to the second heat exchanger called the condenser. Condenser has heat distribution system connected to it which is heated by the vaporized refrigerant. After the heat transfer the refrigerant condensed to liquid. The liquid refrigerant is then passed through expansion valve to further reduce the pressure and temperature and the cycle is continued. Geothermal source heat pump also has water to water heat pump and water to air heat pumps with same working principles, the choice of heat pump depends on the type of heat distribution to be selected.

Geothermal Loop System

A geothermal system typically consists of an indoor handling unit and a buried system of pipes. The pipes that make up an earth loop are usually made of polyethylene and are buried under the ground (in different ways) depending on the characteristics of the site and thereby making up the following types of layout:

A. Horizontal closed loop system:

This type of installation is generally cost-effective for new construction and is applicable where there is sufficient land for trenching. It requires deep trenches (depending upon the condition of the soil and heating load of the building). Then the polyethylene pipes are looped

[5] *https://www.kensaheatpumps.com/how-a-ground-source-heat-pump-works/*

by laying horizontally in the trenches in any of the following ways to draw heat from the ground.

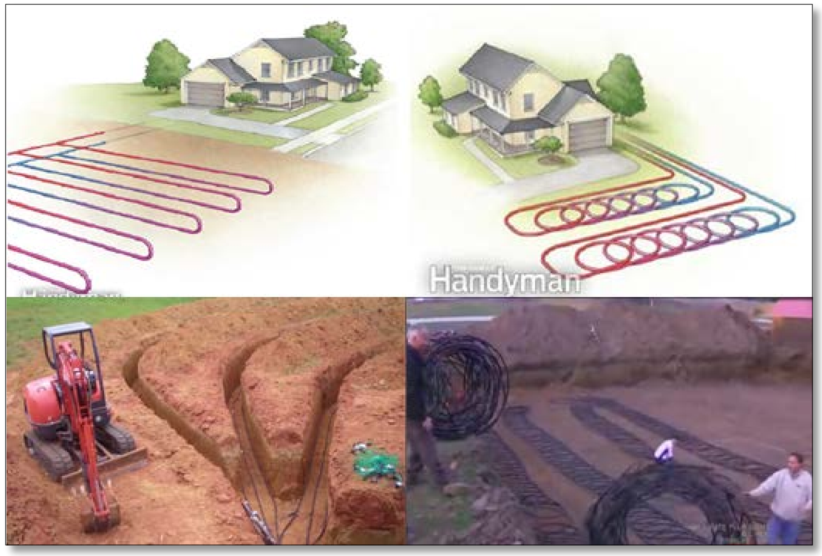


Figure c: Horizontal closed loop system[6]

B. Vertical closed loop system:

This type of installation is more suited for a location where land is limited, where the soil is too shallow for trenching and when existing landscape has to be retained. For a vertical system, holes (approximately four inches in diameter) are drilled about 20 feet apart and 100 to 400 feet deep (depending on the condition of the soil and heating load of the building). Into these holes go two pipes that are connected at the bottom with a U-bend to form a loop. The vertical loops are connected with horizontal pipe (i.e., manifold), placed in trenches, and connected to the heat pump in the building.

Figure d: Vertical closed loop system

[6] *https://www.familyhandyman.com/heating-cooling/5-things-to-know-about-a-geothermal-heat-pump/view-all/*

Since GHP used the earth's heat to provide space heating, the space availability to lay the pipe loops is the one of the basic requirements along with thermal conductivity of the surrounding soil, local ground water availability and temperatures. For best efficiency, proper insulation of the building is highly recommended. Since, no or limited GHP are installed till date, it is vital to assess the market availability of the system from the nearest countries in order to reduce the transportation cost.

2.1.2 AIR SOURCE HEAT PUMPS

An air source heat pump (ASHP) is another very efficient heat pump, which extracts heat from the atmosphere and distributes inside the building. It runs on electricity but has a very high coefficient of performance (CoP), which is one of the most prominent advantages of air source heat pumps. It is important to note that air at a temperature above absolute zero always contains some heat, which is extracted by ASHP. However, there are many of these pumps available, which can extract heat even at low temperatures as **-15 to -20 C** degrees.

Figure e: Example of Air Source Heat Pump Installation[7]

An average ASHP has an outside unit, a pump itself and a water storage and distribution system. The air from the environment is drawn through the outside heat pump unit by a fan.

[7] *http://isle-eco.com/air-source-heat-pumps/*

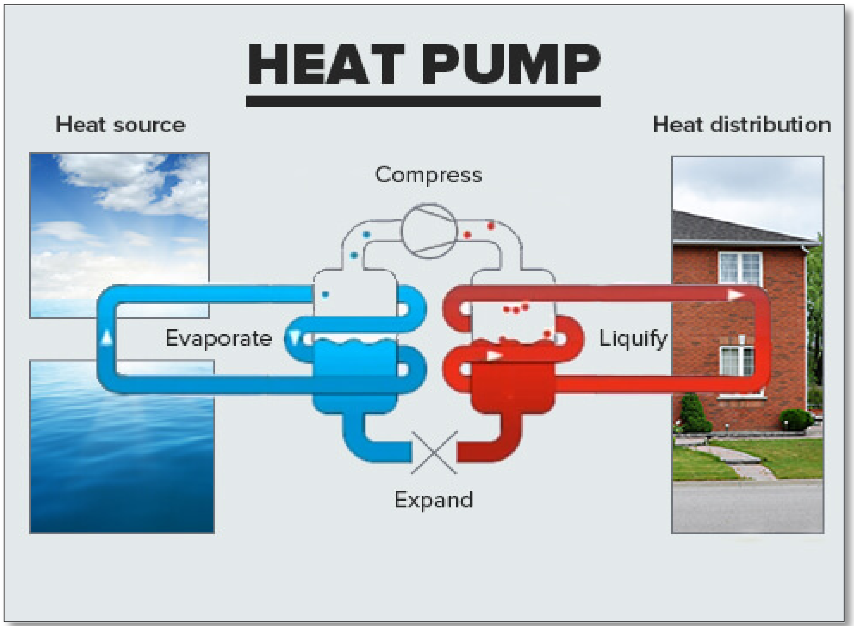


Figure f: Working Principle of Air Source Heat Pump[8]

The working principle of the heat pump is similar to that of GHP. The heat is transferred and transported by the refrigerant, which flows over the heat exchanger, coils in two forms – gaseous and liquid states. Inside the heat pump unit, there is a closed-looped system that has evaporation and condensation cycles for a refrigerant to go through. When the heat gets into the loop it is carried by a refrigerant to the evaporation point. Once the refrigerant is vaporized it then goes to a compressor where the temperature of the absorbed heat is significantly increased by means of high pressure. The high-temperature vapour is brought inside the second coil by a condenser to be released via water storage and distribution system to warm your home. When the refrigerant cools down, it turns back into a liquid state and the cycle starts over again.

