GERMAN - MONGOLIAN INSTITUTE
FOR RESOURCES AND TECHNOLOGY

The present work was submitted to the Faculty of Electrical and

Mechanical Engineering

Direct Utilization of Solar and Wind Energy in Thermal Energy Storage Systems to Enhance Power-to-Heat Conversion in the GMIT campus

Bachelor Thesis

by

NOMUNDARI Bat-Erdene

Study program: Energy and Electrical Engineering

Student ID: B210434

1st Supervisor / Examiner	**Mr. Bold Enkhbold**
2nd Supervisor / Examiner	**Mr. Nikita Abramov**

Ulaanbaatar/Nalaikh, 2025.05.02

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Statutory Declaration

Bat-Erdene Nomundari	B2100434
Last Name, First Name	Student ID Number

I hereby affirm in lieu of an oath, that I provided the submitted bachelor thesis

DIRECT UTILIZATION OF SOLAR AND WIND ENERGY IN THERMAL ENERGY STORAGE SYSTEMS TO ENHANCE POWER-TO-HEAT CONVERSION IN THE GMIT CAMPUS

I did not use any sources other than those stated. In case that the work is additionally submitted on a data medium, I declare that the written and the electronic form are completely identical. The work was not submitted in the same or similar form to any examination authority.

Nalaikh, 2025	
Place, Date	Signature

Acknowledgement

I thank my supervisor, Mr. Nikita Abramov, for accepting me as his bachelor's student and guiding me through my thesis. He is always patient and willing to support me with helpful suggestions and guidance. I am grateful to Mr.Bold, who is excellent at his work, and helped me without hesitation, and encouraged me. Also, thank Mr. Tuguldur, an engineer at GMIT, for supplying a lot of information about heating, data, solar panels, and electrical systems. Particular thanks to Prof. Ariunbolor. P for sharing her knowledge and experience. Special thanks to Jorg Grotefendt for helping and guiding me to a deep understanding of my research and achievement, and for supplying all the necessary materials that he processed. I appreciate all the GMIT staff who helped me warmly and supplied all the materials I needed in a rush.

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Abstract

This thesis investigates the feasibility and effectiveness of renewable-based heating systems on the German-Mongolian Institute for Resources and Technology (GMIT) campus in Nalaikh, Mongolia. With long, severe winters and rising energy demands due to campus expansion, maintaining thermal comfort in an energy-efficient and sustainable way has become a key challenge. This study compares three configurations: a fully renewable system using solar thermal and wind energy, a hybrid system combining renewables with limited conventional backup, and the existing traditional system powered entirely by coal-based centralized heating. Through detailed analysis of campus heating bills, climate data, energy simulations, and cost modeling, the study demonstrates that a hybrid solar-wind system offers the best balance of economic, technical, and environmental performance. It reduces long-term heating costs, significantly lowers emissions, and ensures system reliability. A fully renewable system, while environmentally superior, remains cost-prohibitive without external funding. The findings suggest that transitioning to a hybrid renewable heating model, supported by wind power and thermal energy storage, is a viable and scalable pathway toward energy sustainability for cold-climate institutions.

1. Introduction

1.1 Background information

In Nalaikh, where winters are long and extremely cold, reliable heating is essential for maintaining comfortable indoor conditions. This thesis explores how renewable energy, specifically solar and wind power, can be used directly to heat buildings on the German-Mongolian Institute for Resources and Technology (GMIT) campus. The focus is on using this energy to heat water, which then circulates through the building's heating system to keep indoor spaces warm.

Based on heating bills and data from heat meters, the GMIT campus requires around 700 kW of thermal energy during the coldest periods. To meet this demand sustainably, a hybrid system has been designed. The main source of heat will come from solar thermal collectors installed on the rooftops of four buildings, which together provide about 6000 m² of usable space. 1,660 collectors (occupying ~4,950 m²) can be installed, producing most of the required annual heating energy.

These solar collectors heat water directly. The heated water is stored in large insulated tanks known as thermal energy storage, which act like a buffer. In simple terms, this means the tanks store hot water when there is plenty of sunlight and keep it ready for use during cloudy periods or at night. This helps make sure the building stays warm even when solar energy isn't immediately available.

To store enough hot water for this system, we estimate that roughly 200 m³ of floor space per 1,000 liters of water is needed, depending on the tank shape and insulation. For a heating demand of 700 kW, assuming 13 hours of storage capacity, this could require around 200,000 liters of hot water storage. Therefore, the estimated ground space needed would be approximately 196 m², which is manageable within the ground floor of one of the buildings.

To cover the rest of the energy demand, the system also uses wind energy from the Salkhit Wind Farm. Wind-generated electricity can be used to run heat pumps or electric heaters that add to the building's heating supply. About 400 kW of the total heating load will still come from the existing grid or backup systems, while the rest will be provided by solar and wind.

1.2 Objective of the study

The main goal of this study is to identify the most effective and sustainable heating solution for the GMIT campus by comparing fully renewable, hybrid, and traditional heating systems, both technically and economically. The aim is to ensure a stable and affordable heat supply using solar and wind energy, supported by smart energy storage and reliable backup options suited for Mongolia's cold climate.

- First, the total heating demand of the GMIT campus will be analyzed using utility bills and heat metering data. This includes calculating the average daily consumption and peak demand during winter.

- Based on the available 5892.36 m^2 rooftop area across four buildings, the study will determine how many solar thermal collectors can be installed and how much heating demand they can realistically cover.

- A thermal energy storage system will be designed to store hot water generated by the solar collectors, helping maintain stable indoor temperatures even when there is little or no sunlight.

- The study will compare three different heating system options: a fully renewable system using only solar and wind energy; a hybrid system that combines renewables with about 400 kW of backup power from the grid or power plant; and a traditional system that relies entirely on centralized heating.

- Each system will be evaluated through a life-cycle cost analysis, taking into account the initial investment, operating and maintenance costs, collector lifetime (e.g., 20 years), long-term contracts for wind energy (e.g., with Salkhit Wind Farm), and energy prices. These costs will be compared to the ongoing payments made to the central power plant.

- Finally, the study will identify which system provides the best long-term value for GMIT, balancing economic performance, environmental benefits, energy reliability, and the ability to meet future heating demands.

2. Analysis of Heating Demand and Environmental Conditions

2.1 Overview of GMIT Campus Energy Use

GMIT currently operates several buildings on its campus in Nalaikh, Ulaanbaatar. Historically, the heating system supplied only the academic building and one dormitory. In December 2022, a second dormitory was added, significantly increasing the heating demand. The campus relies on district heating through a hydronic hot water system powered by a nearby power plant. With a new laboratory building planned and increasing occupancy, there is a clear need to reassess the system's capacity and explore sustainable alternatives.

Table 1. GMIT DEMAND AND BILL

	Hot water (m^3)	Heating Tariff (₮/ m^3)	Total Tariff in ₮	Total kWh annually
Old dormitory	4571.49	604	2761179.96	520260.9774
University	22,833.60	604	13791494.4	
D block dormitory	20727.12	604	12519180.48	782031
E block dormitory	11147.93	604	6733352.68	
Laboratory	14953.89	604	9032149.56	724680

Over the past year, GMIT's four main buildings including the university building, old dormitory, and two new dormitory blocks together consumed approximately 60,000 m^3 of hot water for space heating. At the standard heating tariff of 604 ₮ per cubic meter, this resulted in a total heating bill of around 36.2 million ₮. The laboratory building, while constructed, was not yet in full heating operation during this period and is therefore excluded from these calculations. In energy terms, the volume of heated water consumed by GMIT's four main buildings corresponds to approximately 6.75 GWh of thermal energy delivered to the campus. The academic building alone accounted for

roughly 22,800 m³ (≈2.6 GWh), making it the largest single user. The two newer dormitory blocks, D-Block with 20,700 m³ and E-Block with 11,150 m³ together required another ≈3.1 GWh. The original dormitory used just under 4,600 m³ (≈0.52 GWh). Spread evenly over the year, this results in an average of approximately 770 kW of continuous thermal power demand with peak loads exceeding 700 kW during the coldest winter days. This updated consumption profile sets a realistic performance target for any renewable-based heating solution: to offset up to 6.75 GWh annually and reliably deliver at least 700 kW of peak thermal output to ensure consistent comfort throughout Mongolia's long, harsh winters.

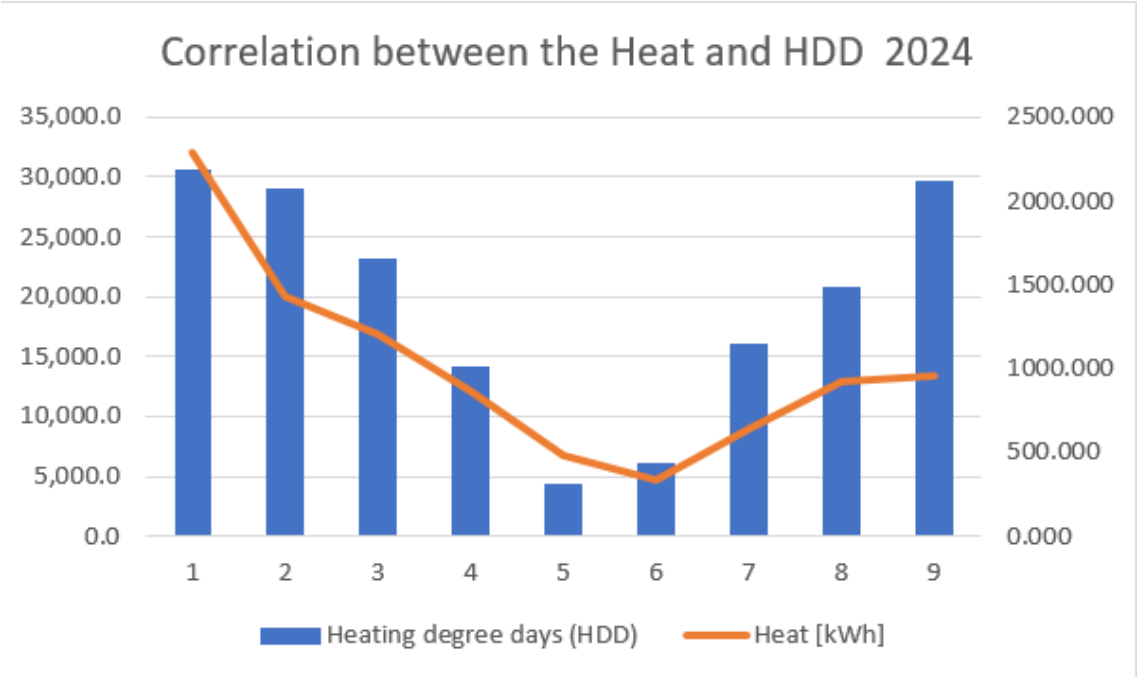

Figure 1 Correlation Between the Heat and HDD

In the chart above, the blue bars show Heating Degree Days (HDD), which we calculate by taking the difference between the indoor setpoint (22 °C) and the average outdoor temperature on each day. For example, if the outdoor temperature is 12 °C, that day contributes 10 HDD (22 – 12 = 10). HDD gives us a simple way to quantify how "cold" it has been over time and therefore how much heating is required.

