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Techno Feasibility Analysis for steam-to-hot Water Conversion for West Virginia University, Morgantown Campus

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ABSTRACT

The WVU campus in Morgantown, located in north central WV is identified to have elevated heat flows by low-temperature geothermal play fairway analysis of the Appalachian basin. Along with the elevated subsurface heat flows, WVU also has surface demand necessary to develop a deep direct-use geothermal system in the eastern United States. West Virginia University is currently using a steam-based water heating system. This study focuses on converting the current heating system to a geothermal deep-direct-use district heating system. A comprehensive evaluation of the current heating system is being conducted to determine the university's heating energy demand. Energy demand is calculated for the whole campus based on the equipment survey and readings from the steam meters. Based on the steam meter readings, the approximate hot water usage of the whole campus is in the range of 10,000-12,000 GPM (gallons per minute). For buildings where there are no existing data or steam meters available, the energy usage is estimated using e-Quest. The tool e-Quest (Quick Energy Simulation Tool) is available through the U.S. Department of Energy and can provide monthly building energy usage data for comparison purposes. The study includes an in-depth analysis of existing heating and cooling equipment, such as air handling units (AHUs) and heat exchangers, to determine their compatibility with hot water systems. The potential for retrofitting these systems to enhance energy efficiency, reduce operational costs, and contribute to the university's sustainability goals is evaluated. This retrofit requires significant infrastructure changes, including installing new pumps, pipes, and heat exchangers. A detailed study for retrofitting was conducted on one of the buildings, which includes air handling units, pumps, valves, and expansion tanks. The total retrofitting cost was found to be approximately $130,000. A preliminary hot water distribution model using Aspen HYSYS is developed, incorporating key system components like heat pumps and geothermal plate heat exchangers with a hot water distribution temperature of 180°F. Similarly, Aspen HYSYS models are developed to study and compare the normal hot water distribution model.

1. INTRODUCTION

Recently, deeper geothermal energy resources have been considered for direct-use applications, referred to as deep direct-use (DDU). At the same time, there is no standard that defines a system as "deep"; generally, 2 km is often used as a limit. DDU systems enable geothermal development in areas with lower geothermal gradients, such as the eastern United States. In these regions, deeper drilling is necessary to achieve target temperatures of less than 120°C, especially when compared to areas with higher geothermal gradients (Beckers et al., 2021). Direct-use applications, such as heating houses, buildings, and food processing, can be supplied with relatively low geothermal temperatures ranging from 50°C to 100°C. These temperatures are widespread throughout the country at low to moderate subsurface depths. Electricity production typically requires geothermal temperatures above 120°C, limiting these systems to higher-grade resources mainly found in the western United States (Beckers et al., 2021). The Department of Energy (DOE) Geothermal Technologies Office awarded $4 million to six DDU projects to increase the understanding of DDU technical performance and cost competitiveness. The locations of the six projects are shown in Figure 1.

Out of the six locations studied, Cornell University and West Virginia University (WVU), Morgantown campus, are focused on converting steam heating systems to Geothermal DDU heating systems. This research will conduct a detailed study of the technical and economic aspects of converting a steam heating system to a geothermal heating system for West Virginia University, Morgantown Campus.

The Morgantown Campus of WVU is situated in this Appalachian Basin region with elevated heat flows, which offers a desirable and unique combination of critical factors necessary to develop a deep direct use (DDU) of geothermal energy for district heating and cooling systems. The Morgantown campus of West Virginia University (WVU) is equipped to host the first geothermal deep direct-use district heating and cooling (GDHC) system in the eastern United States (Garapati, 2021)Garapati et al., 2019). While much of this region lacks elevated heat flow, the Morgantown area in West Virginia stands out due to the favorable temperatures found at the depth of the Tuscarora formation. This formation is anticipated to yield a desirable geothermal flow rate fluid (Zhang et al., 2020). As part of the Department of Energy (DOE)'s DDU research program, a GDHC system for the WVU Morgantown campus has been proposed to replace the current steam heating and cooling system. A typical method to understand a proposed geothermal system and reduce exploration risk is to perform subsurface modeling to predict reservoir impedance as well as thermal behavior for designs of interest.

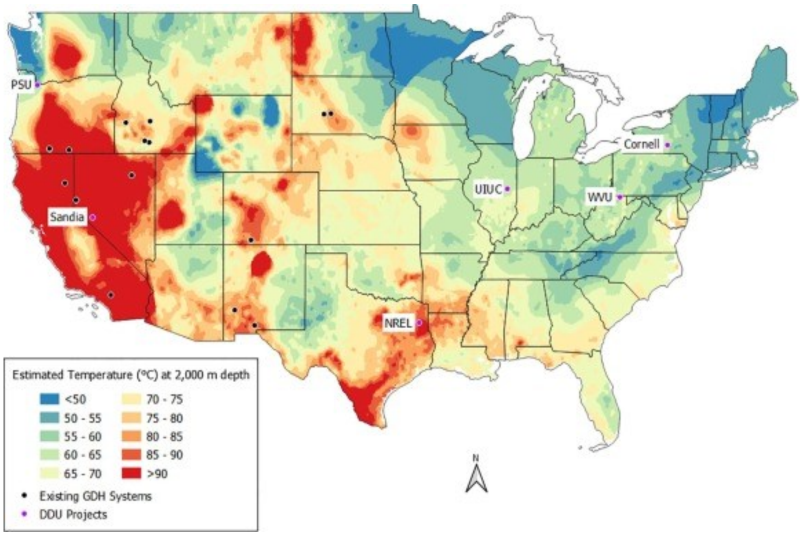

Figure 1: Locations of possible geothermal DDU projects and existing GDH system. (Beckers et al., 2021).