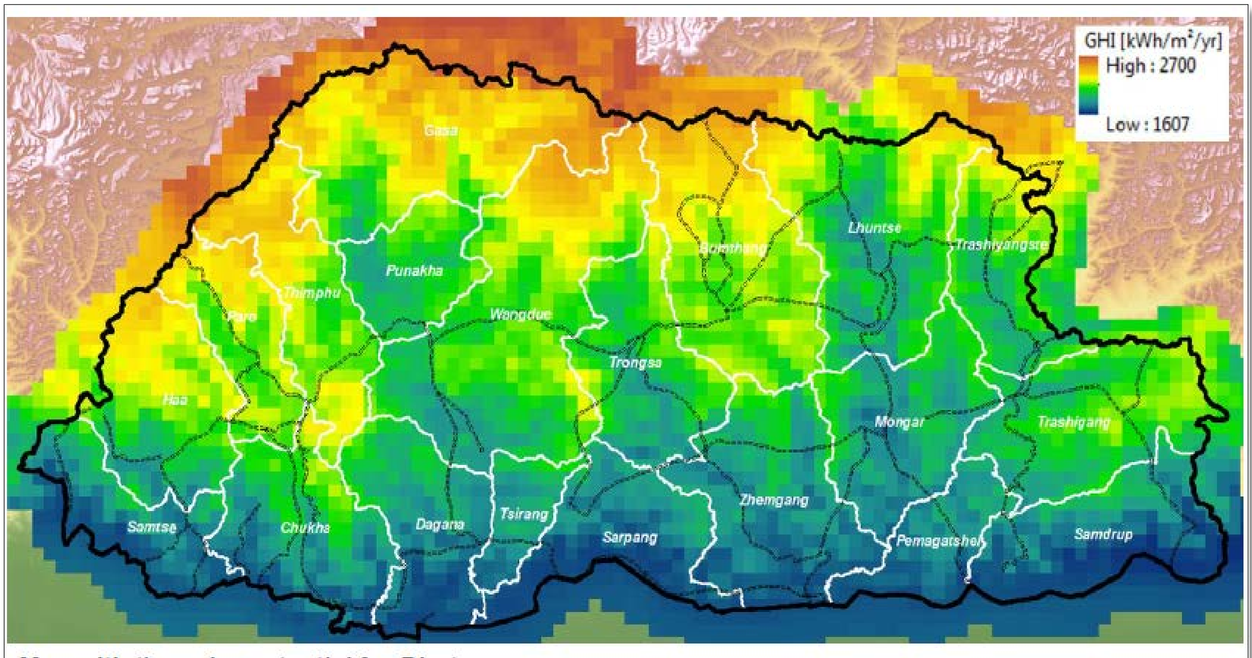
Followings are certain points to be considered while opting for an Air Source Heat Pump.

- While the pump itself is not overly bulky, it will require a decent amount of space around it to draw in the air. A sun facing wall with plenty of space is ideal.
- As with other renewable energies, it's wise to fully insulate the building for maximum energy efficiency.
- Unlike traditional heating, ASHP work better with options such as under floor heating rather than normal radiators because of the lower water temperatures used.

[8] *http://airsourceheatpumptsushiten.blogspot.com/2017/07/principles-of-air-source-heat-pump.html*

2.1.3 SOLAR WATER HEATING

The resource assessment carried out in 2014 showed that Bhutan receives sun radiation of 1607 kWh/m^2/yr to 2700 kWh/m^2/yr especially in the northern part of the country as shown in Figure 2. The target schools mostly lie in the area where solar radiation is from medium to high. Therefore, it is possible to tap solar energy for the purpose of heating. However, other factors such as the local terrain, weather, and cost among others should be taken into consideration. This study is limited to the existing technology successfully implemented in other countries based on which this theoretical feasibility analysis has been carried out.



Map with the solar potential for Bhutan

Figure g: Solar potential for Bhutan[9]

SWH prefeasibility study may contain not limiting the following factors:

- South facing shadow free space availability (On roof as well as on ground)
- Type of roof (Flat/Slopping) (RCC/Tin)
- Water Quality (Hardness of water)
- Solar Insolation
- Heat demand and forecast
- Month wise occupancy details (for hotels, hospitals & institutions)
- Estimated length of pipeline required for hot water distribution which can be used proportionately for hot water consumption and space heating.

9 *Source: Renewable Energy Master Plan, DRE*

Solar water heating (SWH) system is not a new technology in the country; however, using the system for the purpose of space heating hasn't been installed yet. There are various types of SWH with the following comparison:

Table 1: Various types of SWH

System Type	Climate & Description	Advantages	Disadvantages	Installation
Integral Collector Storage (ICS)	Passive: Open loop for mild climates	Simplicity; lowest cost	Poor freeze protection; poor tank insulation	Heavy units; easy to install; can have cosmetic-appearance issues
Thermosyphon	Passive: Open loop for mild climates; closed loop can be used in harsh climates	Simple open loop; tank is insulated	Open loop has poor freeze protection; closed loop needs a heat exchanger; potable water lines to collector subject to freezing	Very heavy systems; easy to install; can have cosmetic-appearance issues
Direct Pump: Direct circulation	Open loop for mild climates only	Simple active system; can be PV powered	Poor freeze protection; freeze valves can give false security	Easy installation; needs electrical source
Drainback: Closed loop, forced circulation	Closed loop for all climates	Simple system when compared to antifreeze systems; limited overheating	Needs a high-head pump and heat exchanger; harder to power with PV	Slope of collectors and piping is critical
Closed-Loop Antifreeze: Forced circulation	Closed loop for all climates	Best freeze protection; easily PV powered	Most complex; can have overheating problems; needs a heat exchanger	Most difficult installation

3. MERITS & DE-MERITS OF THE SYSTEMS

Table 2: Merits & De-merits of each system

Type of heating system	**Merits**	**De-merits**	**Coefficient of Performance (CoP)**
Geothermal Heat Pump (GHP)	-Clean way to heat structures -Makes efficient use of thermal energy in the ground -They have a long lifespan with proper care -Safe and silent technology -Heat pumps can provide heating in winter as well as cooling in summer	-Expensive to install -Requires more space -Requires thorough study of movement of heat in ground and local geology. -Thermal modelling required to match the ground loop and the heating requirement	-For a ground source heat pump it is expected that a typical seasonal performance factor is about 4-5. That means the changing seasons do not have any impact on the performance of the system.
Air Source Heating Pump (ASHP)	-Can also be powered by wind energy or solar power -Can deliver heat at a lower temperatures at -15^{o} C to -20 ^{o} C -They have a long lifespan with proper care -Ease and faster installation -Provides cooling in the summer and heating in the winter	-They perform better with underfloor heating or warm air heating and work more efficiently when coupled with larger radiators -Highly insulated home is required to reap the high energy savings benefits -Noisy like an air conditioner when it is running -Efficiency is reduced during extreme winter	-For an air source heat pump it is assumed that a typical seasonal performance factor is 2.5 – 2.8. This takes into account that during the cold winter, the CoP will fall well below the 2.5 level, but during the summer it might be as high as 4

Solar water heating system	-Renewable source -Energy stored can be used at night -Efficient -Ease in installation	-Low market availability (as a room heating system) -Retrofit of structures required to lay the water pipes -The current SWHs in the country do not have energy storage facility	-Solar heating system uses free energy. Solar energy is free and abundant (even in cloudy weather). They are efficient and approximately 80% radiation is turned into heat energy.

4. SOCIAL AND ENVIRONMENTAL IMPLICATIONS

Ground Source Heat Pump:

Geothermal is a source of renewable energy, which doesn't produce pollution. The loops are laid deep underground and operate safely without any harmful emission thereby not causing any environmental concerns.