The orange line plots the actual thermal energy delivered by the campus heating plant, expressed in kilowatt-hours (kWh). We compare kWh against HDD because, in theory, the more HDD accumulate, the more energy the central boiler must generate to maintain comfortable indoor conditions. By overlaying these two series, we can see how closely the plant's output follows the weather-driven demand: as HDD rise in winter months, kWh consumption climbs in near lockstep, and as HDD fall in late spring, the kWh curve drops accordingly. In other words, using kWh on the same chart lets us verify that our degree-

day estimates are a reliable proxy for actual heat consumption, and it helps us predict future energy needs directly from temperature forecasts.

2.2 Assessment of Space Heating Demand

2.2.1 Data Sources and Collection Method

To accurately evaluate the heating demand of the GMIT campus, this study utilized a combination of metered heating data, official billing records, and campus occupancy data. Together, these sources provide both detailed technical measurements and broader system-level trends over multiple years. This study first analyzed five years of heat metering data recorded by devices installed in the academic building and the older dormitory. These two buildings were equipped with a shared heat metering system that recorded hourly data, including water volume consumption, inlet temperature, and outlet temperature of the heating system.

Using this data, the daily heat consumption was calculated based on the following thermodynamic equation:

$$Q_{\text{heat}} = \dot{m} \cdot c_p \cdot \Delta T$$

$$Q_{heat} - is\ the\ heat\ energy\ transferred\ (in\ joules\ or\ kW)$$

$$Mass\ flow\ rate - the\ value\ of\ water\ flow\ per\ second$$

$$c_p = \ specific\ heat\ of\ water\ (\sim 4186\ J/kg \cdot °C)$$

$$\Delta T \ = \ temperature\ difference\ between\ supply\ and\ return\ water\ (°C)$$

The purpose of this analysis was to observe the heating patterns before the addition of the third building in late 2022. Before the new dormitory came online in late 2022, we tracked two years of heating data from the original campus buildings to establish a clear baseline. As expected, heating demand followed a very regular seasonal cycle surging to roughly 400–450 kW in the coldest months of January and December, tapering off through spring, and then climbing again in autumn. Aside from small week-to-week variations, the overall profile was remarkably steady, reflecting two buildings with stable occupancy and usage patterns. These two years therefore give us a dependable picture of how much heat those first two buildings alone require information we can now use as a reference point for gauging the impact of expansion.

Once the third dormitory began hosting students in late 2022, our on-site hydronic system could no longer keep up on the chilliest nights, and occupants resorted to electric

space heaters just to stay comfortable. To quantify exactly how much extra heat the new building adds, we turned to the district heating bills, which record both energy delivered and cost on a monthly basis. From those invoices it was immediately clear: total campus heat consumption jumped sharply once the third dorm came online.

In order to build a complete picture of our heating challenges and to size a renewable-powered solution we combined several data streams:

- **Solar Atlas & Wind Atlas**: We used international solar and wind resource maps to estimate how much energy a rooftop collector field or nearby wind farm could generate at our latitude and elevation.

- **SAM Weather Files**: The System Advisor Model's built-in Typical Meteorological Year (TMY) files gave us hourly temperature, irradiance, and wind data tailored to our campus coordinates.

- **Campus Blueprints**: Our chief engineer provided detailed floor-plans and roof layouts so we knew exactly how much collector area we could install.

- **Billing Records & Meter Logs**: We reviewed five years of district-heating bills alongside hourly flow-and-temperature records from our campus heat meters, capturing every spike and lull in usage.

- **Population Growth**: Finally, we overlaid student and staff headcount data growing from about 200 to 360 residents and 64 to 75 employees to correlate building occupancy with rising heat demand.

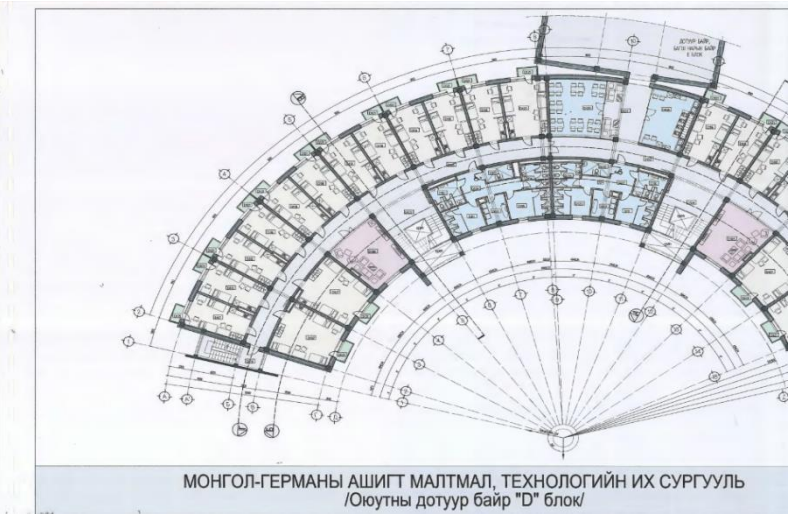

Figure 2 NEW DORMITORY D BLOCK

By weaving together resource atlases, weather files, building schematics, billing statements, meter data, and population trends, we now have a comprehensive, “real-world” foundation for designing a hybrid solar-and-wind heating system that can keep the entire expanded GMIT campus warm, without leaving anyone reaching for space heaters again.

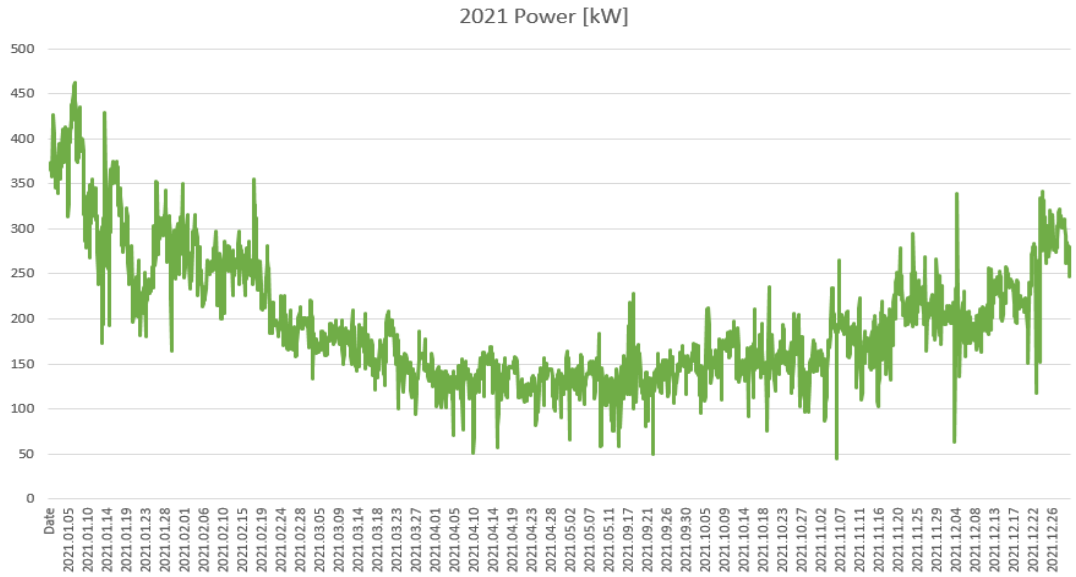

Figure 3 2021 POWER CONSUMPTION 2021

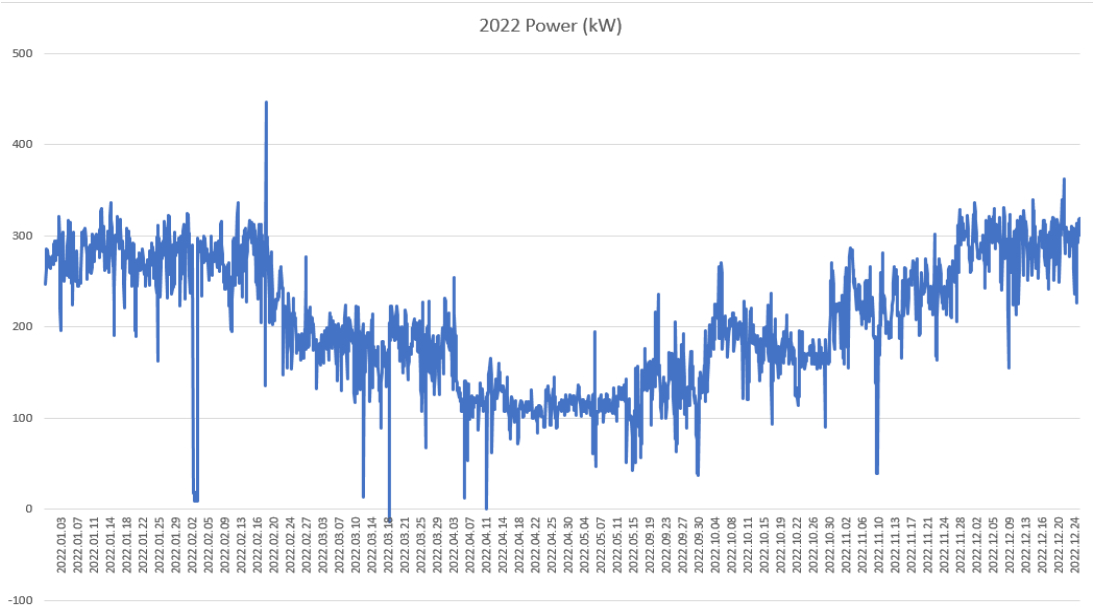

Figure 4 POWER CONSUMPTION 2022

The second key dataset comes from billing records issued by the central power plant that supplies heat to GMIT. These bills cover the same five-year period and monthly cost paid for heating, and the unit price of thermal energy, which is increased over time from 25,813 ₮/GJ to 66,082 ₮/GJ. From this calculated that the actual demand meets the previous data analysis to show a rise. This billing data reflects the total heat consumption for all buildings connected to the heating system and is particularly useful for identifying when and how total campus demand increased. For instance, a noticeable spike in both GJ usage and cost appears starting from December 2022, when a third dormitory building was added to the system. This makes the billing records a reliable source for analyzing how building expansion has affected energy demand at the system level.