The Morgantown campus of West Virginia University (WVU) spans 1,892 acres and includes approximately 245 buildings. It comprises three main campuses: the Health Sciences Campus, the Evansdale Campus, and the Downtown Campus. The heating and cooling system for the WVU Morgantown campus operates using steam, which is provided by a district heating system that covers the entire campus (Garapati,2021).

There are five distribution points across the campus, as shown in Figure 2:

1. Health Sciences Distribution point
2. Towers Distribution point
3. Agriculture Annex Distribution point
4. Life Sciences Distribution point
5. Downtown Distribution point

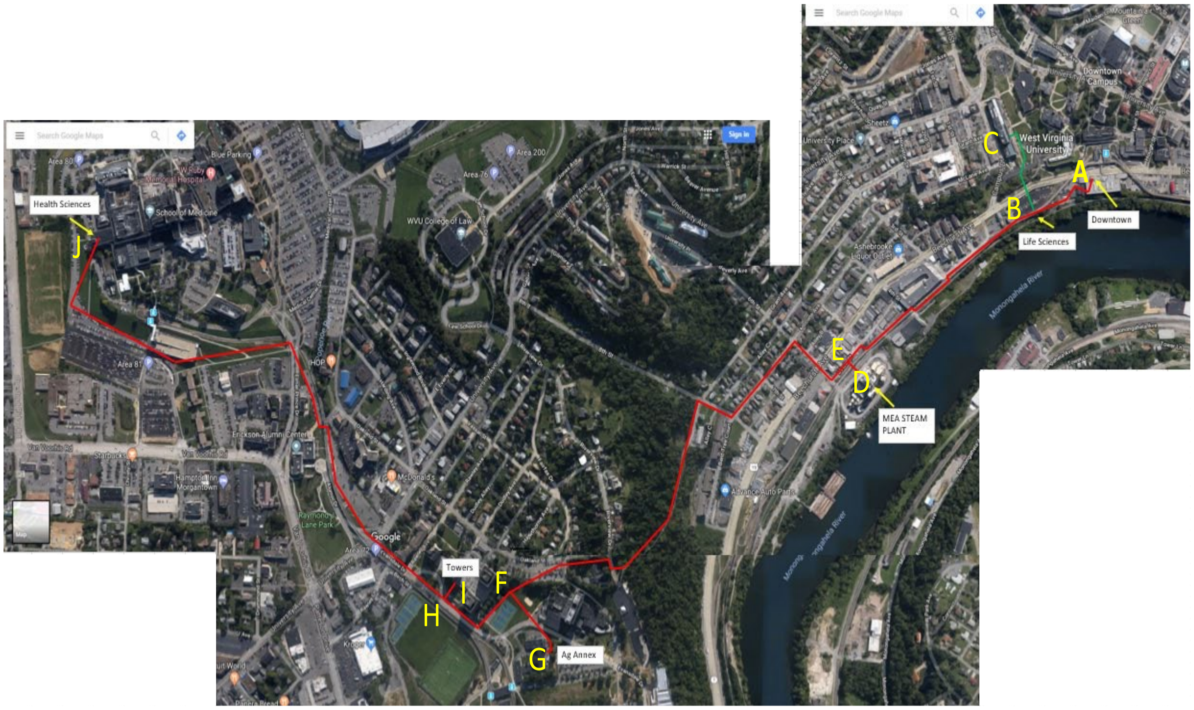

Figure 2: Google map showing the current locations of meter points and the distribution pipeline path. (Garapati, 2021).

Steam-powered systems are often outdated and inefficient, and their maintenance can be expensive. As they age, these systems also become hazardous. However, replacing these legacy steam systems with hot water district heating will reduce energy and water usage, improve indoor comfort and temperature control, and even integrate with renewable energy sources. Converting steam systems to more efficient hot water heating systems significantly reduces energy usage and carbon emissions. Hot water systems operate at a lower temperature than steam, which means they retain more energy in transmission and reduce water loss due to evaporation. This can result in up to 70% reduction in water use and waste heat loss (Hot Water District Heating).

2. SURFACE FACILITIES CHARACTERIZATION

To develop a hot water GDHC system, a thorough evaluation of the current steam utilization at WVU's Morgantown Campus is conducted with the help of the WVU Facilities Management. Steam meters have been installed in various buildings on campus to monitor weekly steam usage starting from June 2022. The data collected is analyzed monthly to study the peak and average usage for each month. Furthermore, the collected data is extrapolated to the buildings without steam meters to evaluate the steam usage of the entire campus.

As part of the current equipment evaluation on campus, an assessment is conducted to determine the effectiveness of the air handling units, heat exchangers, and other equipment responsible for heating and cooling across the campus regarding their compatibility with hot water. If needed, these systems will be retrofitted to improve their efficiency. This analysis will focus on both the technical feasibility of retrofitting the equipment to a hot water system and the financial implications of the proposed changes. It aims to create a more environmentally friendly and cost-effective heating and cooling system for the campus.

White Hall, a building located on the Downtown campus of WVU, is identified to perform a case study to calculate maximum energy demand based on an equipment survey, e-QUEST model, and also equipment analysis. The building's peak energy consumption was analyzed across different operational scenarios and seasonal conditions.

