Modelling the Climate Resilience of Historic Buildings through Geothermal Heating

This study will assess whether geothermal heating can improve the climate resilience of historic buildings while preserving heritage significance, reducing operational carbon and identifying practical constraints on retrofit delivery.

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Project Brief:

Geothermal energy is renewable energy produced from heat stored beneath the Earth's surface. This heat can be used for heating buildings and generating electricity by producing steam to drive turbines. Geothermal energy is reliable and has low carbon emissions, but it can be expensive to develop because of drilling costs and is mainly suitable in areas with appropriate geological conditions.

The aim of this project is to investigate how geothermal energy heating can improve the thermal stability, humidity control and climate resilience of historic buildings, while maintaining occupant comfort and protecting historic materials. The project will develop a numerical building heat-loss and performance model to investigate how historic buildings respond to different heating systems and climate conditions. The model will assess the potential benefits of geothermal heating under both current and future UK climate conditions.

The interns for this project will carry out desk-based research into geothermal heating, historic buildings and climate data to create a resource library of materials. Collect and analyse building material thermal and hygrothermal properties. Develop a numerical heat-loss and building performance model to demonstrate a buildings condition. Model seasonal variations in heat demand and indoor conditions. Compile a reuseable building materials and climate data library and adapt the model for use with different building types, materials, and occupancy patterns.

Project Timeline:

During our twenty-day project, we produced:

- A 7,000+ word report
- Material library with its U-values
- A numerical building heat-loss and performance model
- A building materials and climate data library
- Charts, tables, and visualisations showing key findings
- A final presentation summarising methods and conclusions

On the first week of our internship, we firstly gathered an understanding of geothermal energy and how the system works for buildings. When we began, CeraPhi helped guide us for the first couple of days to help us settle in and understand how to do the assigned tasks. In this week, we learned about U-values and the importance of it, and we learned about the challenges CeraPhi face when planning a project for historic buildings. Our main building we referred to was Great Yarmouth Minster as it was local, historic and faced many problems with heating. On the third day, CeraPhi took us to Great Yarmouth Minster which was only down the road, to visually see the building, help us gain an understanding of the building and see the challenges they face with heating a historic building.

On week two, we focused again on the historic buildings and started creating a list of other well-known historic buildings and collected data from online, Excel and AI to compare later the results to see which method was most accurate. We gathered the list and created a Excel spreadsheet for each building including floor, wall, roof, door and window materials, dimensions and its U-values. We created a summary chart that we would use on week three to create charts of data under different conditions. Also in week two, we fixed many errors that were made whilst filling out the Excel spreadsheet, CeraPhi guided us to fix these errors and what each error meant.

On week three, we completed the summary table for each building, and we expanded the columns which included more information such as volume, degree days, comparison and more. With this information, we could create charts showing the data in the table. CeraPhi also told us to create a spreadsheet of our houses to compare an average house to a church or other historic building, and the difference we found was huge like energy consumption.

On week four, we focused on our report planning and writing. We planned out different approaches and what we would write for different pages and sections. During this week, we managed to complete our report, create a literature review of our findings, finish off any uncompleted work and fix any existing errors in the formula on Excel.

Introduction to Geothermal Energy

As previously mentioned before, geothermal energy is renewable energy produced from heat stored beneath the Earth's surface. This heat can be used for heating buildings and generating electricity by producing steam to drive turbines. Geothermal energy is reliable and has low carbon emissions, but it can be expensive to develop because of drilling costs and is mainly suitable in areas with appropriate geological conditions. However, CeraPhi have a slightly different method.