The excavation works at the initial stage may cause dust and noise pollution which can however be controlled. The life span of the loops is very long (if the installations are done properly), thereby eliminating the repetitive digging of the ground for maintenance.

Apart from that, since the compressor and heat pump functions like any refrigerator, the system can be installed indoor which eliminates any disturbance to the neighbors unlike other heavy duty Heating, Ventilation and Air Conditioning (HVAC) system.

Air Source Heat Pump:

Air source heat pumps are also widely used outside Bhutan and is quite popular in heating and cooling system, however not many are installed in the country and thus like GHP, this system is also fairly new for a lot of people and institutes in the country.

ASHP does not produce any pollution; however the pump produces noise while operating which can be disturbance for the resident and nearby settlements.

Solar Water Heating:

Solar water heating systems are already in place in Bhutan, and it is normally used for heating water. A lot of the houses in rural areas and institutes in the colder regions have the system installed under various funding and programs. The general public is aware of the system and has accepted the system as one of the green technologies. However it is important to note that the solar water heating systems used in the country is primarily for hot water for bathing and washing. Heating the buildings using solar water heating system has not been executed as of now.

Since solar water heating taps solar energy and heats the water, except for the disposal of the solar collectors (which will take up to 20 years), there is no environmental impact of installing the system.

5. APPLICABILITY OF THE HEATING SYSTEMS IN EACH SCHOOLS

There are 21 schools listed as priority by the Ministry of Education for providing heating system. Out of 21 schools 4 schools were short listed for the site visit using the following criteria:

a. Accessibility of the school for the assessment of the site, transportation and monitoring of the system.
b. Land availability to install the system
c. Number of beneficiaries from the project
d. Manpower availability for the operation and maintenance at site

5.1 GROUND SOURCE HEAT PUMP IN SCHOOLS

Geothermal heat pump (GHP) is a fairly new technology in the Country and there is no record of any system being installed till date. For the purpose of calculating the size of the heat pumps, the study resorted to standards, rules and costs from other countries. The guiding standard for installing any air conditioning system is taken from Air Conditioning Contractors of America (ACCA) manual[10] according to which the four major steps for designing a GHP are:

i) Heat loss/Gain calculations

General Thumb rule as per the ACCA manual J for calculating heat loss/gain is that 16 to 23 British Thermal Unit (BTUs) of heat loss occurs per square foot per hour. Assuming that the peak heat loss for the schools is 20 BTUs, the total heat loss from the academic blocks and the hostels can be determined as below:

*Total heat loss = Area of the structure * peak heat loss per sqm per hour*

ii) Size of the heat pump

As per the ACCA manual J standards, 12,000 BTUs per hour is One Ton of capacity of the GHP. The design and installation of geothermal systems are not do it yourself projects and therefore require the services of a professional. In addition, the integration of geothermal exchange systems with other systems in a home requires special expertise. Geothermal heating system price varies depending on the type of loop system, usually either vertical or horizontal. On average, a typical home of 2500 square feet, with a heating load of 60,000 BTU will cost from $20,000 to $25,000 to install[11]. The cost of heat pump is only about 20% of the total cost[12].The payback for a system can range from 2-10 years, while the lifetime of a system can be 18-23 years.

iii) Size of the loop field

The main considerations that determine the depth of borehole is needed or feet of horizontal tubing, is the deep earth temperature, soil characteristics, and site

[10] *https://blog.heatspring.com/how-can-i-design-geothermal-systems-a-4-step-guide-to-designing-geothermal/*
11 http://www.energyhomes.org/renewable-technology/geoinstallation.html
[12] *https://www.greenmatch.co.uk/heat-pump/ground-source-heat-pump/ground-source-heat-pump-prices#1st*

characteristics. However, it's a standard rule of thumb to have 150 to 200 feet for vertical borehole per ton and between 400 to 600 feet for horizontal pipe loop per ton.

iv) Determining the distribution method
The distribution of the heat can be done by two ways; water and air. The water/air running through the loops transfers heat from the ground to the pump.

a) *Gongzim Ugyen Dorji Central School*

- Gongzim Ugyen Dorji Central School in Haa Dzongkhag
- 27°23′03.86″N 89°16′56.53″E Elev 8891 ft
- Established in 1913.
- 579 students
- School area 11.83 acres
- Current heating system: mix of oil-filled column heaters of 1.5 kW rated capacity and oil-filled panel heaters of 2 kW rated. Used for 12 hours daily in November, December, February and March (during cold days)

Figure h: Aerial view of Gongzim Ugyen Dorji Central School (google map: 2003)

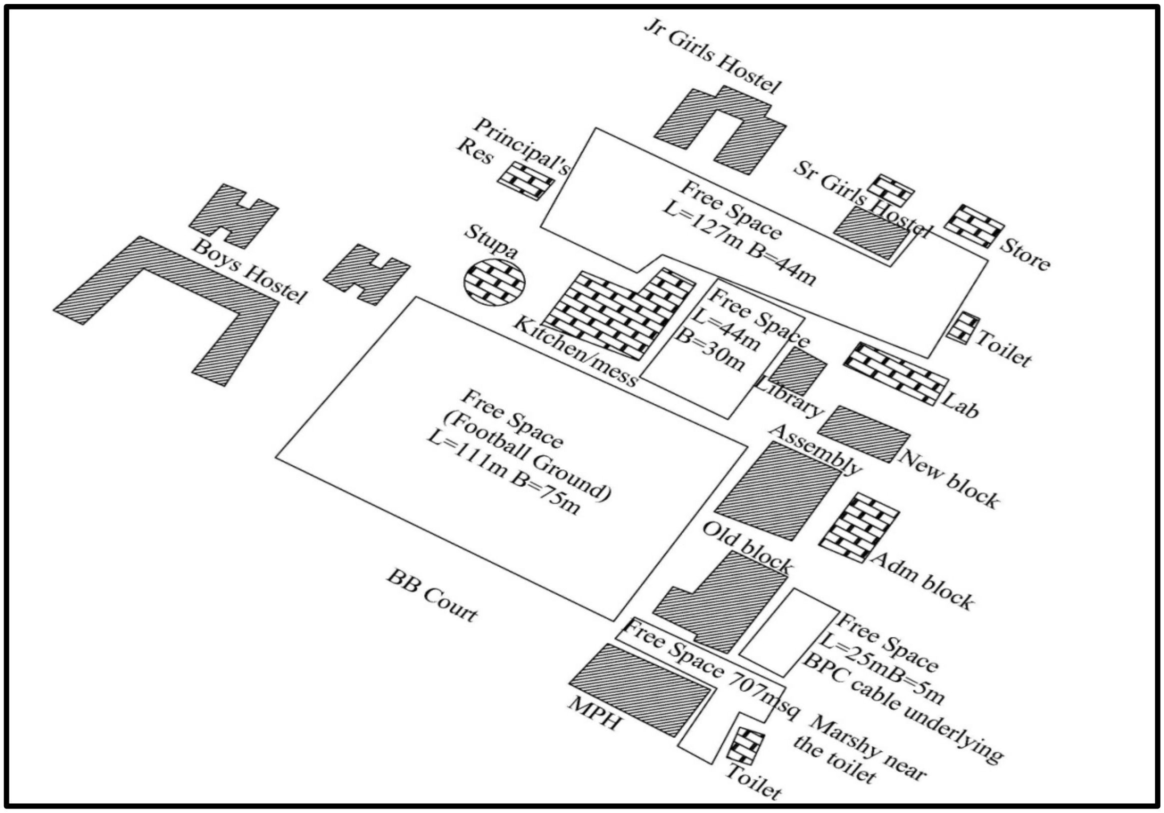


Figure i: Sketch map of Gongzim Ugyen Dorji Central School

Sizing the heating systems

Total plinth area to be heated is **1476 m^2** which includes Old Academic Block, New Academic Block, Library and Multipurpose hall