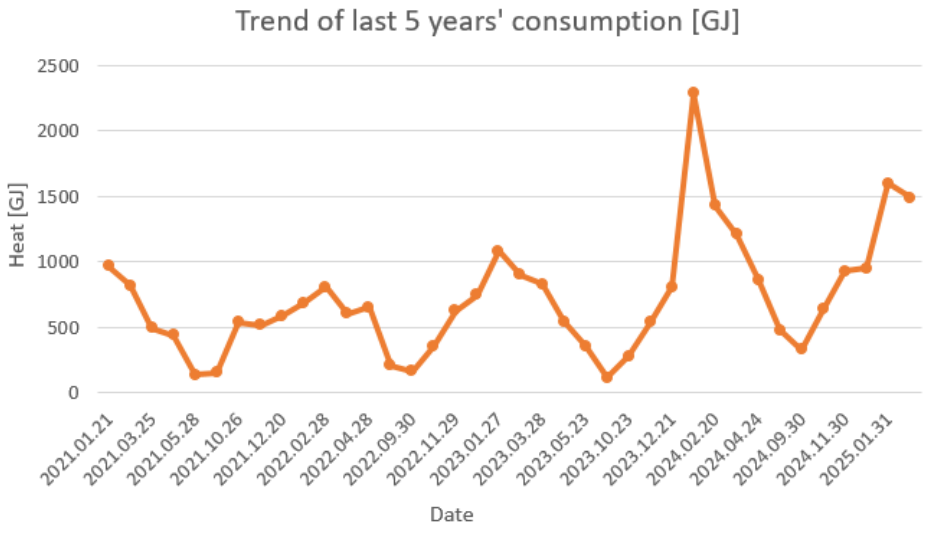

Figure 5 Trend of last 5 year's consumption

In addition to technical and financial data, student and staff population records were also reviewed to estimate how changes in occupancy may have influenced heating needs. The number of students living in dormitories increased from approximately 200 in 2021 to 360 in 2025, while staff numbers rose from 64 to 75 over the same period. These figures support the interpretation of increased thermal energy demand observed in the metering and billing data. Together, these data sources form the basis for understanding GMIT's heating profile and guide the system design decisions presented in this study.

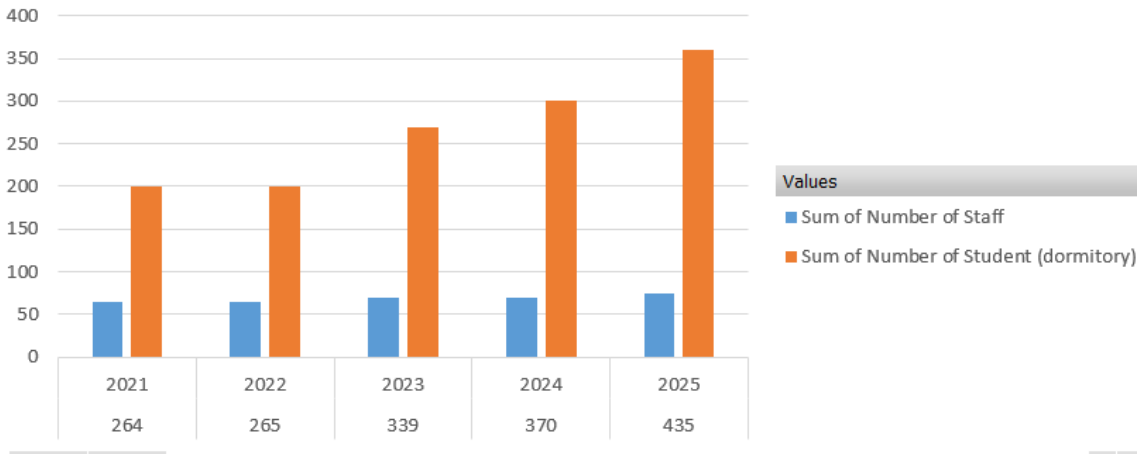

Figure 6 Trend of population

2.2.2 Daily and Monthly Consumption Trends

To better understand the overall heating demand on the GMIT campus, billing data from the central heating supplier was used to calculate monthly average power consumption between January 2021 and January 2025. This data reflects actual usage measured in energy units (GJ and kWh), which were then converted into average daily power (in kW).

As the graph shows, heating demand follows a clear seasonal pattern, with higher consumption during the colder months and lower usage during spring and early autumn. For the first two years, when only the academic building and one dormitory were in operation, the monthly demand stayed relatively stable, generally between 300 and 500 kW, depending on the time of year.

However, a noticeable shift occurred beginning in early 2023, which is when the third dormitory building was added to the heating network. From that point onward, energy consumption steadily increased, and by winter 2024, demand peaked at nearly 800 kW. This marked increase confirms the impact of campus expansion on heating needs.

Now, while the graph shows monthly average power levels, it's important to understand that real heating demand varies throughout each day. It's not constant for 24 hours, it rises during the early morning and evening when people are active, and drops at night. So, if we designed a system based only on monthly averages, it might not be able to keep up during the busiest hours. On the other hand, assuming the peak value lasts all day would overestimate the actual energy needed and lead to oversizing the system.

To balance these factors, 700 kW was chosen as the design heating capacity. This value is just below the highest observed peak but gives enough flexibility to handle daily fluctuations and unexpected cold spells. It also accounts for future growth: with plans

already underway for a new laboratory building, the heating load is expected to rise even further.

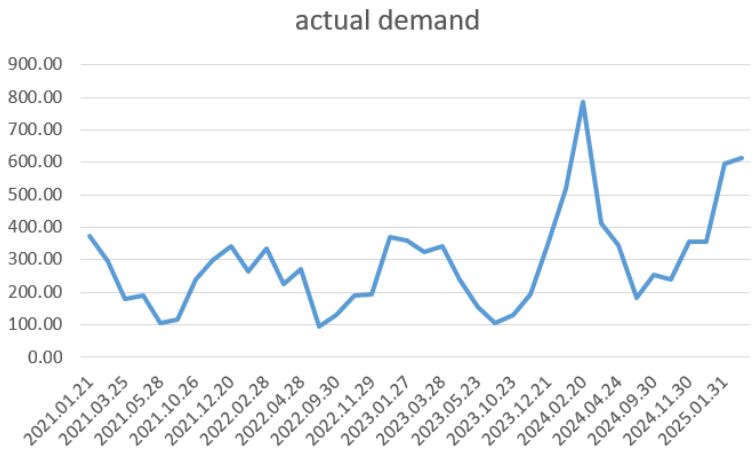

Figure 7 Actual Demand

2.3 Environmental Resource Assessment

2.3.1 Solar Energy Potential in Nalaikh

The GMIT campus situated at roughly 47.85° N, 107.27° E in the Nalaikh district on the outskirts of Ulaanbaatar, enjoys exceptionally favorable solar conditions, even in the heart of its frigid winters. At an elevation of about 1,500 m, the thinner mountain- valley air allows more sunlight to reach the surface, and the typically clear Mongolian skies further boost irradiation. According to high- resolution satellite mapping, the site's annual global tilted irradiation (GTI) is approximately 2,120 kWh/m², assuming panels are mounted at an optimal 47° tilt facing due south. This value is among the highest in the region and reflects both the cold, dry climate (which reduces cloud cover and atmospheric scattering) and extended daylight on clear days. Expectations given the campus's solar resource annual GHI ~ 1,575 kWh/m² and DNI ~ 2,127 kWh/m².

Crucially, the cold winter ambient temperatures (annual average ~ −0.7 °C) actually improve PV performance, as panel efficiency increases under lower operating temperatures, and also help minimize heat losses from solar thermal collectors. Snow accumulation a potential concern can be mitigated by steeper tilt angles and simple brushing or melting strategies.

Taken together, these factors indicate that rooftop solar at GMIT could capture 6–7 GWh of thermal energy per year (at 50 % collector efficiency) or nearly 1 GWh of electricity from PV, easily covering a large fraction of the campus's ~2 GWh annual heating

requirement. The remaining challenge, matching this summertime surplus against the campus's long, cold winter demand, will be addressed through appropriately sized thermal energy storage and complementary wind energy from the Salkhit Wind Farm.

By leveraging its high- altitude, high- irradiance location, GMIT is therefore uniquely positioned to demonstrate a nearly self- sufficient, renewably powered heating system, one that could serve as a model for similarly challenging cold- climate environments.

Several utility- scale solar PV plants now feed into Mongolia's grid: a 10 MW installation in Darkhan-Uul Province and a 10 MW plant on Ulaanbaatar's outskirts came online in 2017, followed by a 15 MW facility in Zamyn-Uud, Dornogovi Province in 2018 [1]. On the demonstration side, Winston et al. designed and installed a 3 kW non imaging- optics solar concentrator atop Mongolia National University in February 2014, proving that even in sub-zero winter conditions a small system can deliver steam heat directly to campus buildings [2]. At the household level, flat-plate solar collectors are beginning to appear in Ulaanbaatar's ger districts to preheat domestic hot water and displace coal-stove use [3].

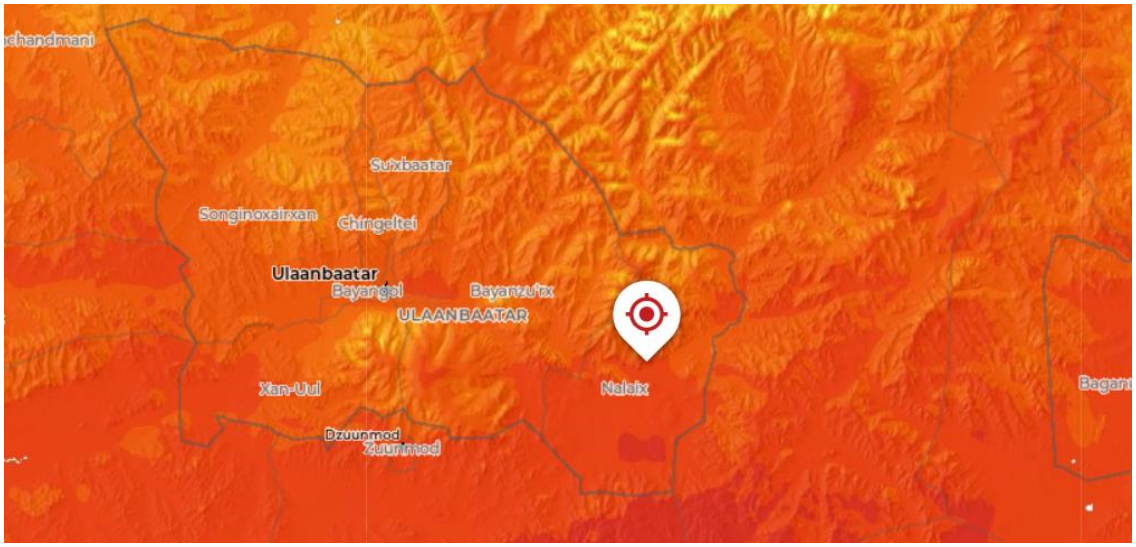

Figure 8 Solar Potential

2.3.2 Wind Energy Potential

Wind resource assessments classify around 10 % of Mongolia's territory as "excellent" for wind power development (mean wind speeds above 7 m/s at 50 m height), with a technical potential of about 1 113 GW of installable capacity and an estimated annual output of ≈2 550 TWh [4]. Although the strongest winds blow across the Gobi Desert and eastern steppe, even areas around Ulaanbaatar at higher elevations enjoy substantial wind speeds [5]. The Salkhit Wind Farm on Salkhit Uul ("Windy Mountain") in Töv

province was Mongolia's first utility- scale installation; it comprises 31×1.6 MW turbines for a total 49.6 MW capacity and produces about 168 GWh per year a capacity factor of roughly 38 % [6]. This single farm contributes around 4 % of the central grid's electricity supply [7]. Since Salkhit's commissioning, Mongolia has added the 50 MW Tsetsii wind farm in the Gobi (2017) and a 55 MW installation near Sainshand, bringing wind's share of the national grid mix to approximately 6 % by 2023 [8].