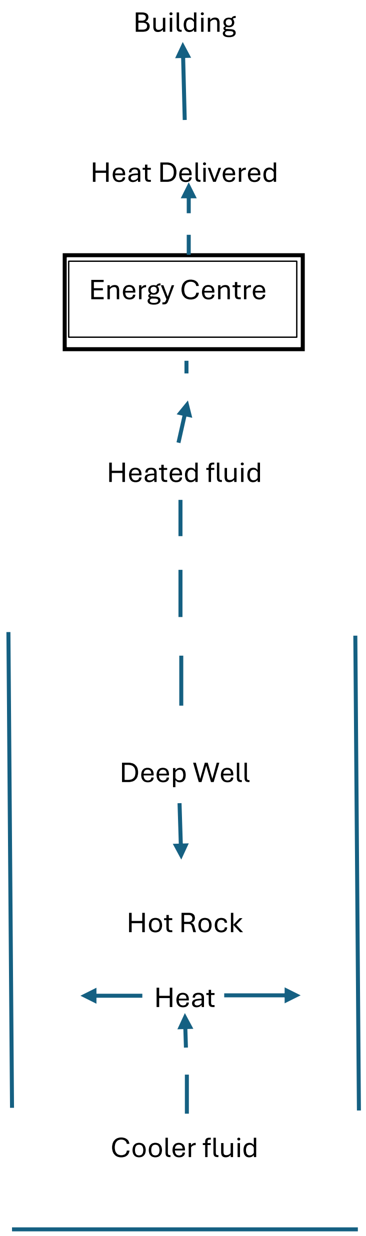
How CeraPhi Geothermal Technology Works

CeraPhi mainly use a closed-loop system to collect heat from the hot rock underground.

1. A deep well is drilled, CeraPhi either drill new holes or they repurpose old oil and gas wells. The deeper the well, the hotter the surrounding rock generally becomes. CeraPhi say the average temperature increase is around 30◦C per kilometre of depth.
2. A closed-loop system is installed. Inside the well, CeraPhi uses its CeraPhiWell system. A working fluid is circulated through pipes that extend deep underground. The fluid stays inside the pipes, rather than being taken from the underground aquifers.
3. The fluid heats up underground. As the fluid travels down the well, heat from the surrounding rock passes through the pipe into the fluid. This is essentially the same principle as a heat exchanger.
4. The heated fluid returns to the surface. The heated fluid travels back up to the surface, carrying the geothermal heat with it.
5. The heat is used. At the surface, the heat can be transferred into a heating system. CeraPhi focuses on particularly on direct heating, meaning the geothermal heat can be used to heat buildings, rather than necessarily converting the heat into electricity. Heat pumps can also be used to increase and control the temperature.

6. The fluid goes back underground. Because it is a closed-loop system, the fluid is circulated back down the well and the process repeats. CeraPhi states that it reinjects 100% of the fluid back into the ground to repeat the process.

This can simply be demonstrated by a flowchart, to help visualise the process.



Technical Terminology

- **Coefficient of Performance (COP**)- compares the heat output of a heat pump with electrical energy it uses.
- **Cumulative**- total energy used over a product's entire life cycle
- **Degree days**- a measure of heating or cooling, calculated based on the difference between the daily mean temperature and a base temperature. Used to estimate energy consumption.
- **Geothermal energy**- energy obtained from the Earth's natural underground heat
- Heat exchanger- transfers heat between two fluids or systems without necessarily mixing them
- **Heat pump**- a system that transfers heat from one location to another, rather than generating heat directly.
- **Thermal conductivity (W/mK)-** describes how easily a material conducts heat. Lower values indicate better insulating material.
- **Thermal conductivity of ground**- indicates how effectively heat can move through the ground surrounding a geothermal system.
- **Thermal resistance (R-value)-** measures how strongly a material or construction resists heat flow.
- **U-value (W/m^2K)-** a measure of thermal transmittance, indicating how easily heat passes through a building element such as windows. A lower U-value means better insulation and less heat is lost.
- **Window percentage-** the amount of wall space taken up by windows

Degree Days

What is a degree day?

The degree day that CeraPhi uses is the difference between the outside temperature and the maintained internal temperature of a building. This is calculated each hour and added together to produce a daily value.

Heating Degree Days (HDD)

Are used when the temperature is below a chosen base, our base was 20◦C and 12◦C, this is because 20◦C is the normal residential building temperature and 12◦C is the lowest temperature at which a building can be preserved at. The more HDD= greater heating demand.

Cooling Degree Days (CDD)

CDD works in the opposite way, they measure how far the temperature is above the chosen base temperature. The more CDD= greater demand for cooling/ air conditioning. For example, with an 18◦C base temperature and an average temperature of 23◦C, that would give 5 cooling degree days.