Using the above mentioned calculations, the sizing of GHP for Gongzim Central School was calculated as show below:

Table 3: GHP capacity for Gongzim Central Shool

Building type	Total area	Total Heat loss	GHP capacity
Old Academic Block	1008 m^2 ≈ 10846 ft2	= 1,008 sq.ft* 20 BTUs =20,160 BTUs per hour	$\frac{20,160}{12,000} \approx 2\ ton\ unit$
New Academic Block	180 m^2 ≈ 1937 ft2	= 1,937 sq.ft* 20 BTUs =38,740 BTUs per hour	$\frac{38,740}{12,000} \approx 3\ ton\ unit$
Library	108 m^2 ≈ 1162 ft2	= 1,162sq.ft* 20 BTUs =23,240 BTUs per hour	$\frac{23,240}{12,000} \approx 2\ ton\ unit$

Multipurpose Hall	180 m^2 ≈1,937 ft2	= 1,937 sq.ft* 20 BTUs =38,740 BTUs per hour	$\frac{38,740}{12,000} \approx 4\ ton\ unit$

In total, if the whole school is to be heated using GHP, the estimated size of the heat pump would be **11 ton unit**.

The spaces available for the installation of GHP are free space infront of the girls' hostel (5588 m^2), inbetween kitchen and library (1320 m^2), behind the old academic block (125 m^2) and Football ground (8325 m^2).

The most potential site recommended is the football ground[13] since it is centrally located with rest of the structures as seen in the map above. If the site is to be chosen, the total capacity required to target the above four structures can be clubbed together in one system of 11 ton unit.

Since the hostels were not prioritized by the school, it has been not included in this study.

b) Jakar Higher Secondary School, Bumthang

- Jakar Higher Secondary is located in Jakar, Bumthang
- 27°32′48.57″N 90°44′23.50″E Elev 8907 ft
- Established in the year 1961
- 523 students
- Area of 36 acres
- Current heating system: Siemens Panel Heaters of 1.5 kW rated. Used 7 – 8 hours daily in November, December, February and March months (during cold days).

[13] *GHP pipes will be laid underground which will not affect the functionality of the football ground*

Figure j: Aerial view of Jakar Higher Secondary School (google map:2003)

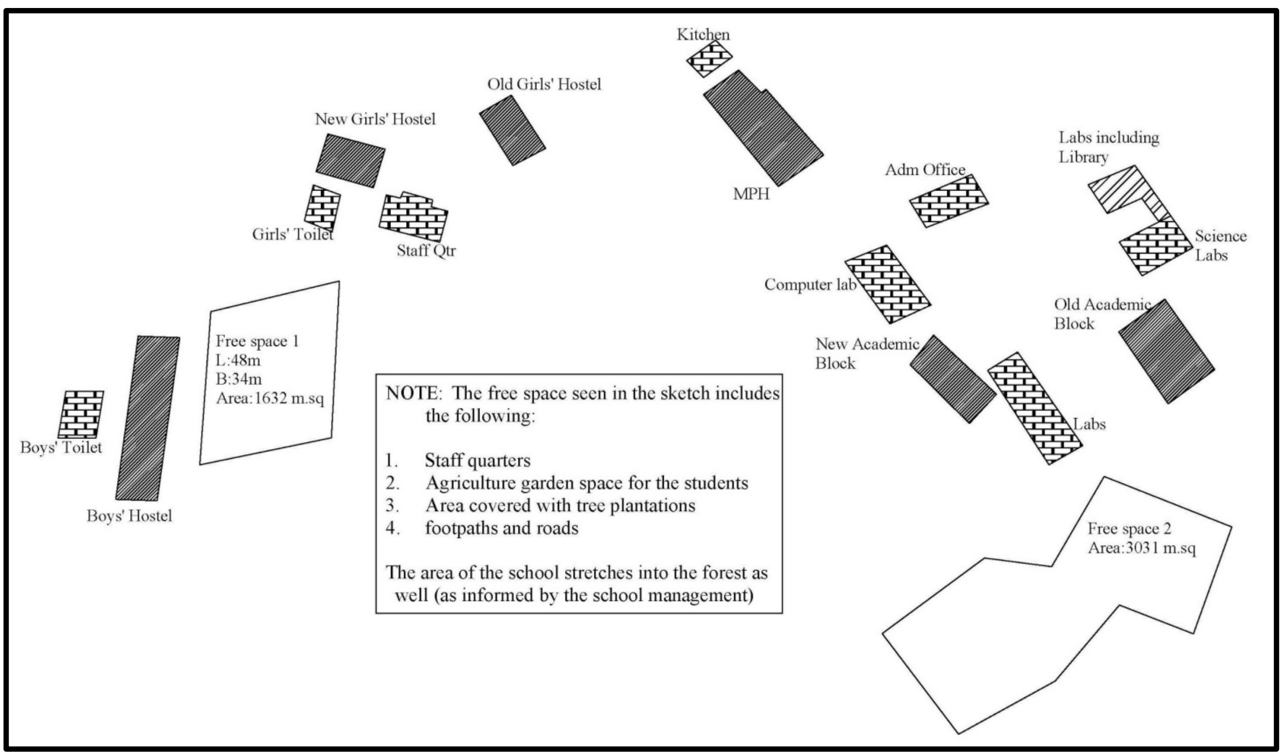


Figure k: Sketch map of Jakar Higher Secondary School

Total plinth area to be heated is **1921.8 m^2** which includes Old Academic Block, New Academic Block, Girls' New Hostel, Girls' Old Hostel and Boys' Hostel

Sizing the heating systems

The sizing of the GHP for Jakar Higher Secondary School is calculated as follows.

Table 4: GHP capacity for Jakar Higher Secondary

Building type	Total area	Total Heat loss	GHP capacity
Old Academic Block	595 m^2 ≈6402.2 sq.ft	= 6,402.2 sq.ft* 20 BTUs =128,044 BTUs per hour	$\frac{128,044 + 77,480}{12,000} \approx 17\ ton\ unit$
New Academic Block	360 m^2 ≈ 3874 sq. ft	= 3874 sq.ft* 20 BTUs =77,480 BTUs per hour	
Girl's New Hostel	240.8 m^2 ≈ 2591 sq. ft	= 2591 sq.ft* 20 BTUs =51,820 BTUs per hour	$\frac{51,280}{12,000} \approx 5\ ton\ unit$
Girl's Old Hostel	330 m^2 ≈ 3550 sq. ft	= 3550 sq.ft* 20 BTUs =71, 000 BTUs per hour	$\frac{71,000}{12,000} \approx 6\ ton\ unit$
Boy's Hostel	396 m^2 ≈ 4261 sq. ft	= 4261 sq.ft* 20 BTUs =85,220 BTUs per hour	$\frac{85,220}{12,000} \approx 7\ ton\ unit$

In total, if the whole school is to be heated using GHP, the estimated size of the heat pump would be 35 ton unit.