While the GMIT campus doesn't generate its wind power on-site, it can benefit from energy supplied through the national grid from the Salkhit Wind Farm, located about 70 kilometers southeast of Ulaanbaatar. Salkhit is Mongolia's first large-scale wind farm and has a total capacity of 50 MW, made up of GE 1.6 MW turbines. Under typical wind conditions, it generates more than 150 GWh of electricity annually, which helps prevent about 180,000 tons of CO_2 emissions each year. Because it's already connected to the national grid and produces power reliably, Salkhit is a practical and sustainable option for supplying part of the energy needed to support the heating system at GMIT, particularly during times when solar energy isn't sufficient.

In the context of Mongolia, the concept of power-to-heat is relatively new, but highly relevant. Currently, because the share of renewables in the grid is still modest (~9% in 2023), there is rarely "excess" renewable generation causing low electricity prices. However, as renewable capacity grows (the government aims for 30% by 2030), there will be times when renewable output is high relative to load, especially in certain regions or off-peak hours. Rather than curtail clean power, using it for heating could displace coal use. Even in the present situation, dedicating a portion of wind farm output for heating purposes (via an electric boiler) can be a strategy to directly decarbonize heat. Essentially, wind can serve as a "virtual fuel" for heating, via the grid or via direct connection.

For the GMIT campus system, we envision using wind-generated electricity (sourced from the central grid, which includes Salkhit and other wind farms) to run an electric heater that charges the thermal storage when needed. This can occur especially in winter when solar alone is insufficient. By drawing on wind power, the heating system can maintain renewable input even during sunless periods. Although the campus will not have its own wind turbine, tapping into grid electricity during high-wind periods is conceptually similar: the grid acts as a buffer, and the campus draws cleaner electricity when it's abundant. An alternative approach (beyond the scope of this thesis) could be a direct power purchase agreement with a wind farm or even installing a mid-size wind turbine near campus, but those involve complexity and cost. For now, using the existing grid connection is the practical way to utilize wind energy for heating.

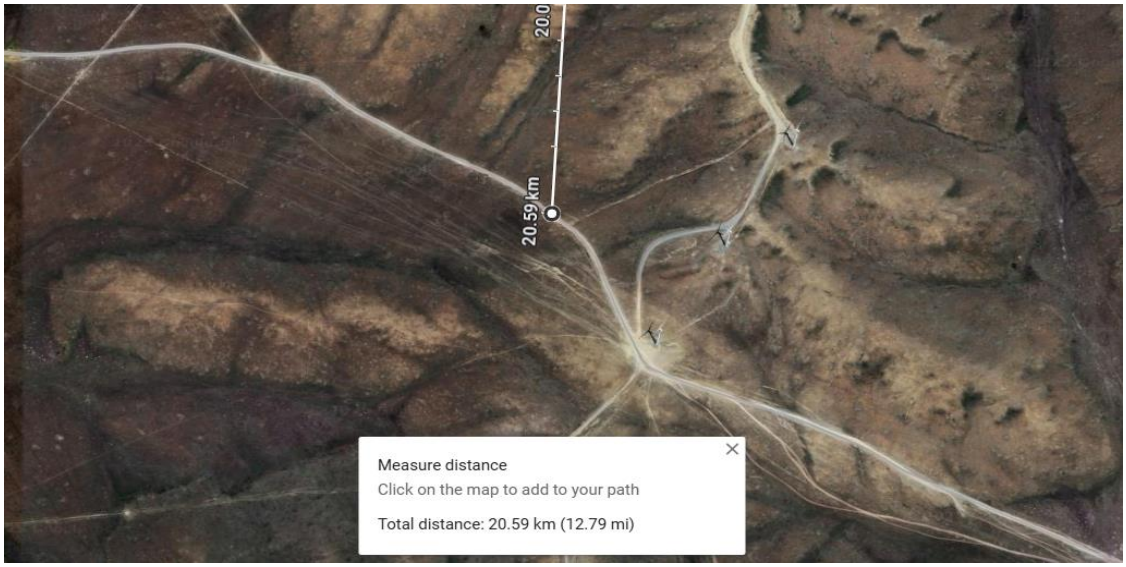

Figure 9 Salkhit Wind Station

2.3.3 Power to heat

Power-to-Heat (P2H) is an increasingly important concept in the transition to low-carbon energy systems, particularly in regions with strong renewable energy resources and high heating demands. The principle is straightforward: instead of curtailing surplus renewable electricity especially during times when production exceeds grid demand this excess energy is converted directly into thermal energy for space heating, domestic hot water, or storage in thermal tanks. This approach not only prevents renewable energy waste but also displaces fossil-fuel-based heat generation, providing environmental and economic benefits.

The simplest implementation of power to heat involves electric resistance boilers, which operate with a coefficient of performance (COP) of 1, meaning that one kilowatt-hour (kWh) of electricity produces one kWh of thermal energy. While these systems are not particularly efficient in terms of energy conversion, their low cost, simplicity, and near-instantaneous response make them ideal for on-demand backup heat or peak-shaving operations. They can be cycled quickly to match intermittent solar or wind input and integrated seamlessly into existing hydronic heating systems, making them an attractive choice for campus or district-level applications.

A more advanced implementation of power to heat is the heat pump, which can achieve COPs between 3 and 5, depending on the source temperature and system design. These systems use a refrigeration cycle to extract heat from ambient air, ground, or wastewater and upgrade it to useful temperatures for heating buildings. In effect, heat pumps multiply the useful heat output per unit of electricity consumed, making them far more efficient

than resistance boilers. However, their efficiency declines sharply in extremely cold environments, especially for air-source variants without supplemental ground loops or auxiliary heating. Additionally, their higher capital cost, larger footprint, and greater maintenance requirements can make them less appealing in institutional settings with limited budgets or severe climate conditions, such as GMIT's campus in Nalaikh.

Globally, many countries have adopted power to heat at scale as part of their decarbonization strategy. Denmark provides a leading example. With over 50% of its electricity coming from wind, Denmark frequently experiences periods of excess power. To absorb this surplus, cities like Aarhus and Copenhagen have installed massive electric boilers, such as the 100 MW electrode boiler at Avedøre Power Station (commissioned in 2006) and the 80 MW boiler at Studstrup (2014). These systems enable district heating networks to respond dynamically to renewable electricity availability, reducing coal use and stabilizing the grid. More recently, Denmark has added large-scale industrial heat pumps (20–50 MW) in cities such as Roskilde and Odense to further optimize the renewable-to-heat conversion process.

Other European countries are also advancing power to heat adoption. In Germany, the Moorburg power station in Hamburg incorporated a 30 MW electric boiler and a 15 MW heat pump in 2018, offering a fast-reacting backup for balancing intermittent solar and wind power. Munich's district heating system features a 40 MW wastewater-based heat pump with a COP above 4, operating year-round to heat residential areas. In Sweden, municipalities often pair 10–25 MW electric boilers with combined heat and power (CHP) plants to store excess heat and reduce peak-time fossil fuel use. These examples demonstrate how power to heat systems can become a cornerstone of national heating strategies, enhancing energy security and reducing emissions.

For the GMIT campus in Mongolia characterized by long, harsh winters and an increasing share of renewables on the national grid Power to heat offers a highly practical and scalable solution. GMIT's proposed hybrid system incorporates electric boilers as the primary backup heat source, powered by grid electricity which includes contributions from wind farms such as the 50 MW Salkhit Wind Farm. When solar thermal output is insufficient particularly during overcast winter days or nighttime, the system can draw from wind-generated electricity to charge the thermal storage or directly meet the space heating demand.

Electric boilers are particularly well-suited to GMIT's needs because they:

- Respond rapidly to variable loads,

- Require low maintenance compared to heat pumps,
- Integrate easily into existing hydronic systems,
- Have compact footprints and simple installation procedures.

Given the peak design heating load of ~700 kW, electric boilers can be sized and operated flexibly to fill any residual gap not met by solar thermal energy or wind power. As Mongolia's grid decarbonizes further and wind generation increases, the carbon footprint of P2H systems will decline, making them an even more environmentally advantageous choice. Moreover, their ability to "absorb" surplus renewable energy helps reduce grid curtailment, improves system flexibility, and lowers heating costs in the long term. Thus, integrating P2H at GMIT not only addresses current backup heating needs but also contributes to national energy transition goals.

2.3.3 Seasonal Variation Considerations

In Mongolia, the district heating system follows a fixed seasonal schedule, dictated by climatic conditions and operational logistics. The heating season officially begins on 15 September and ends on 15 May each year. During this 8-month period, heating infrastructure including coal-fired plants and distribution pipelines operates continuously to provide warmth for residential, educational, and institutional buildings. The remaining four months (15 May to 15 September) are considered the off-season, during which space heating is suspended. This scheduling reflects the significant temperature variations between Mongolia's bitter winters and relatively mild summers.

While the district system shuts down during summer for maintenance, cleaning, and inspection, solar thermal systems continue to produce heat, especially given that June, July, and August are among the sunniest months in Mongolia, with long daylight hours and high solar irradiance. This creates a seasonal energy surplus for systems like GMIT's, which are designed to generate heat year-round. Without thoughtful planning, this summer surplus can lead to system inefficiencies, stagnation of fluid in collectors, or even overheating especially if there is no demand from the building's heating circuits.

To address this, the system design must incorporate summer-use strategies, ensuring that solar energy generated during the off-season is not wasted. Several solutions are proposed:

Domestic Hot Water Preheating:

Although space heating is suspended, hot water demand remains year-round. Solar collectors can be reconfigured seasonally to supply domestic hot water (DHW) for dormitories, kitchens, and staff housing. This ensures that the system continues to offset electricity or coal used for water heating during the summer.

Seasonal Thermal Storage:

A large insulated water tank (e.g., 200–300 m^3) can store excess solar heat over days or even weeks. While this cannot bridge the entire summer-winter gap, it allows day-night and week-scale smoothing, supporting September start-up or May shut-down transitions. Stored heat could also be used for occasional laboratory or kitchen needs.

Process Loads and Small Heating Loads:

During summer, the surplus thermal energy can be diverted to low-temperature industrial or laboratory processes, laundry systems, or preheating ventilation air in buildings that remain partially active. These loads, though modest, help utilize collector output and prevent overpressure events in the circulation loop.

3. Comparative Analysis of Heating System Configurations

In the quest to enhance energy efficiency and sustainability, especially in colder climates like Mongolia, the choice of energy-generating systems for heating has garnered significant attention. Both solar thermal collectors and photovoltaic (PV) panels are commonly used for renewable energy generation, but their application in heating systems, particularly for space heating, differs markedly. This section explores why solar thermal collectors are a more viable choice than PV panels for GMIT's heating needs, considering efficiency, cost, space requirements, system integration, and maintenance.

1. Efficiency in Converting Solar Energy into Heat

One of the primary factors influencing the choice between solar thermal collectors and PV panels is the efficiency of energy conversion. Solar thermal collectors, such as the Heliodyne Gobi 408-001, are specifically designed to capture sunlight and directly convert it into heat, which can then be used for heating purposes. These systems achieve a thermal efficiency of around 50-70% depending on the collector type and the ambient temperature.