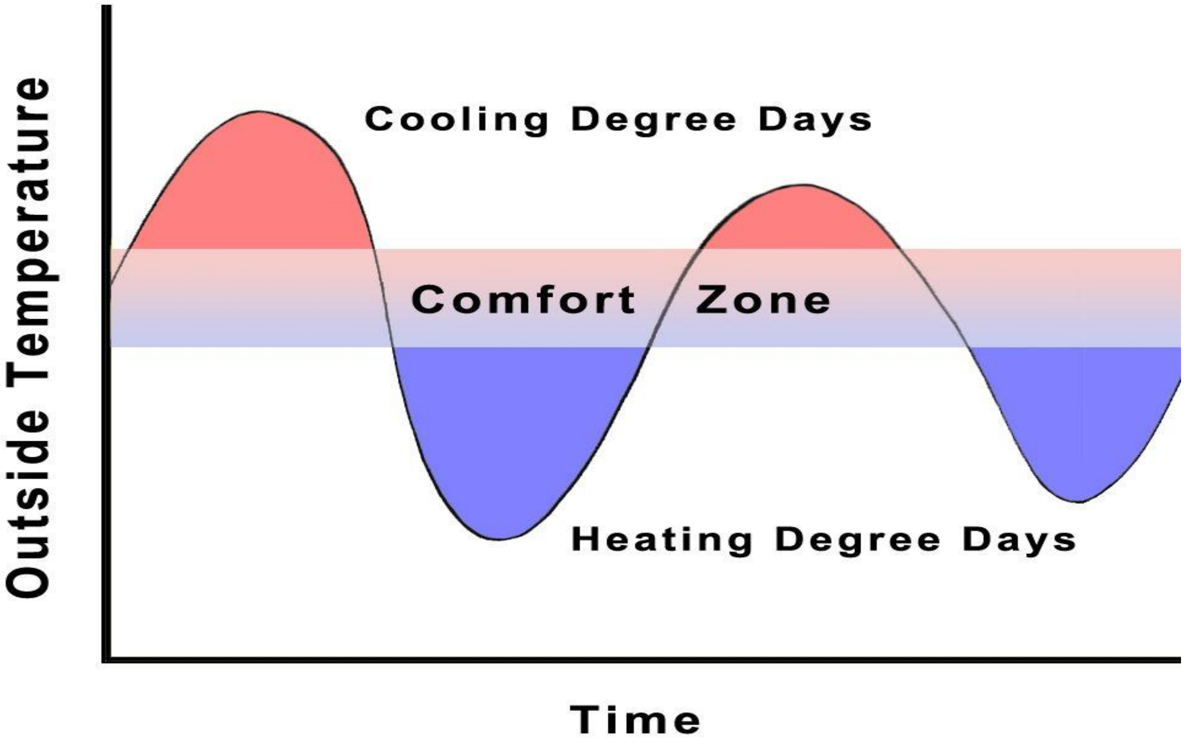


Figure 2- Degree Day Illustration

Relevance

With the use of HDD and CDD, it can help assess how changes in climate could affect the building's energy requirements. For a historic building such as Great Yarmouth Minster which was our case study, this can help investigate whether geothermal technology could provide a suitable way of maintaining comfortable indoor conditions while reducing reliance on conventional heating and cooling. Overall, degree days provide a useful bridge between climate data and the energy performance of the historic building. The difference between HDD and CDD can be seen in figure 2 above.

U-Values

What is a U-value?

a measure of thermal transmittance, indicating how easily heat passes through a building element such as windows. A lower U-value means better insulation and less heat is lost.

How is a U-value measured?

The U-value is calculated as the reciprocal of the total thermal resistance (R-value) of the assembly:

U = 1 / R_value

What we found

During the first week, we were tasked by CeraPhi to expand on the materials library they had created which only contained of about 20 building materials including roof, walls and floors. By the end of week one, we found 457 different types of building materials which we also included windows and doors used over hundreds of years.

What surprised us the most was the number of different types of timber that has been used over hundreds of years. Timber has been used as a primary building resource for a very long timber, mainly used for supports in frames and floor, but the many different types of timber surprised us as we were only aware of very few. In addition, we also found that even though the different types of timber are similar, they carry quite different U-values due to properties and different types of materials it also contains of.