The spaces available for the installation of GHP are free space behind the old academic block 3031 m^2 and free space in front of the boy's hostel 1632 m^2

Since the two academic blocks are closely constructed, one GHP of 17 ton can be installed for providing heat to these two blocks. For the boys hostel a 7 ton GHP can be installed in the free space. For the Girls' hostels, since there was limited space (for laying the piping) installation of GHP for the two buildings is not recommended.

c) Chumey Central School, Bumthang

- Chumey Central School in Bumthang
- 27°29′38.00″N 90°42′41.13″E Elev 9178 ft
- Established in the year 1983.

- 460 students
- School area is 35.52 acres
- Current heating system: Wall mount electric heaters (1.5 kW each) in few of the class rooms. Used for 8 hour daily during winters.

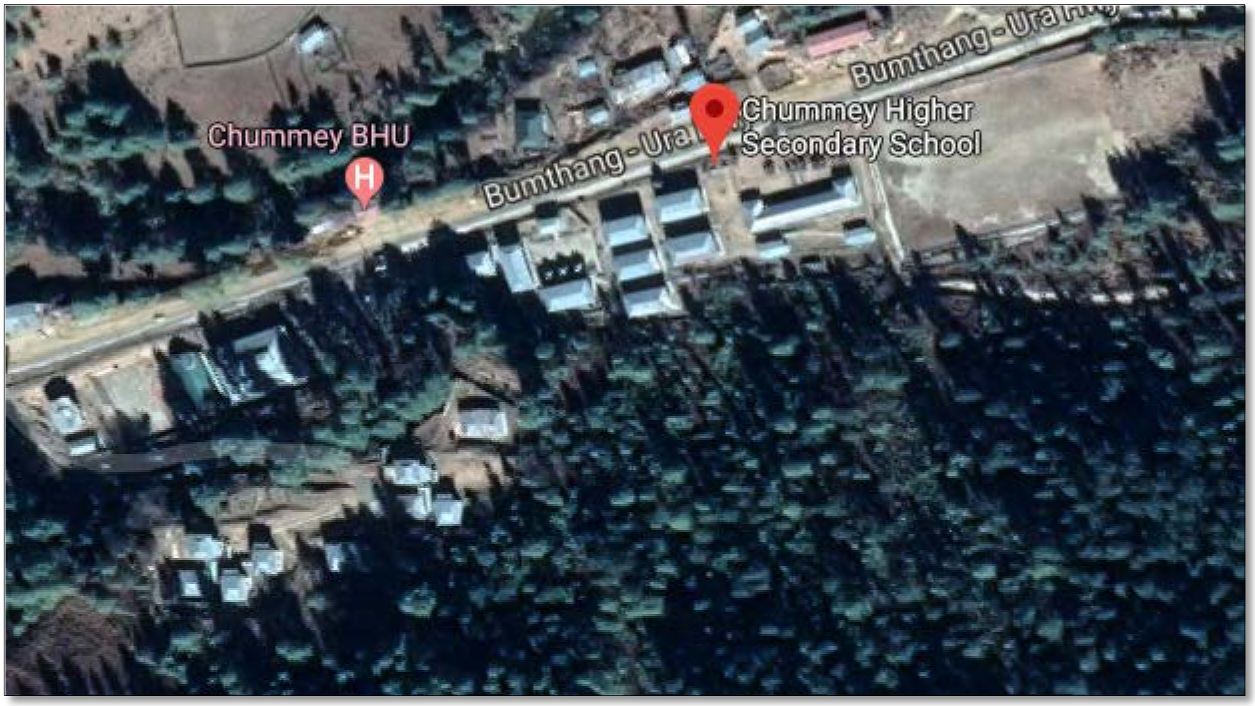


Figure l: Aerial view of Chumey Central School (google map: 2003)

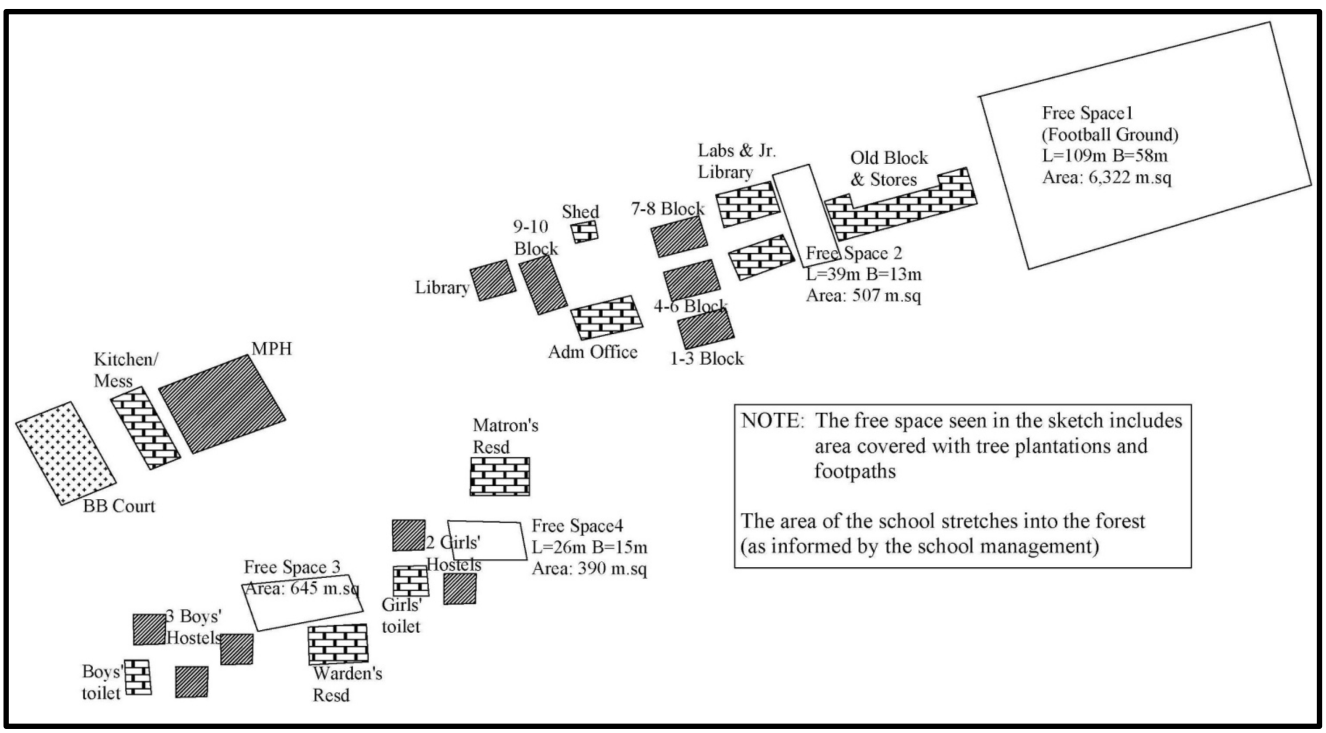


Figure m: Sketch map of Chumey Central School

Total plinth area to be heated is **1581.22 m^2** which includes IX-X Academic Block, VII-VIII Academic Block, IV-VI Academic Block, I-III Academic Block, Girls' Hostel A&B, Boys' Hostel A, B&C, MPH and Library.