2.1 Characterization of Current Energy Demand

The university campus consists of a variety of buildings, each with a unique purpose and function. To study and estimate steam usage efficiently, all buildings have been categorized into four types based on their usage. These categories include classroom buildings, laboratory buildings, residential buildings, and general-use buildings. There are three different ways to determine the steam consumption of a building. They are:

2.1.1 Install Steam meters:

Steam usage data is collected from the existing steam meters and analyzed throughout the year for various building types. The results are plotted in Figure 3, which provides detailed information on the steam meter usage for December 2022. In addition to the old steam meter, four new clamp-on steam meters were installed in Brooks Hall, Hodges Hall, Armstrong Hall, and the Engineering Science building.

The steam usage of buildings with preexisting steam meters is analyzed to determine their maximum and average usage. This analysis is conducted over a 27-month period, starting in June 2022 and ending in September 2024. The results are plotted as a bar graph, as shown in Figures 4a and 4b, showcasing the average and maximum steam usage (PPH) for different locations. The graph indicates that the steam requirement is at its highest during the winter months of December, January, and February.

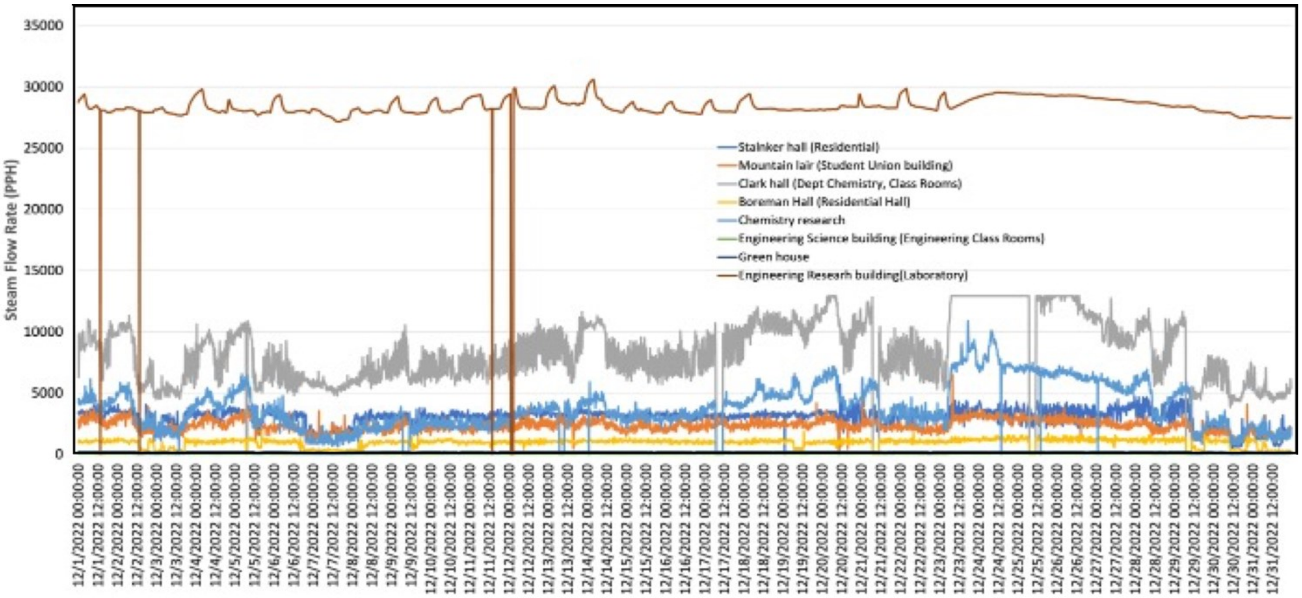

Figure 3: Steam flow rate (pph) from different buildings across WVU in December 2022.

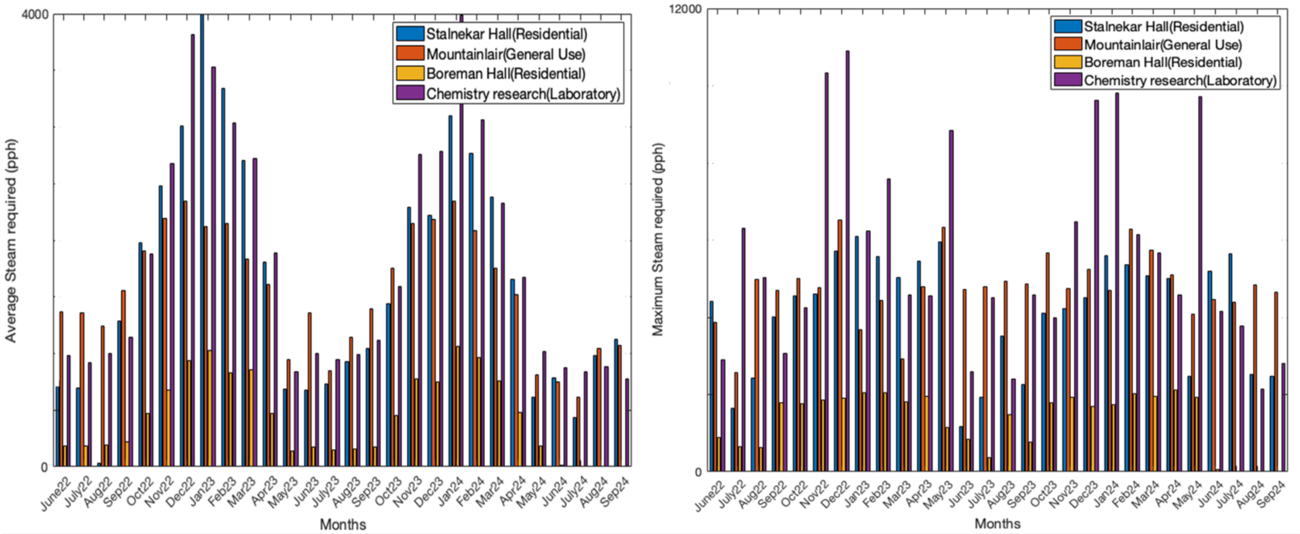

Figure 4: a) Average steam usage from June 2022 to September 2024, b) Maximum steam usage from June 2022 to September 2024