U-values are important because it helps engineers, builders and architects:

- Reduce heat loss
- Improve energy efficiency
- Lower heating and cooling costs
- Meet UK building regulations

- Reduce carbon emissions

U-values can be affected by many different things, that's why lots of thought goes into the planning before because it must be accurate. For example, it can be affected by:

- Material type (brick, timber, concrete, glass)
- Thickness of material
- Amount and type of insulation
- Number of layers (double or triple glazing)
- Air gaps between layers

In figure 3, the U-values are located on the far-right column. Every wall, floor, roof or door has a U-value, therefore, having a specific value. Figure 3 contains the floor plans of Norwich Cathedral; however, this is not 100% accurate as there are no existing building plans or documents regarding dimensions or material type. This is a guesstimate, and we allow a 10% max error margin accounting for this. This is one of the biggest problems CeraPhi faces when taking on a historic building project. In figure 3, the U-value is colour coded, this is because it visually allows the reader to understand the reading of the u-value. On Excel, we used three colours: green, yellow and red, also using different shades of those colours. This is to make it easier to understand and add colour to the spreadsheet. Additionally, when taking notes of the walls, we do not take notes of the internal walls. This is because we are calculating heat loss externally and if the heat was to transfer through an internal wall, then the heat would still be internal.

Nave Floor	15	124	15	1860	Limestone and stone flag paving over compacted ground	1.1
North Aisle Floor	15	124	8	992	Black slate ledger stones and limestone paving	1.3
South Aisle Floor	15	124	8	992	Black slate ledger stones and limestone paving	1.3
North Transept Floor	15	40	20	800	Stone flag paving	1.3
South Transept Floor	15	40	20	800	Stone flag paving	1.3
Choir Floor	15	40	15	600	Limestone paving with historic stone slabs	1.3
Presbytery Floor	15	30	15	450	Victorian decorative tiled pavement with stone paving	1.3
Lady Chapel Floor	15	25	12	300	Stone flag flooring	1.2
Chapter House Floor	15	18	18	324	Stone flag flooring	1.2
Cloister Walkways	15	65	4	347	Stone paving with black slate and Purbeck ledger stones	1.5

Figure 3- Data from Norwich Cathedral spreadsheet

Setting a Clear Aim

At the beginning of the project, it was important for us to establish a clear and realistic aim so that we understood exactly what we were trying to achieve. Our main aim was to develop a numerical model on Excel that assesses how geothermal heating can improve the thermal performance, humidity control and climate resilience of historic buildings while supporting the preservation of historic materials.

This aim was chosen because with historic buildings, heating them can be a challenge. So being assigned this project, doing deep research into it, and having a useful outcome can benefit the company with future projects. For example, as previously mentioned many historic building have restriction such as Grade I and Grade II listings which can halt a process or even abandon it, so being assigned this task really engages us to find a solution around this. Working on this project really determines no matter the type of building, if there is a way to find a sustainable way to preserve the building and heat it efficiently without damaging the building. The main case study was Great Yarmouth Minster, and CeraPhi approached Great Yarmouth Minster with the geothermal heating system as the price of oil was increasing and it was too much for the charity funded building.

What we were tasked to do was we needed to see firstly if the building was suitable for this system. Depending on the regulations of the building, it could make the process harder to complete. Great Yarmouth Minster has a Grade II listing meaning that the building cannot be demolished, extended, or altered without special permission from the local planning authority including exterior and interior. Therefore, it would take a long time to get permission from the local planning authority and put the church under a lot of stress. As Great Yarmouth Minster is a church, the building is surrounded with graves from many years ago making it extremely difficult to make this happen, so during our tour around Great Yarmouth Minster we looked for the current method of heating and we noticed they use old radiators which could be a possible method of connecting. After research and collecting data, we discovered that only 1 well would be required as it is primarily used throughout winter, meaning that there would be enough space locally to place a well.