Sizing the heating systems

The sizing of the GHP for Chumey Central School is calculated as follows.

Table 5: GHP capacity for Chumey Central School

Building type	Total area	Total Heat loss	GHP capacity
IX-X Academic Block	123.42m^{21}≈1328 sq.ft	= 1328 sq.ft* 20 BTUs =26,570 BTUs per hour	$\frac{26,570}{12,000} \approx 2\ ton\ unit$
VII-VIII Academic Block	123.42m^2≈1328 sq.ft	= 1328 sq.ft* 20 BTUs =26,570 BTUs per hour	$\frac{26,570 + 26,570 + 34,574}{12,000} \approx 7\ ton\ unit$
IV-VI Academic Block	123.42≈1328 sq.ft	= 1328 sq.ft* 20 BTUs =26,570 BTUs per hour	
I-III Academic Block	160.6≈1729 sq.ft	= 1729 sq.ft* 20 BTUs =34,574 BTUs per hour	
Girl's Hostel A	106.07≈1142 sq.ft	= 1142 sq.ft* 20 BTUs =22,835 BTUs per hour	$\frac{22,835 + 22,835}{12,000} \approx 4\ ton\ unit$
Girl's Hostel B	106.07≈1142 sq.ft	= 1142 sq.ft* 20 BTUs =22,835 BTUs per hour	
Boy's Hostel A	106.07≈1142 sq.ft	= 1142 sq.ft* 20 BTUs =22,835 BTUs per hour	$\frac{22,835 + 22,835 + 22,835}{12,000} \approx 6\ ton\ unit$
Boy's Hostel B	106.07≈1142 sq.ft	= 1142 sq.ft* 20 BTUs =22,835 BTUs per hour	
Boy's Hostel C	106.07≈1142 sq.ft	= 1142 sq.ft* 20 BTUs =22,835 BTUs per hour	
MPH	422.45≈4547 sq.ft	= 4547 sq.ft* 20 BTUs =90,944 BTUs per hour	$\frac{90,944}{12,000} \approx 8\ ton\ unit$
Library	97.56≈1050 sq.ft	= 1050 sq.ft* 20 BTUs =21,003 BTUs per hour	$\frac{21,003}{12,000} \approx 2\ ton\ unit$

In total, if the whole school is to be heated using GHP the estimated size of 29 ton unit will be required to provide adequate heating to all the above listed structures.

The vacant spaces available are free space in football ground (6322 m^2), free space between old and new academic block (507 m^2), free space in front of the boy's hostel (645 m^2) and free space in front of the girl's hostel (390 m^2)

Since all the academic blocks are constructed closely as seen in figure 8, one GHP can be installed in the football ground[14] to provide heating to all the academic blocks. For this option, the total capacity of the GHP will be 9 ton unit.

GHP capacity of 10 tons can be installed in the free space for all the hostels. Since, the area is relatively small, the option of installing vertical pipe loop will be feasible than the horizontal pipe loop which requires bigger space.

Since the MPH hall and library are used on timely basis and also with the school showing more concern with the academic blocks and hostels, the MPH and library are not considered for GHP.

d) Bjishong Central School, Gasa

- Bjishong Central School in Gasa
- 27°48′36.37″N 89°43′37.07″E Elev 7597 ft
- Established in the year 2007.
- 499 students
- School area: 20.7 acres (proposal requesting for additional 10 acres)
- Current heating system: Oil filled panel electric heaters (1.5 kW each) in few of the class rooms.
- 2 nos of 1000 ltrs of solar water heating system installed (currently both the solar water heating systems are non-functional)

[14] *GHP pipes will be laid underground which will not affect the functionality of the football ground*

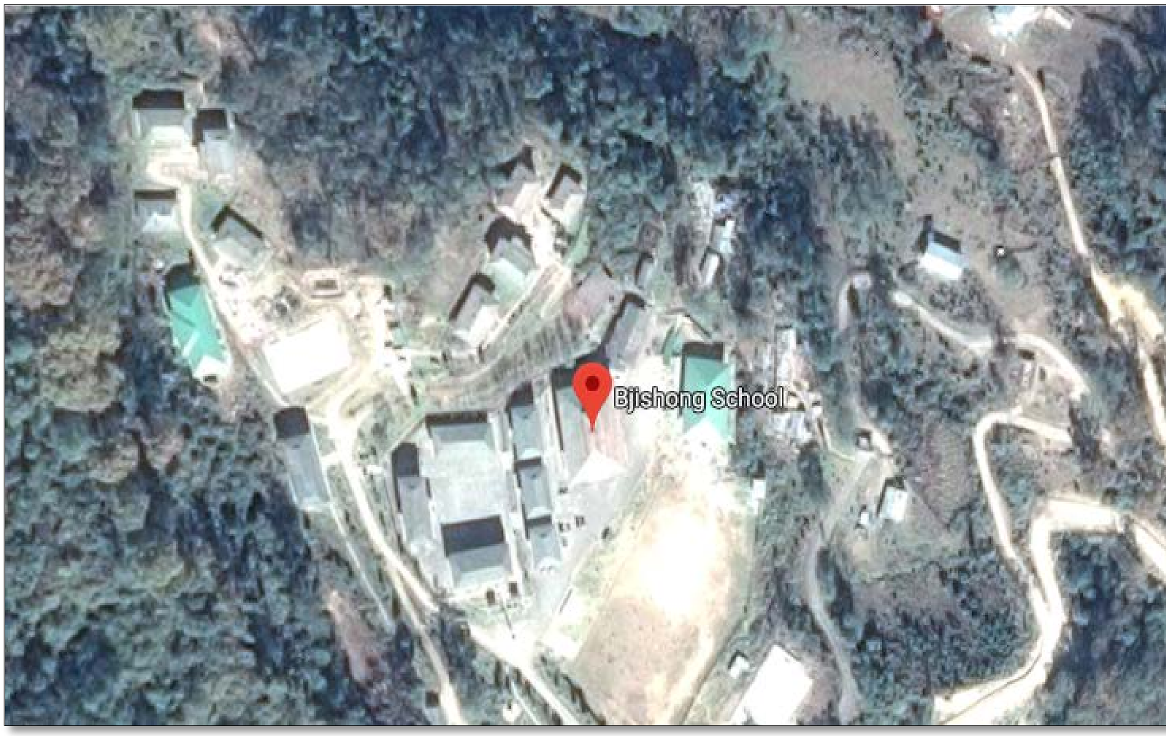


Figure n: Aerial view of Bjishong Central School (google map: 2006)