On the other hand, PV panels, like the 460W JA Solar panel, convert sunlight into electricity at an average efficiency of 15-20%. While PV systems have improved in terms of efficiency, the electricity generated must then be converted into heat, usually through resistive heaters or heat pumps, both of which introduce additional losses. The coefficient of performance (COP) of heat pumps typically ranges from 3-5, meaning that for every unit of electricity, three to five units of thermal energy can be generated. However, even with a heat pump, the energy conversion process is still less efficient than directly capturing solar energy as heat.

In cold climates, thermal systems tend to perform better as they are designed to operate efficiently even at low temperatures. In contrast, PV panels may be less effective due to the lower solar radiation in winter months, and additional energy losses occur in the conversion to electricity, and then to heat.

2. Space Efficiency and Installation Costs

Another crucial factor is space efficiency. The GMIT campus has a significant amount of unused rooftop space on its academic and dormitory buildings. The Heliodyne Gobi 408-

001 collectors have a relatively large surface area (2.77 m² per collector), but this size is optimized for direct heat production, ensuring that a significant portion of the available energy is utilized for heating.

When compared to PV panels, which also require a significant amount of space, the energy output per square meter for thermal collectors in winter conditions is far superior. The PV panels, although smaller in area per unit (about 2.22 m² per 460W panel), would require more panels to achieve the same thermal output because their conversion efficiency into heat is lower.

For GMIT, given the amount of rooftop space available, installing solar thermal collectors is more efficient in utilizing space for thermal energy generation. This configuration also minimizes the additional equipment required, such as inverters and electrical storage, which would be necessary for a PV-driven system. In comparison, solar thermal systems are simpler and more direct, needing fewer components to deliver the required energy.

3. Cost Comparison

Cost is always a significant factor in choosing the appropriate technology. While initial investment costs for solar thermal collectors and PV systems can vary, the thermal collectors tend to be more cost-effective for heating applications. The levelized cost of heat (LCoH) for thermal systems is generally lower than that for PV systems when the latter are used in conjunction with heat pumps. In a typical installation scenario, solar thermal collectors can offer a lower installed cost per unit of thermal energy compared to the costs of a PV system plus the required heat pump or resistive heating system.

For instance, a 460W photovoltaic (PV) panel typically costs between $100 and $150 per panel, but once the cost of a heat pump, inverter, electrical wiring, and installation is included, the total system cost can exceed $1,500 per kW installed. This makes PV-based heating (especially with heat pumps) a significantly more expensive upfront option for thermal applications. In contrast, solar thermal collectors such as the Heliodyne Gobi 408-001 are purpose-built for direct heat generation and offer better cost efficiency in thermal energy delivery. The Gobi 408-001 collector, which has a gross area of approximately 2.98 m², typically costs around $1,200–$1,500 per unit installed, depending on local labor and balance-of-system components. This results in a cost of about $400–$500 per square meter of collector area. Given its ability to deliver up to 1.7 kW of thermal power per panel under peak conditions, the installed cost per kW is approximately $800–$900, making it significantly more cost-effective for large-scale space heating compared to PV-based systems. For GMIT's long-term heating needs

especially in cold climates with high heat demand and limited electricity budgets solar thermal emerges as a more suitable and economically viable solution.

4. System Integration

The integration of solar thermal systems into GMIT's existing heating infrastructure is relatively straightforward. The campus already utilizes a hydronic heating system, where hot water is circulated through radiators to provide heat. Solar thermal collectors integrate directly with this system, using a heat exchanger to transfer heat from the collector to the water circulating through the radiators. This process is simple and efficient, requiring minimal additional infrastructure.

In contrast, PV systems would require an additional layer of complexity. The electricity generated by the PV panels would need to be converted into heat using either electric resistance heaters or heat pumps, both of which require inverters and other electrical components. The installation of such systems would increase both the complexity and cost of the project. Additionally, since PV systems generate electricity, they would require a storage solution to manage the intermittent nature of solar power, adding further to the upfront cost and operational complexity.

5. Maintenance and Reliability

The maintenance of PV panels is relatively straightforward due to their passive operation. Once installed, they require minimal upkeep, typically limited to cleaning and occasional inspections. The longevity of PV panels is typically around 25 years, with a warranty guaranteeing 80% of rated power output after this period.

Solar thermal systems, while requiring more maintenance than PV panels, are still quite reliable. The main maintenance requirements for thermal collectors are checking and replacing the glycol solution (which can degrade over time), maintaining pumps and controllers, and ensuring that the collectors remain free of dirt and debris. These systems typically have lifespans of 20-25 years, with maintenance needed every 5-10 years. In practice, thermal systems require a little more service compared to PV but are robust in cold climates and typically require less intervention than more complex PV systems combined with heat pumps.

The performance of 100 PV panels and 100 solar thermal collectors were simulated in SAM.

Table 2 Collector vs Panel

PV	Electricity generated PV (kWh/mo)	System Energy (kWh/mo) Collector
JAN	3584.96	385.929
FEB	4260.55	358.559
MAR	5835.26	397.294
APR	6463.19	374.75
MAY	6942.76	368.984
JUN	6527.82	338.577
JUL	6006.72	332.906
AUG	5934.98	323.72
SEP	5449.72	314.885
OCT	4077.45	335.451
NOV	2959.09	341.106
DEC	2947.71	371.079

Solar thermal collectors, even though they produce less total energy than PV panels in terms of electricity, are designed specifically for heating applications. Therefore, the thermal energy generated is directly usable without needing conversion, which makes thermal collectors highly efficient for space heating. PV panels require an additional step (electricity → heat), which results in higher inefficiency for direct heating purposes. The 100 PV panels consistently generate higher electricity output every month than the 100 solar thermal collectors. However, solar thermal collectors generate thermal energy, which is directly usable for heating applications, whereas PV panels generate electricity, which requires conversion (either through heat pumps or electric resistance heaters) to be used for heating.

3.1 System Overview

In this study, three different heating system configurations were explored for the GMIT campus, each representing a different approach to balancing sustainability, reliability, and cost. These are:

1. A **fully renewable system**, powered entirely by solar and wind energy,
2. A **hybrid system**, where most of the energy comes from renewables, with additional support from the existing district heating network,
3. A **traditional system** that relies fully on centralized heating from the power plant.

The goal of this comparison is to understand which system would best support the campus's growing energy needs in a reliable, efficient, and environmentally responsible way.

Figure 10 Heating system

Solar Collectors:

- The system begins with **solar thermal collectors**, typically installed on rooftops or areas with optimal sunlight exposure. These collectors absorb solar radiation and convert it into heat. The fluid inside the collector absorbs this heat.

Controller & Pumps:

- When there is sufficient heat in the solar collectors, a **controller** activates the **pumps** to circulate the heated fluid from the collector. The controller ensures the system operates efficiently by controlling when to pump the heated fluid into the system.

Heat Transfer:

- The heated fluid flows through a **heat exchanger** (step 3), where the heat from the fluid is transferred to the water stored in the **storage tank** (step 4). This process is crucial because it ensures that the water in the tank is heated to the desired temperature for use in space heating or domestic hot water.

Storage Tank:

- The **storage tank** (step 4) stores the heated water for later use. The tank is typically well-insulated to prevent heat loss, ensuring that the hot water remains at an optimal temperature even when the sun is not shining.

Re-circulation:

- Once the heat is transferred to the water, the cooled fluid is pumped back to the **solar collectors** (step 5) to be reheated. This creates a continuous loop of heat transfer, ensuring that the system efficiently provides hot water whenever it is needed.

Backup Heating System:

- On days when there is little or no sunlight, the system relies on a **backup heating system** to provide hot water. This could be an **electric heater, boiler, or other heating system** that ensures the building has enough heat to maintain comfort levels. The backup system is activated when the temperature of the water in the storage tank drops below a set threshold, ensuring that heating needs are consistently met.

3.1.1 Fully Renewable System

The fully renewable option is the most ambitious of the three configurations considered in this study. This system aims to meet the entire winter heating demand of the GMIT campus, which is estimated at approximately 700 kW, using only solar thermal energy and wind-generated electricity. This model does not utilize district heating or fossil fuel backup. Renewable energy will be provided by solar thermal collectors installed on

building rooftops. At the same time, any shortfalls during periods without sunlight will be supplemented by electricity from the Salkhit Wind Farm, accessed through the national grid.

Several assumptions were made to estimate the number of solar collectors needed to meet a demand of 700 kW. The Gobi 408 001 collector was chosen due to its effectiveness in cold climates, proven performance, and compatibility with glycol-based working fluids that prevent freezing. Each collector has a gross area of approximately 2.98 m² and is expected to deliver around 1.7 kW of thermal energy under average winter sun conditions in Ulaanbaatar. Based on these estimates, approximately 450 collectors would be required to supply the 700 kW demand. Together, these collectors would occupy roughly 1,345 m² of rooftop area, which is within the 1,900 m² of usable roof space available across four buildings on the GMIT campus.

Table 3 Fluid comparison

Feature	Water	Glycol (Antifreeze mix)
Specific heat	4.18 kJ/kg·°C (higher)	~3.6–3.8 kJ/kg·°C (lower)
Freezing Point	0 °C	–20 °C or lower
Efficiency	Slightly more efficient	Slightly less efficient due to viscosity
Best Use Case	Warm climates or drainback systems	Cold climates with freezing risk

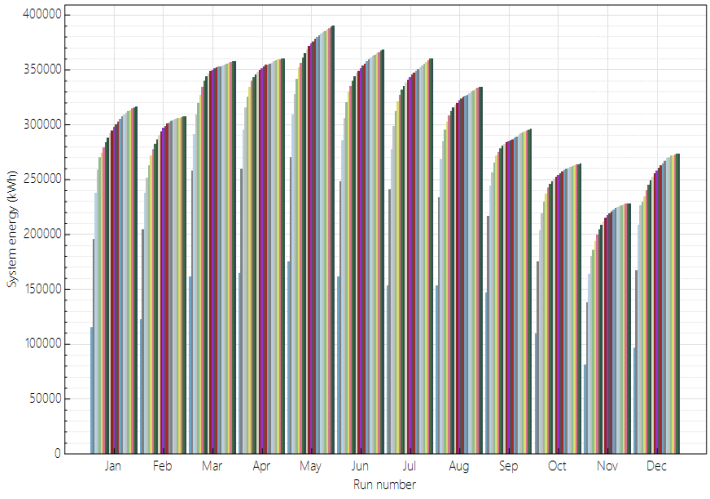

Figure 11 Comparison different numbers of collectors

The graph and table illustrate the relationship between the number of installed solar thermal collectors and the total energy generated by the system throughout the year. As

the number of collectors increases, the system's monthly energy output also rises, but only up to a certain point. In the early stages, increasing the collector count from 450 to about 4500 results in a noticeable improvement in energy generation across all months. This indicates that the system is still operating within an efficient range, where each additional collector meaningfully contributes to the overall thermal output.

However, as the system grows beyond roughly 5000 collectors, the increase in energy generation becomes much smaller. This trend reflects diminishing returns: while the collector area continues to grow, the energy output no longer rises proportionally. Essentially, the system becomes oversized, and the additional collectors add cost without significantly boosting performance.

Looking at the monthly data, the system is capable of generating high energy levels during spring and summer, particularly from March to August. Even in colder months like January, February, and December, when solar radiation is typically lower, the system with around 4500 to 5000 collectors still manages to supply a substantial portion of the heating demand. This demonstrates that a well-designed solar thermal system can reliably contribute energy across the entire year.