2.1.2 Steam Usage Based on Equipment Analysis:

Measuring a building's steam consumption is most accurately done using a working steam meter. However, when such a meter is not available, an estimation can be made based on the building's characteristics, such as its size and usage. Though this method may not provide the same precision as a steam meter, it can still be useful in identifying the building's energy usage patterns and areas for improvement. Maximum steam consumption can be determined through a comprehensive equipment survey of a building. Peak demand scenarios for all steam-consuming equipment are analyzed, considering simultaneous operation under full-load conditions and taking diversity factors into account. The HVAC heating system components are identified as the primary steam consumers in most facilities, including heating coils for air handling units, reheat coils, variable air volume systems, heat exchangers, and perimeter radiation.

There are three Air Handling Units (AHU) present in the White Hall. Two of them have just the heating coils, whereas the third AHU has a preheat coil as well as a heating coil. The maximum steam usage of various equipment present in the White Hall is tabulated below in Table 1.

Table 1: White Hall equipment demand

Item		Steam Demand (MBH)
AHU 1		1,864
AHU 2		2.392
AHU 3	**PRE**	616
	HTG	249
Total		5,121
HW Convertors		5,142
Total Building Demand		10,263

2.1.3 e-QUEST modeling.

A simulation tool named e-QUEST(eQUEST V3.65, 2018) can be used to calculate the annual energy consumption. The e-QUEST(eQUEST V3.65, 2018) simulation incorporates detailed building parameters, including geometric specifications, construction materials, HVAC systems, lighting configurations, and occupancy schedules. The software employs DOE-2 computational engines to process these inputs and generate comprehensive energy performance data. The e-QUEST(eQUEST V3.65, 2018) model provides granular insights into White Hall's energy usage patterns across different operational categories. The simulation examines heating, cooling, lighting, and equipment loads while considering seasonal variations and peak demand periods. This analysis enables facility managers to identify energy-intensive systems and potential areas for efficiency improvements.

A preliminary e-QUEST(eQUEST V3.65, 2018) model is developed for White Hall. Some of the factors included in this model are building construction, usage, exterior envelope, HVAC system type, lighting, and other equipment used inside the building, insulations, people loading, etc. Figure 5 shows a graphical representation of White Hall. The building shell is thermally equivalent to the actual building. Figure 6 is a graphical representation of the gas consumption of White Hall for space heating. From the preliminary results it is estimated that the maximum steam consumption is during January and is approximately 900 MMBtu.