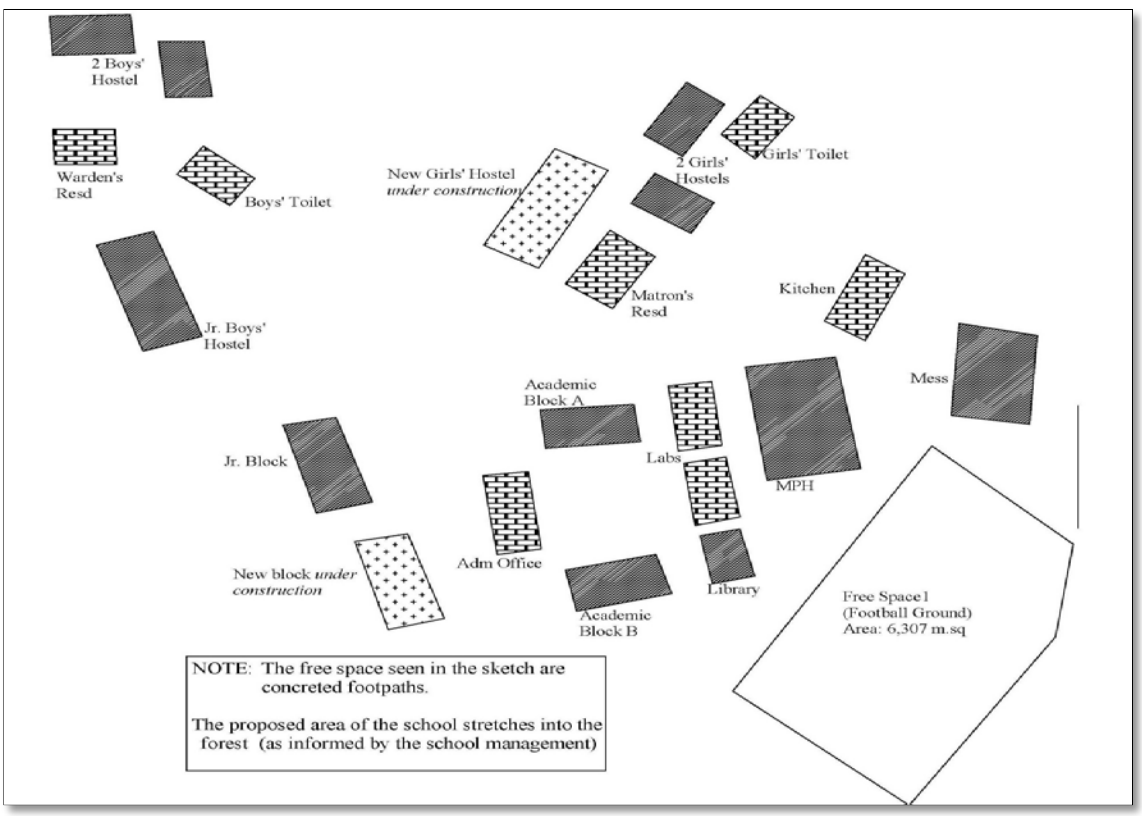


Figure o: Sketch map of Bjishong Central School

Total plinth area to be heated is **3449.2 m^2** which includes Academic Block A, Academic Block B, Library, MPH, Dining Hall, Girls' Hostel A&B, Primary Boys' Hostel, Boys' Hostel A&B and Junior Block

Sizing the heating systems

The sizing of the GHP for Bjishong Central School is calculated as follows.

Table 6: GHP capacity for Bjishong Central School

Building type	Total area	Total Heat loss	GHP capacity
Academic Block A	42.7m^2≈460 sq.ft	= 460 sq.ft* 20 BTUs =9,192 BTUs per hour	$\frac{9,192}{12,000} \approx 1\ ton\ unit$
Academic Block B	42.7≈460 sq.ft	= 460 sq.ft* 20 BTUs =9,192 BTUs per hour	$\frac{9,192}{12,000} \approx 1\ ton\ unit$
Library	76.08≈819 sq.ft	= 819 sq.ft* 20 BTUs =16,378 BTUs per hour	$\frac{16,378}{12,000} \approx 1\ ton\ unit$
MPH	489.42≈5268 sq.ft	= 5268 sq.ft* 20 BTUs =1,05,361 BTUs per hour	$\frac{1,05,361}{12,000} \approx 9\ ton\ unit$
Dining Hall	364.58≈3924 sq.ft	= 3924 sq.ft* 20 BTUs =78,486 BTUs per hour	$\frac{78,486}{12,000} \approx 7\ ton\ unit$
Girl's Hostel A	56.32≈606 sq.ft	= 606 sq.ft* 20 BTUs =12,124 BTUs per hour	$\frac{12,124 + 12,124}{12,000} \approx 2\ ton\ unit$
Girl's Hostel B	56.32≈606 sq.ft	= 606 sq.ft* 20 BTUs =12,124 BTUs per hour	
Primary Boy's Hostel	57.38≈618 sq.ft	= 618 sq.ft* 20 BTUs =12,353 BTUs per hour	$\frac{12,353}{12,000} \approx 1\ ton\ unit$
Boy's Hostel A	56.32≈606 sq.ft	= 606 sq.ft* 20 BTUs =12,124 BTUs per hour	$\frac{12,124 + 12,124}{12,000} \approx 2\ ton\ unit$
Boy's Hostel B	56.32≈606 sq.ft	= 606 sq.ft* 20 BTUs =12,124 BTUs per hour	
Junior Block	43.54≈469 sq.ft	= 469 sq.ft* 20 BTUs =9,373 BTUs per hour	$\frac{9,373}{12,000} \approx 1\ ton\ unit$

In total, if the whole school is to be heated using GHP the estimated size of the heat pump would be of 25 ton unit.

Currently there is only football ground 6,307 m^2 which has enough space for the installation of GHP underground pipes which can cater to 19 ton GHP for the academic blocks, Library, Dining Hall and MPH since the structures are near the free space.

For the Hostels and Junior block, there were no available space for laying piping for GHP therefore the installation of GHP is not recommended.

5.2 HEATING WITH AIR SOURCE HEAT PUMP

This system is applicable to all the schools since it does not require much space and can be installed individually for each structure. However since the system is noisy during operation, it is recommended to do proper study for the location of the heat pump before the installation in order to avoid disturbance in the classrooms during the day and in hostels during the night.

The approximate cost of heat pump system is estimated at Nu. 150,000/- – Nu. 270,000/- (for 1.5ton – 5 ton rated capacity)[15]. The estimated cost doesn't include the cost of installation and the heat distribution system and the actual cost is subjected to the make of the equipment and the country of procurement. It is important to note that in general, the cost of installation of ASHP is much cheaper than installation cost of GHP.

To determine the kW and ton capacity of ASHP required in schools, the BTU/hr (as calculated for GHP capacity in the table above) is converted into kW (1BTU/hr = 0.000293 kW) and ton.