From a practical standpoint, this analysis suggests that installing around **4500 to 5000 solar collectors** offers the best balance between system efficiency, cost, and annual performance. Beyond that point, the marginal gains are too small to justify the extra expense and space. For year-round heating coverage, especially in cold climates like Mongolia’s, a properly sized system supported by **a hybrid backup source**, such as wind or grid electricity, is the most effective and sustainable approach.

Based on the aerial image, the combined rooftop area of the three buildings shown, including the newly added rectangular laboratory, adds up to around 6,000 square meters. To estimate how many solar thermal collectors can realistically be installed on these rooftops, we consider both the physical size of the collectors and practical installation constraints.

The solar collector model used in this project, Heliodyne Gobi 408 001, occupies about 2.98 square meters per unit. However, in real installations, not all rooftop space can be used entirely due to spacing requirements for maintenance, shading prevention, and proper mounting. Typically, only about 75% of the total roof area is considered usable for collectors.

Using this assumption, around 4,950 square meters of the rooftop would be available for collector installation. Dividing that by the area of a single collector:

$$4950 \div 2.98 \approx 1661$$

So, under realistic conditions, approximately 1,660 solar thermal collectors could be installed across these rooftops. This makes full use of the space while ensuring system efficiency and accessibility. This number plays a key role in modeling the system's ability to meet heating demands year-round and supports the case for large-scale renewable integration on campus.

Table 4 1661 vs 4500

	System energy (kWh) 4500p	System energy (kWh) 1661p	Difference	Total cons.
JAN	291570	253019	38551	350536.407
FEB	289887	246385	43502	283860.320
MAR	346596	304486	42110	265640.340
APR	347815	310644	37171	185307.224
MAY	368193	324019	44174	56039.528
JUN	346866	300224	46642	
JUL	337683	292669	45014	
AUG	317680	281078	36602	
SEP	281779	253962	27817	63888.505
OCT	250304	215412	34892	206408.377
NOV	211921	175510	36411	278095.658
DEC	252392	221486	30906	337195.618

The comparison between the two systems clearly shows the advantages of having a larger solar thermal collector array to meet the campus's heating demands. The system with 4,500 collectors consistently generates more energy than the system with 1,661 collectors, particularly during the colder months when heating demand is at its highest. The difference in output, which varies seasonally, shows that the additional collectors in the larger system are crucial for meeting the campus's heating needs, especially during periods of high demand.

However, during the warmer months, the larger system generates more energy than is required, importance of energy storage or integration with backup systems such as wind or grid energy to manage this surplus. This system provides an effective and sustainable way to meet the heating demand throughout the year while ensuring flexibility and adaptability in energy supply.

Table 5 Residual demand

	System energy (kWh) 4500p	Total Cons.	Residual Cons.	System energy (kWh) 1661p	Total Cons.	Residual Cons.
JAN	291570	350536.4	58966.40	253019	350536.40	97517.40
FEB	289887	283860.32	-6026.67	246385	283860.32	37475.32
MAR	346596	265640.34	-80955.65	304486	265640.34	-38845.65
APR	347815	185307.22	-162507.77	310644	185307.22	-125336.7
MAY	368193	56039.52	-312153.47	324019	56039.528	-267979.47
JUN	346866		-346866	300224		-300224
JUL	337683		-337683	292669		-292669
AUG	317680		-317680	281078		-281078
SEP	281779	63888.50	-217890.49	253962	63888.50	-190073.49
OCT	250304	206408.37	-43895.623	215412	206408.37	-9003.62

NOV	211921	278095.65	66174.59	175510	278095.6	102585.65
DEC	252392	337195.61	84803.6177	221486	337195.61	115709.61

In the data provided, it is evident that even with the installation of 4,500 solar collectors, which generate a significant amount of energy, there remains a gap between the total energy consumption and the energy generated by the solar collectors, particularly during the peak winter months (e.g., January, February, and December). The residual consumption shows that the solar system alone, even with an increased number of collectors, is not enough to meet the total heating demand for the campus during the coldest periods. With this evidence, the dependency on the Nalaikh power distribution will not be terminated even if we install the highest system as possible. This ensures that GMIT cannot supply the total heat demand by itself.

3.1.2 Hybrid system

Table 6 Hybrid system collector output

	System energy (kWh)	Total consumption	From power station (kWh)
JAN	253019	350536.4067	97517.4067
FEB	246385	283860.32	37475.32001
MAR	304486	265640.3404	-38845.65963
APR	310644	185307.2242	-125336.7758
MAY	324019	56039.52814	-267979.4719
JUN	300224		-300224
JUL	292669		-292669
AUG	281078		-281078
SEP	253962	63888.50543	-190073.4946

OCT	215412	206408.3769	-9003.623114
NOV	175510	278095.658	102585.658
DEC	221486	337195.6177	115709.6177

This table shows how much of the campus's heating demand is met by the installed solar collectors throughout the year, and where additional energy is still needed. The first column lists the energy produced by 1,661 solar collectors installed across the rooftops. For example, in January, these collectors generated about 253,000 kWh of thermal energy. The second column shows the total heating energy needed each month to keep all buildings warm, including dormitories, lecture halls, and the planned lab building. In colder months like January and December, the demand is very high, reaching over 350,000 kWh.

The third column, residual energy, tells us whether the solar system alone is enough. When the number is positive, it means there is a shortfall that must be covered by another energy source, like wind power or a conventional heating plant. In January, for instance, the solar collectors couldn't cover the full demand, leaving a gap of around 97,500 kWh. On the other hand, when the number is negative, it means the solar system produced more than needed. In May, the system generated about 268,000 kWh more than what was required.

From this table, it is clear that while solar energy can meet a large part of the campus's heating demand, especially in the spring and summer months, additional energy sources will still be needed during the winter. This supports the idea of using a hybrid system, one that combines solar energy with backup sources like wind power to ensure consistent and reliable heating year-round.

To make sure the heating system is reliable year-round, we need to cover this remaining gap using additional sources, mainly electricity or heat from the Salkhit Wind Farm and, when necessary, from a conventional power plant. Since wind energy tends to be more available during cold, cloudy days when solar production drops, it is a strong complement to solar. However, because wind is variable, it cannot always meet demand on its own. That's why we propose a balanced hybrid setup: use wind energy as the primary backup and turn to the conventional power plant only when needed.

The remaining heating demand, referred to as residual energy, is the portion that cannot be covered by the solar thermal system and must be supplied by alternative sources. In this study, the backup energy is assumed to come from the national grid, which integrates electricity from both conventional fossil-fuel power plants and renewable sources such as the Salkhit Wind Farm. The Salkhit Wind Farm, located approximately 70 km southeast of Ulaanbaatar, is Mongolia's first utility-scale wind energy project. With an installed capacity of 50 MW, it supplies clean energy directly into the central electricity transmission grid, contributing approximately 5% of the country's total electricity supply [1].

Since both wind energy and electricity from coal-fired power plants feed into the same grid, any electricity consumed for backup heating will be a mixture of both renewable and non-renewable sources. Therefore, while grid electricity is often referred to as "conventional" in broad terms, a portion of it can be reasonably attributed to wind energy. By analyzing the seasonal grid mix and generation statistics, it is possible to estimate that 10–15% of the residual electricity demand used for heating may be indirectly covered by renewable wind energy, even though it is not physically separated from other sources.

Figure 12 Solar Collector Placement

This integration underscores the importance of expanding grid-connected renewable energy projects in Mongolia. Even though the residual heating demand is covered by "grid electricity," it is not entirely dependent on fossil fuels. As the share of renewables like wind continues to increase, the carbon footprint of grid-based backup heating will progressively decline, aligning well with the long-term sustainability goals of the GMIT campus energy system.

3.1.3 Traditional system

One distinct operational advantage of the traditional, coal-based heating system is its on-demand generation approach. Unlike renewable energy systems—especially solar thermal systems that can produce excess heat during low-demand months—the traditional system is load-following. This means it produces heat in direct response to the actual demand from campus buildings. During summer months (typically May to September), when no space heating is needed and the central district heating network halts supply (from May 15 to September 15), the coal-based system simply stops or reduces output accordingly. As a result, there is no surplus energy that needs to be stored, redirected, or managed, unlike in solar-powered systems where surplus heat during summer can become a logistical or design challenge.

This characteristic makes the traditional system operationally simple and predictable, eliminating the need for complex storage systems or load balancing strategies. It also avoids issues such as thermal oversupply, tank overheating, or system stagnation that may arise in renewable-based systems without sufficient seasonal storage. However, while this may seem efficient from a thermal management perspective, it comes at the cost of high emissions, fossil fuel dependency, and lack of sustainability, which are the primary drivers behind the consideration of hybrid or fully renewable heating alternatives.

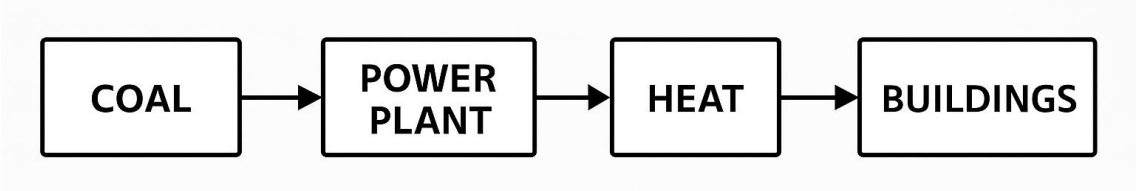

Figure 13 Block diagram of traditional system

3.2 Thermal Storage

To support the solar thermal system comprising 1,661 flat-plate collectors installed across GMIT campus buildings, an appropriately sized thermal energy storage tank is required. This storage unit will buffer solar heat, enabling stable indoor heating even during non-sunny periods such as nights or cloudy days.

Based on simulation data:

* Peak monthly energy output from 1,661 collectors~324,000 kWh
* Daily average in May: 324,000 kWh ÷ 31 ≈ 10,450 kWh/day
* Lower months: ~7,100 kWh/day

To effectively buffer this energy and maintain heat delivery during non-sunny periods, such as at night or on cloudy days, a 200,000-liter (or 200 m^3) thermal storage tank has been selected. The storage tank serves as a thermal buffer, absorbing surplus heat generated during peak periods and releasing it when solar input is insufficient. For the purpose of energy storage calculations, the specific heat capacity of the storage medium, assumed to be water, is taken as 4.18 kJ/kg·°C, and the density is assumed to be 1 kg/L.

Storage Tank Capacity:

* Tank volume = 200,000 liters

* Specific heat (cp) ≈ 4.18 kJ/kg·°C

* Density ≈ 1 kg/L

* Assumed temperature differential (ΔT) = 40 °C

Stored thermal energy:

$Q = m \times cp \times \Delta T = 200{,}000\ kg \times 4.18\ kJ/kg\cdot°C \times 40\ °C = 33{,}440{,}000\ kJ = 9{,}288\ kWh$

The 200 m^3 tank can store up to 9,288 kWh, which is about 89% of the daily output from the 1661 collectors during the highest-yielding month.

$$\text{Hours} = 9288/700 = 13.3$$

This high storage-to-output ratio ensures that the majority of the thermal energy harvested by the solar system can be retained and used as needed, significantly improving the system's reliability and maximizing solar energy utilization. As a result, the thermal storage system not only smooths out daily fluctuations in solar availability but also supports a consistent indoor heating supply for the campus, even under variable weather conditions.