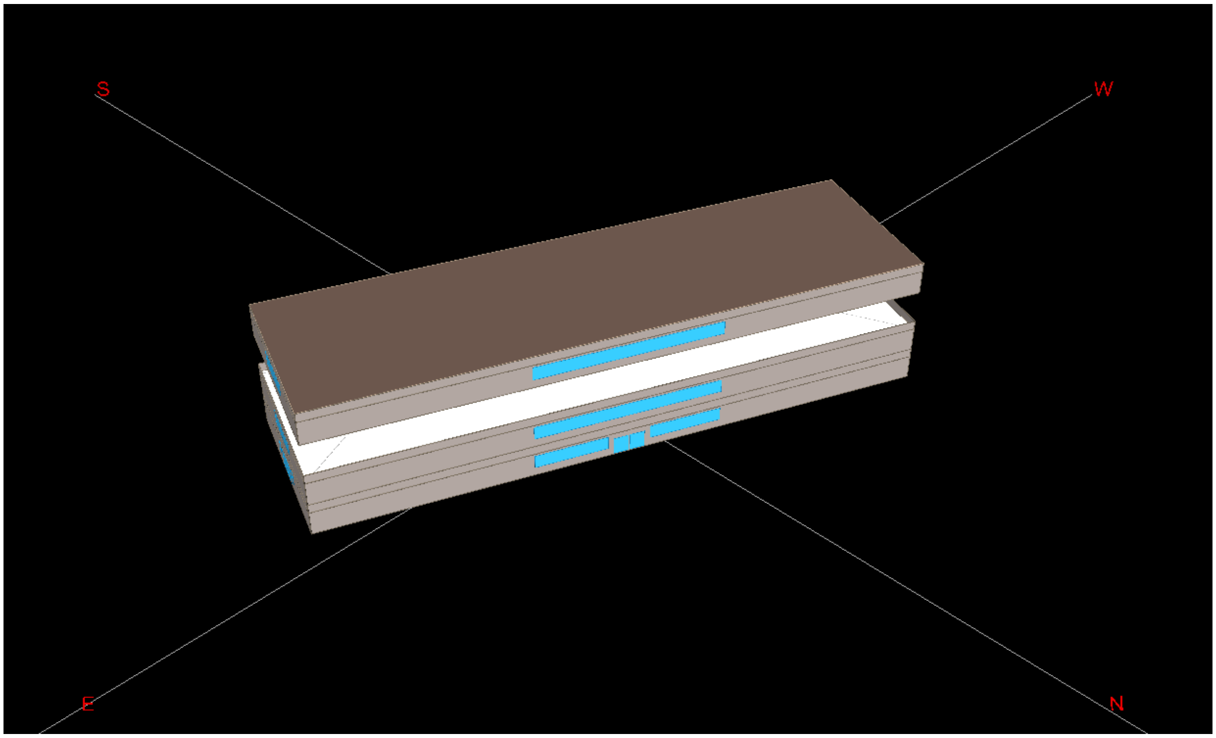

Figure 5: Thermal representation of White Hall in e-QUEST.

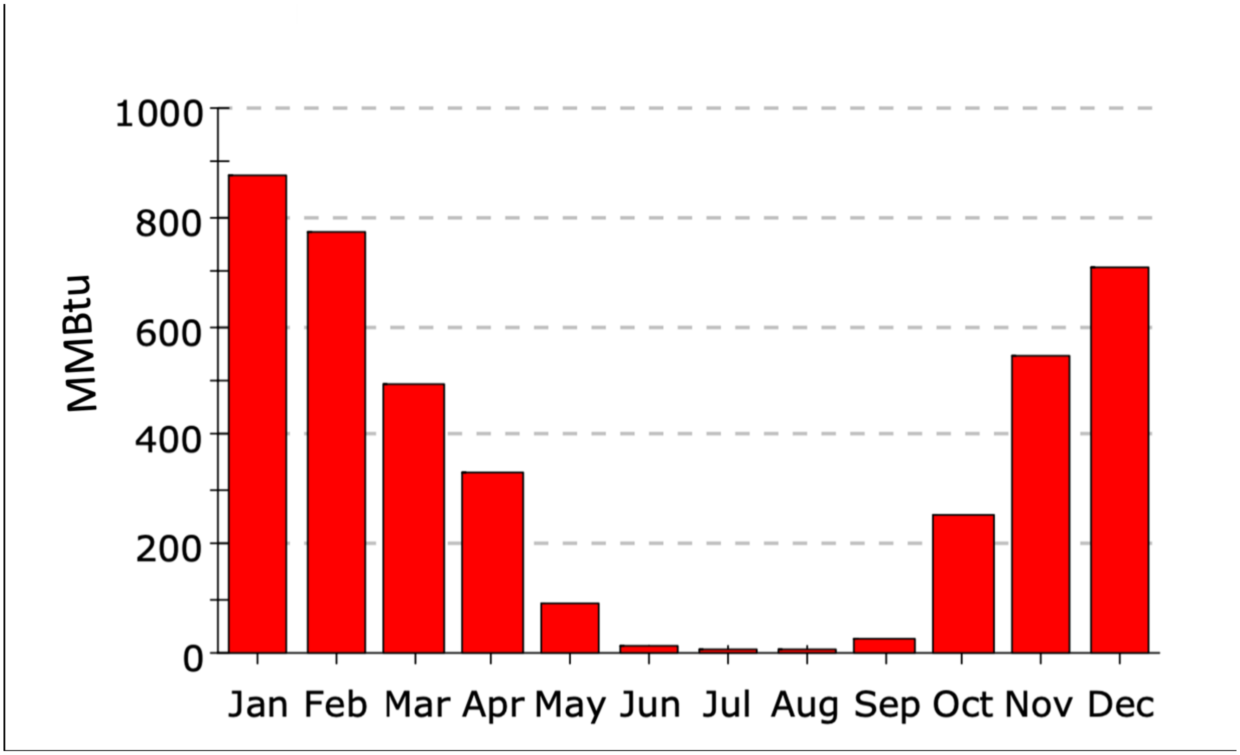

Figure 6: Preliminary results for the annual energy use of White Hall

2.1.4 Hot water demand

The required amount of hot water for space heating can be determined by knowing the enthalpy of saturated steam, the specific heat capacity of hot water, and the temperature drop. Assuming a steam flow rate ($\dot{M}_{steam}$) of 1000 lb/h, we can calculate the necessary quantity.

The pressure of saturated steam = 145 psi
The following properties are calculated from steam tables.
Enthalpy of steam @145 psi ($H_{Saturated\ steam}$) = 1195 BTU/lb
Temperature of steam ($T_{Saturated\ steam}$) = 363 F
Energy ($E_{Saturated\ steam}$) = $m \times H_{Saturated\ steam}$
This same amount of energy must be provided by hot water at the temperature drop of 30 °F.

$$\text{Energy} = \dot{M}_{hot\ water} * C_p * \Delta T$$

$$\dot{M}_{hot\ water} = \text{Energy}/\ (C_p * \Delta T)$$

Specific heat capacity of water (C_p) = 1.008 BTU/lb °F
Assumed Temperature drop (ΔT) = 30°F

The calculation above helps determine the hot water demand for both maximum and average usage from June 2022 to September 2024. This calculation applies to buildings with existing steam meters. The data is plotted for the average and maximum hot water usage in Gallons per minute (GPM) for different locations over a period of 27 months, as shown in Figures 7a and 7b, respectively. Based on the equipment survey conducted on White Hall and converting the steam demand to hot water demand using the above calculations, approximately 350 GPM of hot water is required by the Air Handling Units (AHU), and a total of approximately 680 GPM of hot water is required by White Hall as shown in Table 2.