	Built date	*Roof Space*	*Floor Space*	*Wall Space*	*Floor comparison*	*Total U-Value*	*kWh*	*Degree Days(20°)*	*Volume*	*volume comparison*	*Wells*	*degree days (12°)*	*kWh*	*Wells*
Norwich Cathedral	Norman 1100s	8,394	7,465	13,610	127	53,584	########	1,165,612	72,535	205	12	378,918	########	7
Norwich Castle	Norman 1100s	3,794	3,909	2,826	67	9,473	394,333	666,064	69,436	196	2	216,525	238,075	1
Castle rising	1140	700	540	1,720	9	14,060	585,304	957,345	3,120	9	3	311,215	353,370	2
St Georges Hall	1440	2,112	2,100	3,564	36	8,376	367,081	701,216	68,811	194	2	227,952	210,511	1
Caister Roman Fort	Roman Britain	3,319	2,924	3,865	50	22,797	########	1,623,573	40,563	115	10	527,793	572,949	4
Peter + Paul	1300s	951	951	2,794	16	9,119	392,368	1,247,783	6,480	18	2	405,631	229,190	1
Felbrigg Hall	1615	1,753	876	2,444	15	10,163	423,092	874,209	3,705	10	2	284,189	255,437	1
Holkham Hall	1745	3,900	3,772	6,726	64	24,653	########	2,010,238	74,930	212	11	653,490	619,604	4
Marina Centre	2015	3,723	3,682	4,365	63	3,595	277,985	1,623,573	42,691	121	1	527,793	90,353	1
Westminister Abbey	1245	7,153	7,144	11,976	122	68,962	########	3,556,398	65,880	186	30	1,156,118	########	10
Dragon Hall	1427	597	565	1,006	10	3,831	297,595	1,546,260	1,728	5	2	502,660	96,285	1
GY Minister	1110	1,892	1,701	2,549	29	10,650	823,379	2,551,329	20,880	59	4	829,389	267,664	1
Royal Naval Hospital	1700s	3,900	3,900	4,008	66	24,531	########	1,769,976	38,080	108	11	575,386	616,538	5
Aaron		88	52	179		115	8,899	1,005,569	345		1	326,892	2,893	1
Austin		84	66	182		105	8,086	773,130	363		1	251,330	2,629	1
Average		86	59	180		110	8,493	889,350	354			289,111		

Figure 4- Summary Data Chart

We made the aim realistic by doing as much research on Great Yarmouth Minster as we could, then we talked about other feasible methods. We started creating a data table (as seen in Figure 6) with all 15 buildings which included measuring the building to find the wall, door and roof plan, then we calculated the floor space using Excel formulas. We then used Google and other resources to find the material used for the walls, doors and roofs of each building we included in the Excel spreadsheet. With this information, we could find the U-value which then allows us to find the energy consumption through other channels of data.

Success Criteria

During this project, we set a success criteria to provide a clear and measurable means of evaluating whether the aims and objectives of the project had been achieved. The criteria also provided a framework for assessing the effectiveness of the modelling and the potential sustainability of geothermal energy for improving the climate resilience of the historic buildings.

We included:

- Be able to find a buildings materials used in construction
- Find the surface area of each building
- Calculate the total U-value of the buildings
- Find the total heat demand of the building
- Create a library of all materials and U-values
- Access whether its economically practical for the building
- Create charts and tables to summarise our findings
- Develop teamwork, problem-solving and computer tasks

Project Deliverables

Throughout the four-week placement, we produced several deliverables that demonstrated the work completed during the project. These deliverables included both technical outputs for the company and documents that communicated our findings.

One of the main deliverables was the final project report, which documents the research, methods, data analysis, challenges and conclusions from the project. The report brings together our investigation into geothermal energy, historic buildings, U-values, degree days and building heat loss.

Another important deliverable was the numerical heat-loss and performance model developed using Excel. This included information about building materials, surface areas, U-values, degree days and heat demand. The data was used to compare different historic buildings and investigate their potential sustainability for geothermal heating. We also produced a material and U-value library, alongside charts and tables to make the results easier to interpret.

We also prepared a short presentation for CeraPhi, which summarises the main findings of the project. This allowed us to communicate the results of our technical work to members of the company concisely. We had presented this to the members of CeraPhi on one of the final days of our project.

Finally, the work completed during the placement contributed towards our Gold CREST Award application. This allowed us to demonstrate the skills and knowledge developed throughout the project, including teamwork, problem-solving, data analysis, research, project planning and the use of Excel.

Overall, these deliverables allowed us to demonstrate both the technical outcomes of the project and the skills we developed throughout the four-week placement.