4. Economic assessment

Table 7 CAPEX

	Hybrid system	Full System	Current
Payment to power station	₮ 84,050,000	₮ 2,585,387.90	284,891,689.3
Saved	₮ 200,850,000	₮ 282,306,301.40	0
Loss in summer	-₮ 10,762,616.24	-₮ 12,342,064.11	0
Investment	₮ 11,736,000,000	₮ 30,783,600,000	0
Total	₮ 13,632,252,324.8	₮ 30,491,537,022.39	₮ 284,891,689.30

1. Hybrid System

In the hybrid heating configuration proposed for the GMIT campus, the majority of the annual thermal energy demand is met through renewable sources—specifically, solar thermal collectors and wind-generated electricity. However, to ensure reliability during periods of low solar and wind output, approximately 400 kW of peak heating load is supplemented by conventional district heating from the power station. This balance between renewables and backup heat creates a resilient and cost-effective system.

- The residual heating demand not met by 1,661 solar collectors and wind power totals approximately 353,288 kWh/year. At the 2025 district heating rate of ₮66,082/GJ, this results in an annual backup cost of ₮84.05 million—significantly lower than the current ₮284.89 million under full reliance on centralized heating.
- With the new hybrid configuration, GMIT achieves an estimated 200.85 million tugrik in annual savings.
- A small loss of ₮ 10.76 million occurs in summer when the solar system produces excess heat not used for space heating.
  The required capital investment for this system is ₮ 11.736 billion.

2. Fully Renewable System

This setup eliminates the need for any fossil fuel backup by relying entirely on solar thermal collectors and grid electricity sourced from wind farms like Salkhit:

- The power plant payment drops further to just ₹ 2.59 million.
- Annual savings increase slightly to ₹ 282.3 million.
- However, summer surplus losses also increase to around ₹ 12.34 million, due to greater oversupply during the non-heating season.
- The upfront investment for this system is substantially higher, estimated at ₹ 30.78 billion.
- Thus, the total cost of the fully renewable system reaches ₹ 30.49 billion, making it more costly than the hybrid option despite its cleaner profile.

3. Current System

The traditional heating system involves paying the full cost of heating to the central power plant:

- Annual payments remain at ₹ 284.89 million, with no savings or surplus-related losses.
- While this system requires no initial investment, it results in the highest ongoing operational costs, with no contribution toward decarbonization or long-term cost reduction.

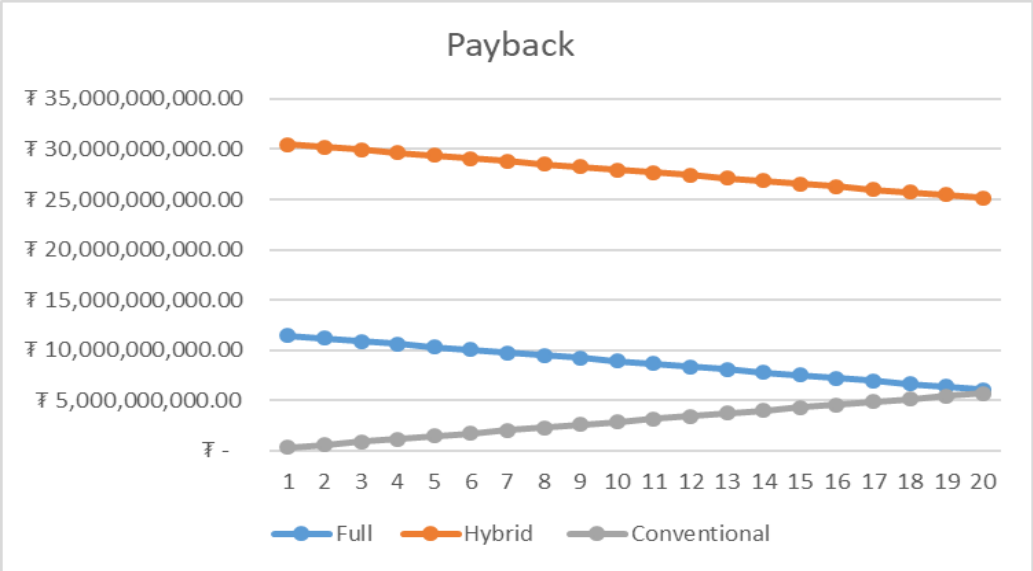

Figure 14 Payback Period

The graph compares the cumulative cost of each system, including both initial capital expenditure and ongoing annual payments, over time, providing insights into their long-term economic viability.

Hybrid System (Orange Line)

The hybrid system, while requiring a substantial initial investment of approximately ₮11.74 billion, benefits from significant annual savings, estimated at over ₮280 million per year. This leads to a steady decline in the total system cost over time. By year 20, the total cost of the hybrid system drops to about ₮5.7 billion, making it the most cost-effective option in the long term. The graph clearly shows a consistent and predictable decline, reflecting the stability of this solution.

Fully Renewable System (Blue Line)

Although the fully renewable system eliminates almost all reliance on grid electricity and achieves the highest environmental benefit, it comes at a much higher upfront cost, over ₮30.78 billion. Annual savings are slightly higher than the hybrid system but not enough to offset the large initial expense within 20 years. By the end of the analysis period, the fully renewable system is still more expensive than the hybrid, despite the absence of fossil-fuel-related operational costs. This indicates a longer payback period and highlights the need for subsidies or external funding if this system is to be considered economically viable in the short-to-medium term.

Current Conventional System (Gray Line)

The conventional system has no capital investment, but incurs a fixed annual payment to the power plant of approximately ₮285 million. As a result, its cumulative cost increases linearly year by year. By year 20, the total expenditure surpasses ₮5.7 billion, and is projected to continue rising indefinitely. This approach offers no return on investment, no carbon savings, and remains entirely dependent on fluctuating energy prices and fossil fuel supply.

This payback comparison shows that although the conventional system requires no upfront investment, it becomes more expensive over time and does not support sustainable development. The hybrid system, in contrast, balances affordability, carbon reduction, and long-term savings, making it the most rational and resilient solution for the GMIT campus.

5. Discussion

This thesis comprehensively evaluated three potential heating solutions for the GMIT campus by integrating climatic, spatial, technical, and financial data. The discussion focuses on five key areas: performance of the solar collectors, storage limitations, economic outcomes, seasonal mismatch, and system flexibility.

The simulation results highlight the strengths of solar thermal collectors over photovoltaic panels for direct space heating in cold regions. Despite PV panels generating more total energy per unit, thermal collectors directly deliver usable heat, minimizing conversion losses. In winter, the Gobi 408-001 collectors showed higher efficiency and practicality, especially when integrated into existing hydronic heating systems.

However, even with 4,500 collectors installed (the full-scale renewable system), peak winter demands could not be fully covered, showing shortfalls of up to 60,000-90,000 kWh in months like January and December. The storage tank, designed to hold around 200,000 liters, is capable of buffering nearly 9,300 kWh, sufficient to handle daily fluctuations but not seasonal deficits. This underscores the critical role of supplemental energy sources.

The hybrid system solves this limitation by relying on renewable sources most of the year and utilizing electricity from the grid (partially wind-sourced) only during high-demand periods. The economic model showed the hybrid system saves around ₮280 million annually in operating costs while maintaining system simplicity and reducing environmental impact. Compared to the fully renewable system, which had significantly higher capital costs (~₮30.7 billion vs. ₮11.7 billion), the hybrid model reached a more favorable 20-year payback threshold.

Meanwhile, the conventional system, while simple and capital-free, continued to accumulate costs year after year, reaching ₮5.7 billion after two decades. More importantly, it lacks any contribution toward Mongolia’s broader decarbonization goals and exposes the campus to fluctuating fuel prices and rising grid tariffs.

Seasonal variation remains the main technical hurdle for solar heating. The central heating system shuts down from May 15 to September 15, during which solar collectors generate surplus heat. This creates a design challenge. The surplus can be redirected for domestic hot water or stored if seasonal tanks are introduced, but without these, energy is wasted.

Overall, the hybrid system provides the most practical and balanced solution. It leverages Mongolia's excellent solar resources, takes advantage of wind energy during cold cloudy days, and uses the existing infrastructure for peak reliability.

The results of this study show that while a fully renewable heating system is technically achievable, it is currently not cost-effective due to high upfront capital costs and underutilized summer surplus. The traditional coal-based system, while reliable, is unsustainable economically and environmentally.

The hybrid system emerges as the most viable path forward. It uses rooftop solar thermal collectors to provide most of the annual heating demand and supplements this with grid electricity, partly sourced from wind power, to meet shortfalls in the winter. With a modest investment (₮11.7 billion), it reduces dependence on fossil fuels, ensures year-round comfort, and reaches payback within 15–18 years.

Final Recommendation

We recommend that GMIT adopt the hybrid renewable heating configuration for its campus. This system strikes the best balance between cost, performance, and sustainability. It will reduce reliance on centralized coal-based heating, align with national renewable energy goals, and provide a replicable model for other institutions in similar climates.

Key implementation steps include:

- Installing 1,661 solar thermal collectors across 6,000 m^2 of available rooftop area.
- Constructing a 200 m^3 insulated thermal storage tank on the ground floor of the central building.
- Establishing grid connectivity prioritizing electricity from the Salkhit Wind Farm for supplemental heating.
- Integrating a basic electric boiler for peak demand coverage.
- Exploring future expansion toward a more fully renewable configuration with seasonal thermal storage.