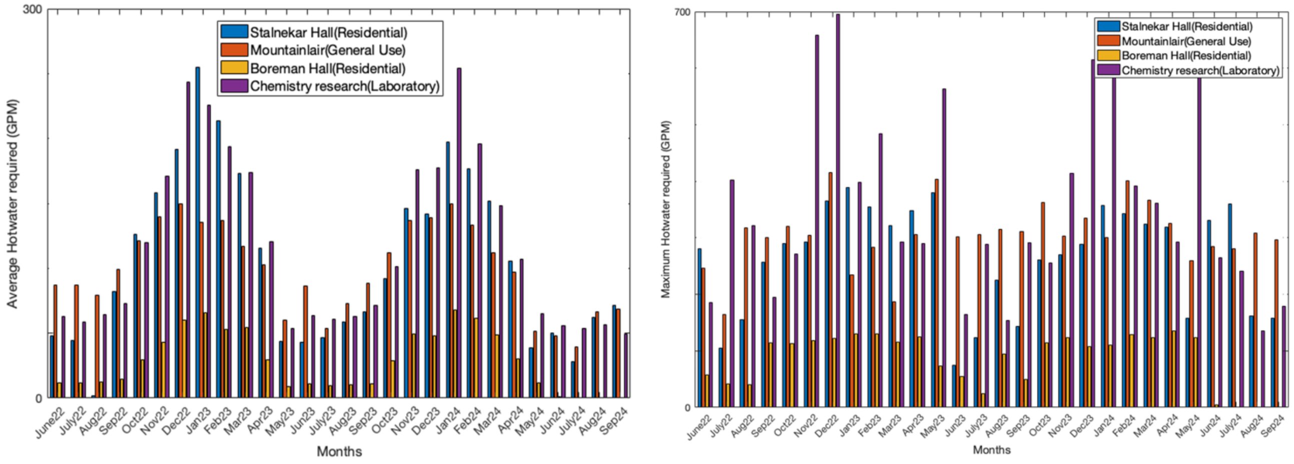

Figure 7: a) Average hot water usage (GPM) from June 2022 to September 2024, b) Maximum hot water usage (GPM) from June 2022 to September 2024

Table 2: White Hall hot water demand based on equipment analysis.

Item		**Equiv. HW Demand (GPM)**
AHU 1		
AHU 2		124
AHU 3		160
	PRE	58
Total	**HTG**	342
HW Convertors		337
Total Building. HW Demand		679

2.2 Equipment Analysis

In this section, WVU's current building equipment is analyzed, including air handlers, heat exchangers, etc., which are responsible for heating and cooling across the campus. The primary objective is to assess the feasibility and potential cost implications of transitioning this equipment to operate with hot water instead of steam. By evaluating the capability of existing systems to accommodate hot water, the project aims to uncover opportunities for retrofitting that could enhance energy efficiency, reduce operational costs, and improve the overall sustainability of the campus infrastructure.

Equipment analysis is conducted for White Hall to check its compatibility for retrofitting purposes. The building's heating and cooling system relies on Air Handling Units (AHU), which provide air at a constant temperature of 60°F to damper-controlled boxes located in each classroom. The variable air volume (VAV) system ensures that the air supplied to each space is adjusted based on the thermostat setpoint. During winter, the air is heated using steam coils in three air-handling units. However, to improve efficiency, these steam coils will be replaced with hot water coils supplied by the geothermal system. Two of the three air handling units are VAV units, while the third unit is a constant volume unit with steam preheat and steam heating coils. The combined design heating load of all three air handling units is 5,121 MBH. To meet the building's hot water demand, 342 gallons per minute of water at a supply temperature of 180°F will be required, and 130°F return water temperature for winter design conditions. During peak winter days, a converter is used to heat the space. The converter requires an additional 337 GPM of hot water to function properly, which brings the total amount of hot water required to 679 GPM, as shown in Table 2. To replace the present steam heating coils in the Air Handling Units 1, 2, and 3, we have obtained quotes from York Engineers, as shown in Table 3. All other costs have been taken from Mechanical Costs with RSMeans Data 2021(Adams, 2021). Pumping costs for White Hall retrofitting are shown in Table 4. It costs approximately $52,000 to retrofit Air handling units from steam coils to hot water coils. As shown in Table 3, it costs a total of approximately $130,000 to retrofit White Hall with a hot water heating system. By extrapolating the cost from this building, retrofitting and cost analysis will be carried out using the equipment information of other buildings.

Table 3: White Hall retrofitting costs

Item	Retrofitting Cost ($)
Air handling units	52,000
Valves	20,000
Pumps	37,000
Other equipment	21,000
Total Cost	130,000