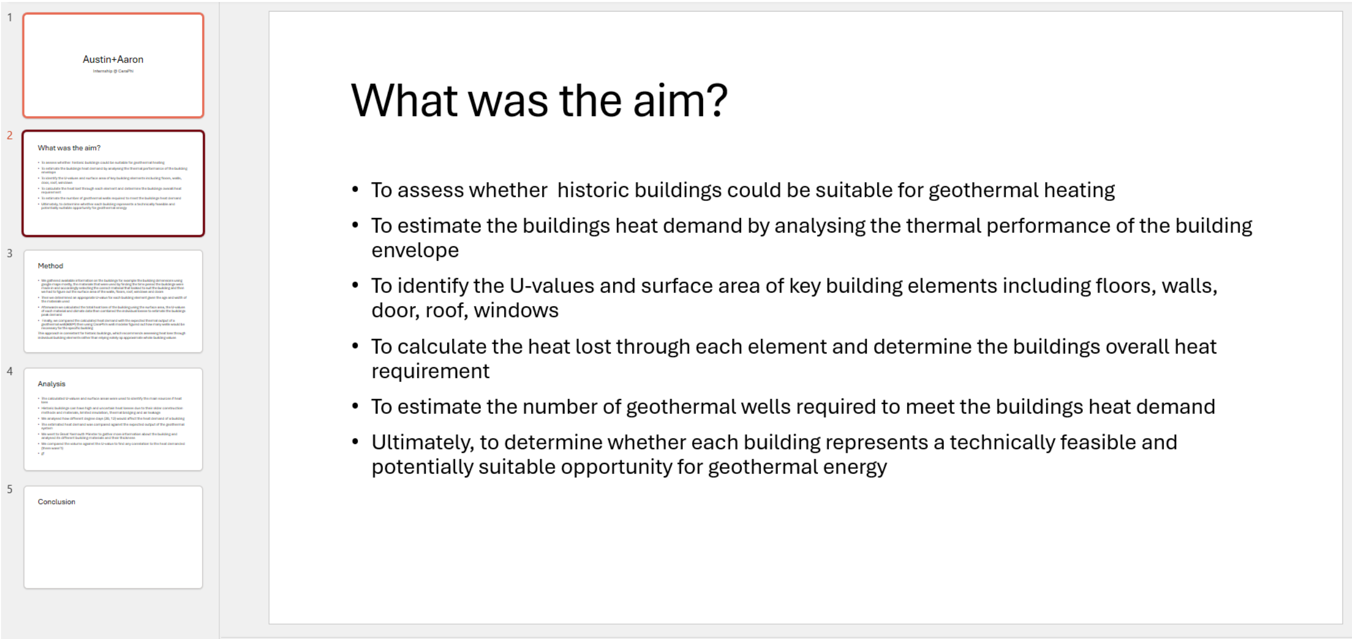


Figure 5- Presentation on Microsoft PowerPoint

	Built date	Roof Space	Floor Space	Wall Space	Floor comparison	Total U-Value	kWh	Degree Days(20°)	Volume	volume comparison	Wells	degree days (12°)	kWh	Wells	Wells Difference	Energy intensity 20°	Energy intensity 12°	kWh per M^3
Norwich Cathedral	Norman 1100s	8,394	7,465	13,610	127	53,584	########	1,165,612	72,535	205	12	378,918	########	7	5	299	180	31
Norwich Castle	Norman 1100s	3,794	3,909	2,826	67	9,473	394,333	666,064	69,436	196	2	216,525	238,075	1	1	101	61	6
Castle rising	1140	700	540	1,720	9	14,060	585,304	957,345	3,120	9	3	311,215	353,370	2	1	1,084	654	188
St Georges Hall	1440	2,112	2,100	3,564	36	8,376	367,081	701,216	68,811	194	2	227,952	210,511	1	1	175	100	5
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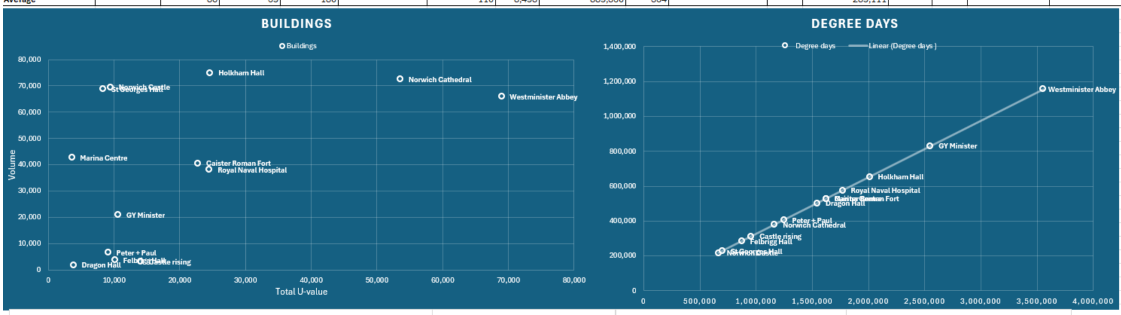
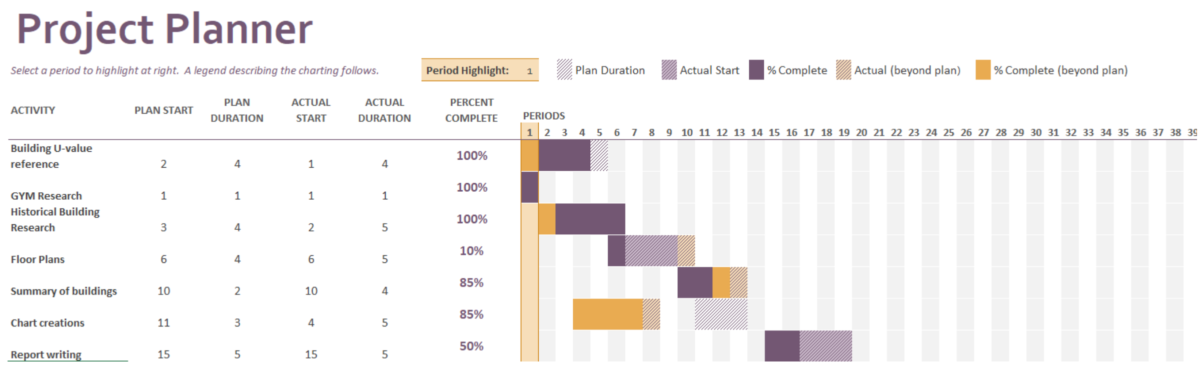


Figure 6- Summary table on Microsoft Excel

Planning Our Project

For our internship project, we were tasked to create a storyboard showcasing the journey of climate data. To plan for this, we had to prepare and develop a timeline to ensure we got all the tasks completed on time to stay on track with deadlines. This planning took place on the first day when we were given the tasks and the completion dates. We started on the 27th of July which is when we initially created the Gantt chart to give us a rough idea of when tasks needed to be completed by.



ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Building U-value reference	2	4	1	4	100%
GYM Research	1	1	1	1	100%
Historical Building Research	3	4	2	5	100%
Floor Plans	6	4	6	5	10%
Summary of buildings	10	2	10	4	85%
Chart creations	11	3	4	5	85%
Report writing	15	5	15	5	50%

Figure 7- Gantt chart

Main purpose of the project

The main purpose of the project was to investigate how geothermal energy could be used to improve the climate resilience and energy performance of historic buildings under changing climate conditions and provide the company with valuable data that can be used and referred to for project planning or future interns. We plan to produce data that explains a buildings conditions and requirements.