Gongzim Ugyen Dorji Central School

Table 7: ASHP capacity for Gongzim Ugyen Dorji Central School

Sl. No	Name of the school	BTU/hr	Rating in kW	Rating in tons
1.	Old Academic Block	20,160	6 kW	1.7
2.	New Academic Block	38,740	11 kW	3.1
3.	Library	23,240	7 kW	2
4.	Multipurpose Hall	38,740	11 kW	3.1

15 *https://www.improvenet.com/r/costs-and-prices/heat-pump-installation-cost-estimator*

Jakar Higher Secondary School

Table 8: ASHP capacity for Jakar Higher Secondary School

Sl. No	Name of the school	BTU/hr	Rating in kW	Rating in tons
1.	Old Academic Block	128,044	38kW	10.8
2.	New Academic Block	77,480	23kW	6.5
3.	Girls' New Hostel	51,820	15 kW	4.2
4.	Girls' Old Hostel	71, 000	21kW	5.9
5.	Boys' Hostel	85,220	25kW	7.1

Chumey Central School

Table 9: ASHP capacity for Chumey Central School

Sl. No	Name of the school	BTU/hr	Rating in kW	Rating in tons
1.	IX-X Academic Block	26,570	7.8 kW	2.2
2.	VII-VIII Academic Block	26,570	7.8 kW	2.2
3.	IV-VI Academic Block	26,570	7.8 kW	2.2
4.	I-III Academic Block	34,574	10 kW	2.8
5.	Girls' Hostel A	22,835	6.7 kW	2
6.	Girls' Hostel B	22,835	6.7 kW	2
7.	Boys' Hostel A	22,835	6.7 kW	2
8.	Boys' Hostel B	22,835	6.7 kW	2
9.	Boys' Hostel C	22,835	6.7 kW	2
10.	MPH	90,944	26.7 kW	7.6
11.	Library	21,003	6 kW	1.7

Bjishong Central School

Table 10: ASHP capacity for Bjishong Central School

Sl. No	Name of the school	BTU/hr	Rating in kW	Rating in tons
1.	Academic Block A	9,192	2.7 kW	1
2.	Academic Block B	9,192	2.7 kW	1
3.	Library	16,378	4.8 kW	1.3
4.	MPH	1,05,361	31 kW	8.8
5.	Dining Hall	78,486	23 kW	6.5
6.	Girls' Hostel A	12,124	3.5 kW	1
7.	Girls' Hostel B	12,124	3.5 kW	1
8.	Primary Boys' Hostel	12,353	3.6 kW	1
9.	Boys' Hostel A	12,124	3.5 kW	1
10.	Boys' Hostel B	12,124	3.5 kW	1
11.	Junior Block	9,373	2.7 kW	1

Note: Since ASHP can be easily installed; wherever GHP and Solar heating are not feasible, ASHP can be installed. However the running noise of the system has to be taken into consideration before any installation.

The distribution of heat in the building with ASHP can be used with both radiant floor heating and forced air system depending upon the feasibility at site.

5.3 HEATING WITH SOLAR ENERGY

The number of solar water heating systems is increasing in the country with over 1400 SWHs installed in the country till date. While the water heating is the main objective of the current project established under DRE, the same system can be used for radiant floor heating with additional modifications. This will not only be efficient but also cost saving if it is used for both hot water and space heating.

Determining the system size:

The installation of 1000 litres per day (LPD) solar water heating system requires 12 panels, which is estimated at maximum of Nu. 650,000 /- for indirect active systems. The payback period is calculated as more than 6 years compared to heating with electricity. For efficiency in the distribution of heat, it is recommended to install the water heaters in a small room in the same building or in the basement. The maximum temperature of the outlet water is 60^{o} C which can be proportionately used for hot water consumption and space heating.

To determine the estimated energy required to heat the rooms, numbers of 1.5 kW electric heaters were estimated to heat different sized room for 8 hours. The following formula is used to determine the total collector area:

$$\mathbf{A_c} = \frac{L}{\eta solar * Imax}$$

where Ac = collector area (m^2)
L = Daily Load (kWh/day)
η_{solar} = efficiency of solar system (typically 0.40)
I_{max} = maximum daily solar radiation ($kWh/m^2/day$)[16]
No of Panels = $\frac{Ac}{2}$
Approximate System Size in liters = $\frac{1000\ ltrs}{12\ panels}$ X Total no of panels

With the above formula, the following required system sizes were determined:

Table 11: SWH system sizing

School	Structures	Estimated Energy consumed (kWh/day)	No. of room	Required Collector area (sqm)	Total no. of panels	System size in Liters	Remarks
Ugyen Dorji CS	New Academic Block	24	6	72	36	3,018	MPH and Old Academic Block not considered due to lack space for panels
	Library	48	2	48	24	2,012	
Jakar HSS	Old Academic Block	24	12	123	61	5,111	New and Old Girls' not considered due to lack space for panels
	New Academic Block	24	6	61	31	2,555	
	Boys' Hostel	24	16	164	82	6,814	
Chumey CS	Girls' Hostel A	24	4	41	20	1,704	Academic Blocks and Library is not considered due to lack space for panels
	Girls' Hostel B	24	4	41	20	1,704	

[16] *https://www.gaisma.com/en/dir/bt-country.html*

	Boys' Hostel A	24	4	41	20	1,704	
	Boys' Hostel B	24	4	41	20	1,704	
	Boys' Hostel C	24	4	41	20	1,704	
Bjishong CS	Girls' Hostel A	24	4	40	20	1,669	No space available for new solar panels therefore considering the size of the existing solar water heating system in Bjishong CS, Hostels can be heated using SHW system
	Girls' Hostel B	24	4	40	20	1,669	
	Primary Boys' Hostel	48	5	100	50	4,174	
	Boys' Hostel A	24	4	40	20	1,669	
	Boys' Hostel B	24	4	40	20	1,669	

The roof mounting of the panels are not recommended in this report since detailed structural strength and drawings will be needed to be undertaken to calculate the strength of the roof for carrying the panels. The systems are therefore recommended to be installed in the vacant spaces available.

6. LIMITATIONS

Although GHP and ASHP are popular in developed countries it is still new concept in Bhutan with no installation carried out till date. The research is solely based on the desktop studies and site visits at the selected schools, therefore, for the piloting of any of the systems in the schools will require further elaborated research with hiring of expertise/consultant for the implementation of the work at site and to document the project for future references and replication at other sites.

This study has been limited to literatures reviews mainly due to lack of in-house capacity to conduct detailed research on the technologies especially GHP and AHP. The conclusions drawn from the study will need to be further refined with the assistance from experts for the purpose of implementation.

7. RECOMMENDATION/WAY-FORWARD

While the study looked into the theoretical research of the systems, for implementation of any project using these heating systems, prefeasibility study will need to be conducted in order to specify the system type and capacity with technical assistance from the experts.

During the site visits to the schools, one major concern raised by the management was regarding the knowledge transfer of the system after the installation (since the operation and maintenance of the systems has to be carried out by the school management). Therefore, it is very important that the expertise build capacity of all the personnel involved in the operation and maintenance.

8. CONCLUSIONS

The research is a desktop study for various type of heating systems that are successfully installed in outside countries and can be installed in schools in the colder regions of the country. The objective is to address the chilblain outbreaks in schools during the cold winters and pilot various heating systems as per the feasibility.

While the solar water heaters are already in place with the department, solar water heating for space heating, geothermal and air source heat pump are fairly new and has not been implemented in the country so far. However, with the completion of this desk research, it can be concluded that GSHP is the most efficient heating system which has life span of more than 20 years. It also concludes that GSHP has the highest installation charges, of the three systems, and needs large spaces for installation (especially for laying the piping).

During the site visits to the schools it was observed that due to irregular spacing of various structures of the school buildings, no school can be installed with GSHP only. Therefore the research recommends various heating systems in different school structures as per the building location and available free space.

As a way forward, subjecting to the availability of fund for implementation, in-depth study for the specific space requirement for each technology, soil stability, market availability, skilled labour and technical assistance will need to be sought before piloting the heating systems in the schools and replicating in the future.

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