3. SURFACE MODELING

3.1 Surface Plant Modeling

ASPEN HYSYS (ASPENtech Products, 2023) is used to develop a hot water distribution model. A preliminary ASPEN HYSYS (ASPENtech Products, 2023) model, shown in Figure 8, is developed for a hot water system, complete with pipes, elevations, and pumps. The hot water system begins with geothermal fluid entering a plate heat exchanger at 90°C (194°F) and 2 bar pressure. This geothermal fluid undergoes heat exchange with the return of cold water from the distribution points, resulting in a supply of hot water at 76°C (168.8°F). Subsequently, this hot water undergoes further heating through heat pumps located near each meter point, raising its temperature to 90°C (194°F). The standard components of a heat pump system include a condenser, compressor, evaporator, and expansion valve. The heat is extracted from the low-temperature heat source in the evaporator where the refrigerant is evaporated, and the refrigerant condenses and rejects heat to produce high-temperature water with a compressor efficiency of 75%. Ammonia (NH_3) is considered a refrigerant, and based on the temperature of the return condensate, commercial NH_3 water source heat pumps can produce hot water at a maximum temperature of 90°C(Garapati et al., 2020). The coefficient of performance (COP) for the four heat pumps, which are placed at each distribution point, is calculated and is found to be 6.2 for all four heat pumps. There are a total of six pumps used with an adiabatic efficiency of 80%. Some additional details of these pumps are provided in Table 3. The pipes used in the system possess specific properties to ensure efficient operation, with an inner diameter of 10 inches and an outer diameter of 10.79 inches. assuming that the roughness of the pipe is very low and that the frictional losses are minimal. Furthermore, the pipe walls exhibit a conductivity of 2.86 Btu/h-ft-°F. It is assumed that the heat loss in all the pipes is zero. The temperature drop across the building is approximately 30°F, so the return cold water temperature is approximately 76.67°C (170°F). To compensate for losses, backup water is added to the cold water coming from the building. Tables 5 and 6 show geothermal plate heat exchanger properties and pump properties, respectively.

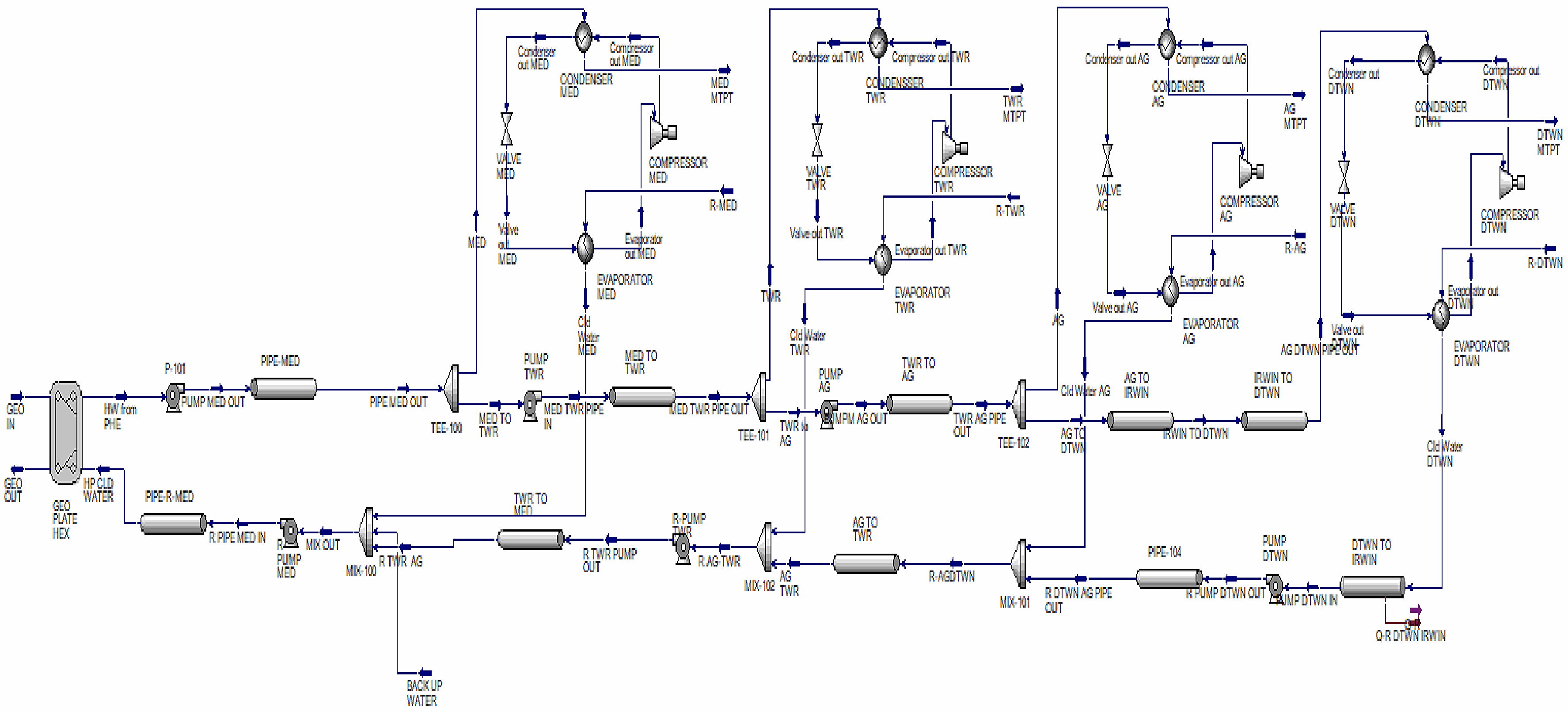

Figure 8: ASPEN HYSYS model with pumps and pipelines for Geothermal hot-water heating system for the WVU campus.