Wider purposes

There are also many wider purposes for this project rather than just if geothermal heating works.

- Reducing carbon emissions is a major wider purpose, investigating whether geothermal energy can reduce the use of conventional fossil-fuel heating and therefore contribute to decarbonising the historic building sector.
- Adapting historic buildings to climate change. Historic buildings were often designed for past climate conditions. As temperatures change, their heating and cooling requirements can change too.
- The project can therefore explore how these buildings can be adapted without compromising their historic character.

Challenges and Solutions

Week One

During the first week, one of the first major issues we faced was determining whether the buildings we had selected were Grade I or Grade II listed buildings. This was important because listed buildings are protected by regulations that can restrict changes being made to the building itself and, in some cases, the surrounding area. This meant that we could not simply install the required equipment wherever we wanted, as digging or making significant alterations could damage the building or its historical features.

When installing geothermal heating systems in areas with many historic buildings, the main challenges are not necessarily related to the geothermal technology itself, but rather to the restrictions created by heritage protection, the existing building fabric and the surrounding urban environment. Many historic buildings are protected by conservation laws, meaning there is limited ability to alter the existing materials or improve the building's thermal performance. For example, it may not be possible to add insulation or change the existing materials to reduce the U-value of the building. This can result in a much higher heat demand than would be expected from a modern building, making the proposed heating system more difficult and potentially more costly to implement.