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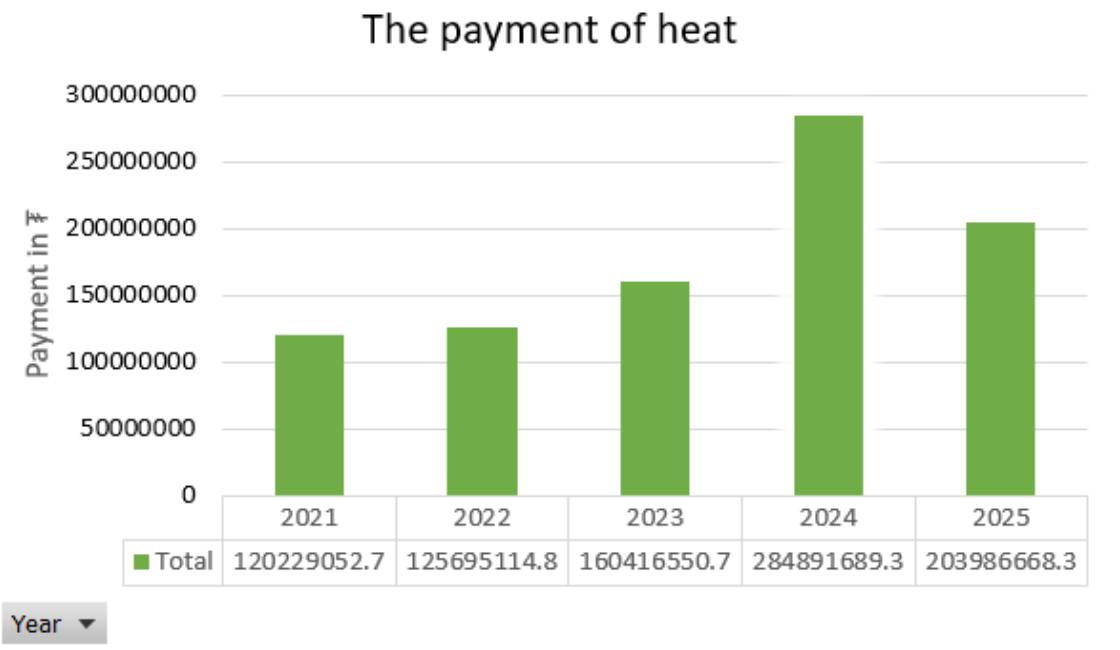
Appendices

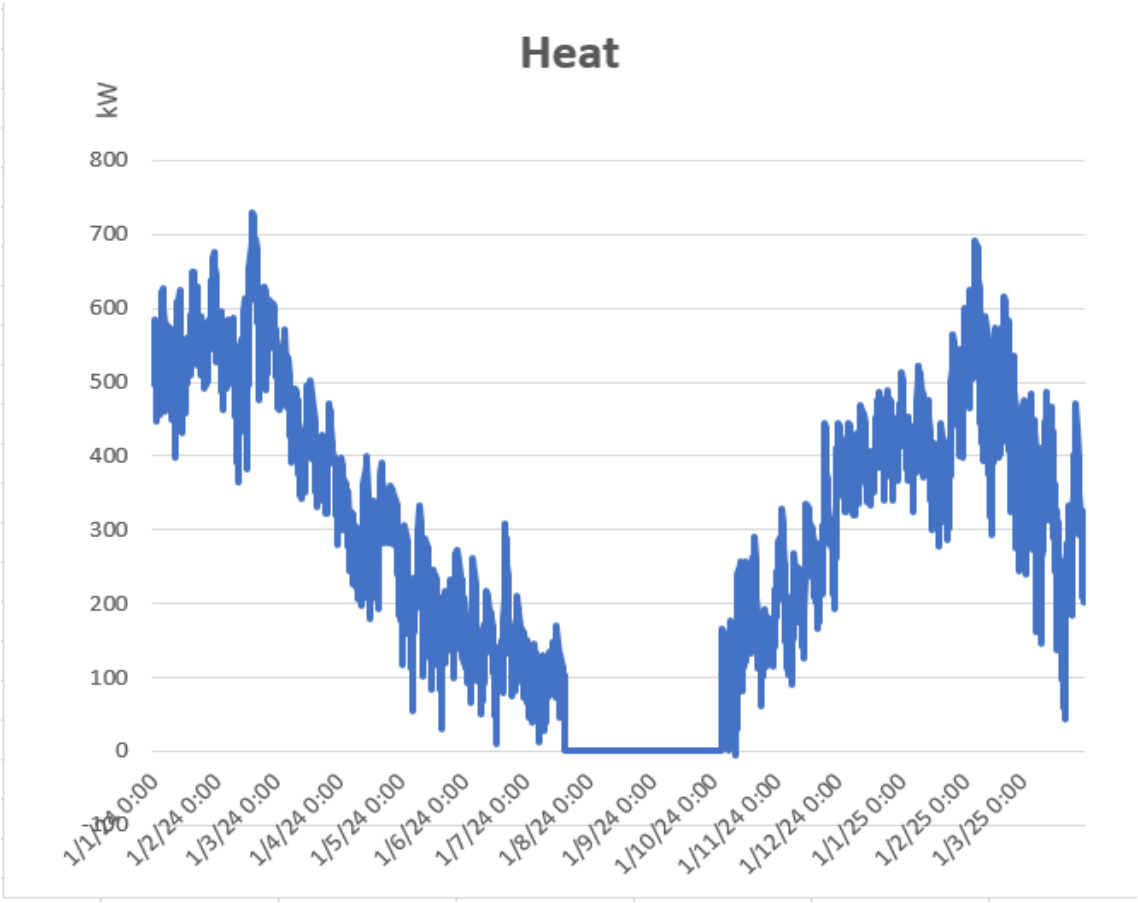


Appendix 1 The payment of heat

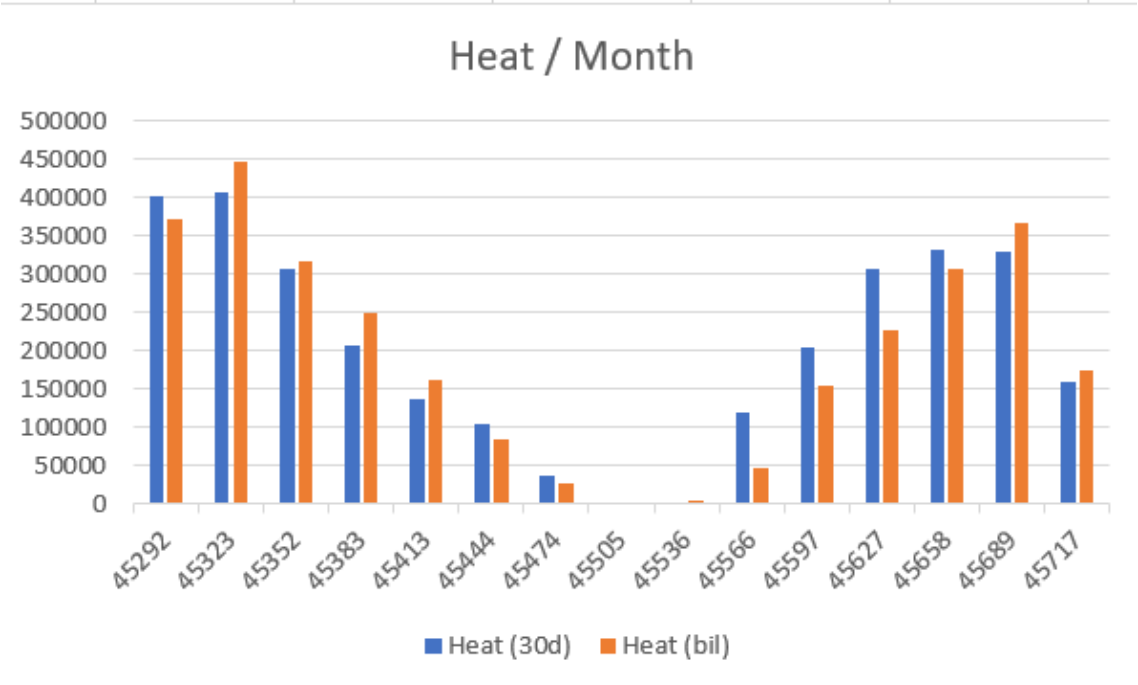
Date	Credit Money (₹)	Selling Price (₹) of 1GJ	Heat [GJ]	Energy	kWh	actual demand
2021.01.21	24,938,193.05	25813	966.110	695599.1	268366	372.73
2021.02.23	21,078,509	25813	816.585	587941.2	226831	295.3528403
2021.03.25	12,820,026.45	25813	496.650	357588	137959.4	179.6346836
2021.04.21	11,414,508.60	25813	442.200	318384	122834.3	189.5591296
2021.05.28	3,557,031.99	25813	137.800	99216.02	38278.09	106.3280287
2021.09.30	3,938,794	25813	152.590	109864.5	42386.32	117.7397906
2021.10.26	13,949,977.62	25813	540.425	389105.6	150119.1	240.575509
2021.11.30	13,326,864.71	25813	516.285	371725.2	143413.6	298.778432
2021.12.20	15,205,148	25813	589.050	424116	163626.3	340.8881438
2022.01.31	17,769,153	25813	688.380	495633.6	191218.2	265.5808283
2022.02.28	20,839,996.49	25813	807.345	581288.4	224264.3	333.7266282
2022.03.31	15,664,283.48	25813	606.837	436922.6	168567.2	226.5687928
2022.04.28	16,921,222.49	25813	655.531	471982.3	182093.4	270.9723358
2022.05.24	5,461,927.52	25813	211.596	152349.1	58777.14	94.19412913
2022.09.30	4,317,509.40	25813	167.261	120428	46461.77	129.0604821
2022.10.22	9,275,140.07	25813	359.321	258710.8	99812.05	189.0379707
2022.11.29	16,132,364	25813	624.971	449978.8	173604.3	195.5003441
2022.12.23	19,313,518.92	25813	748.209	538710.5	207837.5	369.5764418
2023.01.27	28,024,117.58	25813	1085.659	781674.5	301574.4	359.0171149

2023.02.28	23,248,506.69	25813	900.651	648468.8	250182.9	325.7589335
2023.03.28	21,443,427.23	25813	830.722	598119.8	230758	343.3898211
2023.04.26	13,986,503.08	25813	541.840	390124.4	150512.2	241.2054119
2023.05.23	9,273,492.27	25813	359.257	258664.8	99794.32	154.0035743
2023.09.28	3,060,621	25813	118.569	85369.66	32936.09	105.5643899
2023.10.23	7,289,010	25813	282.377	203311.8	78438.82	130.7313615
2023.11.24	13,963,606	25813	540.952	389485.8	150265.8	195.6585575
2023.12.21	20,813,748.40	25813	806.328	580556.3	223981.8	345.6509754
2024.01.30	59,048,993.52	33041	1787.143	1286743	496432.6	517.117288
2024.02.20	47,272,090.77	33041	1430.710	1030111	397422.6	788.5369797
2024.03.26	39,999,497.46	33041	1210.602	871633.4	336281	412.1090643
2024.04.24	28,592,785.21	33041	865.373	623068.5	240383.3	345.3782724
2024.05.24	15,866,762.34	33041	480.214	345754.3	133393.9	185.2693641
2024.09.30	10,908,769.18	33041	330.159	237714.2	91711.45	254.754018
2024.10.31	21,104,928.00	33041	638.750	459899.8	177431.9	238.4837159
2024.11.30	30,663,452.25	33041	928.043	668190.6	257791.6	358.0439524
2024.12.31	31,434,410.57	33041	951.376	684990.6	264273.2	355.2059045
2025.01.31	105,631,478.30	66082	1598.491	1150913	444028.8	596.8129211
2025.02.28	98,355,189.95	66082	1488.381	1071634	413442.5	615.2417565

Appendix 2 Bill



Appendix 3 Heat consumption



Appendix 4 Heat/Month

	Heat (cal) kWh	Heat (invoice) kWh
Jan 24	402.677	372.041
Feb 24	406.856	447.123
Mrz 24	307.401	316.597
Apr 24	207.092	248.615
Mai 24	136.683	161.807
Jun 24	105.182	85.553
Jul 24	35.604	27.807
Aug 24	0	0
Sep 24	2.326	3.971
Okt 24	121.064	47.153
Nov 24	203.807	154.779
Dez 24	302.984	225.999
Jan 25	329.035	306.619
Feb 25	324.521	365.736
Mrz 25	158.076	173.518
Sum tot	3.043.308	2.937.320
Sum 2024	2.231.675	2.091.446

Appendix 5 Heat(cal) vs Heat(invoice)