Table 4: Geothermal Plate Heat Exchanger Properties

Heat Exchanger Name	GEO PLATE HEX
Duty [MJ/s]	30.6
Hot Side Inlet Temperature [C]	90
Hot side Outlet Temperature [C]	74.2
Cold side Inlet Temperature [C]	60.1
Cold side Outlet Temperature [C]	75.9
Hot Side Pressure difference [bar]	1
Cold side Pressure Difference [bar]	1.727
Overall heat transfer Coefficient [kJ/h-m^2-c]	360

Table 5: Pump Properties

Pump Name	**Pump Power [kW]**	**Pressure drops across the pump [BAR]**
PUMP MED	168.4	3
PUMP TWR	297.8	9
PUMP AG	64.26	2
R- PUMP DTWN	115.5	7
R- PUMP TWR	199	6
R- PUMP MED	221.6	4

3.2 Building Temperature Profile

The temperature of hot water required for buildings across the campus (both downtown and Evansdale) is analyzed. Most of the buildings require a temperature of 82°C (180°F), while there are a few buildings that require temperatures less than 180°F and a few buildings with requirements greater than 180°F, so in order to increase the efficiency of the system, a cascade system is proposed. A temperature profile of hot water usage for all the Downtown and Evansdale campuses is used to create a cascade model. ASPEN HYSYS (ASPENtech Products, 2023) will be used to develop a cascade model for a hot water distribution system.

3.2.1 Cascade hot water distribution model for Evansdale Campus

For buildings that require temperatures above 180°F, heat pumps are used to maintain the required temperature. The heat pumps effectively increase the temperature of the supplied water to meet the higher temperature requirements of these buildings.

The water returning from these buildings is approximately 165°F, which is then used to supply hot water to buildings that require temperatures below 180°F, such as 160°F or 165°F. This process ensures that the water is efficiently and effectively supplied to each building according to its specific requirements while minimizing unnecessary energy consumption. Figure 9 shows a draft cascade model for the Evansdale Campus. A hot water distribution model will be developed based on the draft cascade model for the Evansdale Campus.

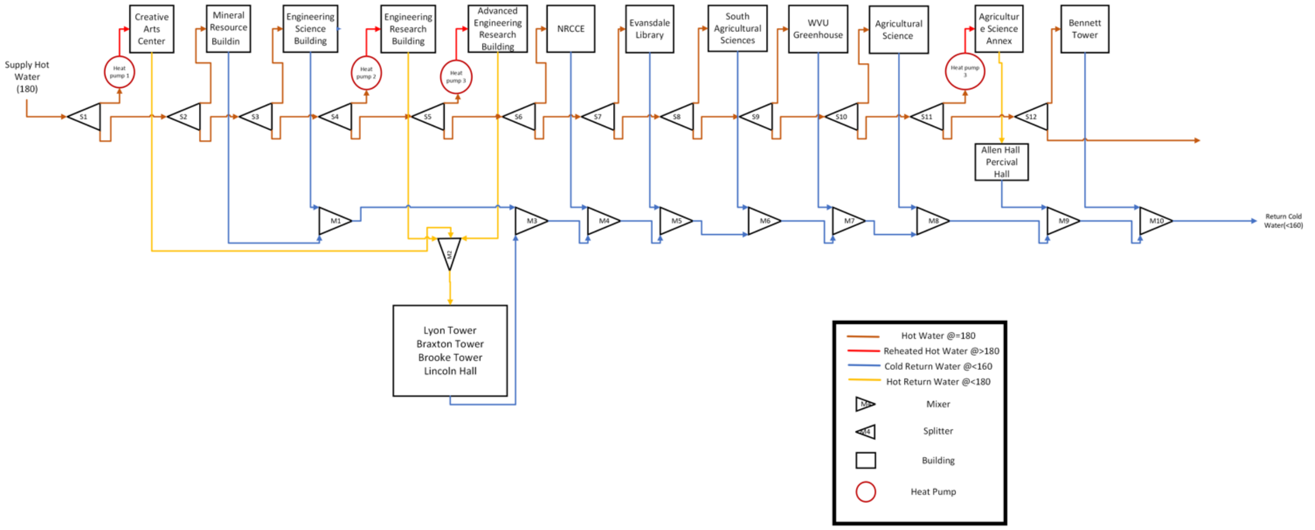

Figure 9: Draft Cascade model for Evansdale campus

CONCLUSION

This study demonstrates significant progress in evaluating the technical viability of transitioning West Virginia University's Morgantown campus from a steam-based to a geothermal deep direct-use district heating system. Various methodologies were used to assess energy demand, including direct steam meter readings, equipment assessments, and e-QUEST modeling, leading to a comprehensive understanding of the campus's heating requirements. Through thorough data collection and analysis, it is estimated that during peak usage periods, the Evansdale campus requires roughly 10,000-12,000 GPM of hot water equivalent. The detailed case study of White Hall proved especially valuable, revealing that retrofitting costs for a single building would be approximately $130,000. This includes replacing steam coils with hot water coils and installing the necessary pumping infrastructure. The ASPEN HYSYS modeling demonstrated the feasibility of a hot water distribution system operating at 200°F. Heat pumps strategically placed near meter points achieved a coefficient of performance (COP) of 6.2. The development of a cascade hot water distribution model for the campus shows promise for optimizing energy efficiency by aligning supply temperatures with building requirements. Buildings requiring temperatures above 180°F can be served by heat pumps, while the return water at 165°F can be used for buildings with lower temperature requirements, thereby maximizing system efficiency.

These findings indicate that although the conversion necessitates a substantial initial investment in infrastructure adjustments, the project seems technically viable. The research lays the groundwork for future in-depth engineering design and economic analysis, positioning WVU to potentially host the first geothermal deep direct-use district heating system in the eastern United States.

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