One of the main concerns was where the wells for the geothermal system could be located. If the wells could not be drilled directly next to or underneath the listed building, they would need to be placed further away. We then had to find a way to connect these wells to the building without affecting its structure. The solution we identified was to locate the wells in suitable areas surrounding the building and connect them to the main building through neighbouring or nearby buildings. This would allow the system to operate while reducing the need to make direct alterations to the listed structure.

This became particularly challenging when considering churches such as Great Yarmouth Minster. As the building is listed, we could not simply alter or remove materials from the structure to accommodate the heating system. In addition, the church is surrounded by a cemetery, which significantly restricted where wells could be installed. Drilling in these areas could potentially disturb graves or archaeological remains, making it both technically difficult and ethically inappropriate. This meant that we had to consider alternative locations and methods for connecting the geothermal system to the building.

Another possible solution for buildings such as churches was to make use of existing heating infrastructure within the building, such as old radiators. This could allow the new geothermal system to connect to an existing distribution system rather than requiring major construction work or alterations to the historic structure.

There were also additional regulations that made the installation process more complicated. Some of the equipment, including the wells and pumps, cannot be visible or placed in locations where they would have a significant visual impact. This is particularly important for historically significant buildings, where maintaining the original appearance of the building and its surroundings is a priority. Therefore, the location and design of the equipment had to be carefully considered to ensure that it would meet the regulations while still allowing the heating system to function effectively.

Week Two

During the second week, we were tasked with finding and laying out the building plans for the 15 buildings that we had previously identified. The purpose of this was to gather more detailed information about each building, including its approximate dimensions, wall area, roof area and floor space. This information would then allow us to make more accurate calculations and assess the suitability of each building for the proposed geothermal heating system.

One of the biggest challenges we faced was the lack of reliable information about the historic buildings. Many of the buildings did not have easily accessible or complete building plans, meaning that we could not always obtain their exact dimensions, layouts, construction materials or even precise information about their age. This made it difficult to produce completely accurate calculations for the heat demand and the requirements of the proposed system.

Because of this lack of information, a significant amount of estimation and research was required. We researched the approximate age and historical period of each building and then investigated the materials that were most likely to have been used during that period. We also examined images and information available through Google Maps to identify materials that appeared to correspond with the construction of each building. Once we had identified the most likely materials, we were able to find typical U-values for those materials and use them in our calculations.

We also had to estimate the dimensions of each building. Google Maps was used to measure the approximate length and width of the buildings, while we then attempted to find or estimate the height of each building so that we could calculate the surface area of the walls. From these measurements, we could estimate the wall, roof and floor areas required for our calculations.

During this process, we also discovered that using the standard map view rather than the satellite view produced more useful results for some of the measurements. The standard map view provided a clearer indication of where the edges and boundaries of the buildings were located. This made it easier to identify the approximate outline of each building and resulted in more consistent measurements. An example of this can be seen in **Figure 8**, where the edges of the building are easier to identify using this method.

Due to the amount of estimation involved, we recognised that some of our calculated values may not be completely accurate. To account for this, we allowed for an estimated error margin of approximately 10%. Although this meant that our results could not be considered completely precise, we used all the information that was reasonably available to us to produce the most accurate estimates possible. These assumptions were necessary because obtaining exact information for every historic building was not always possible.

Another challenge we faced throughout the project was learning and using new software, particularly Excel. At the beginning of the internship, we had limited knowledge of Excel and were unfamiliar with many of the formulas and functions that could be used to process large amounts of data. As the project progressed, we developed our understanding of Excel and learnt how to use formulas to automate calculations. This significantly reduced the amount of time required when entering large numbers of measurements and repeating calculations for different buildings and construction materials.

Developing our Excel skills also allowed us to expand the number of buildings we could analyse. We were able to organise information about the different construction materials and their corresponding U-values, helping CeraPhi to develop a larger library of materials and U-values that could be used when assessing other historic buildings. We also learnt how to create graphs and other visual representations of our analysis and findings. For example, we were able to produce floor maps for each building and create graphs to help present and compare the results of our calculations.

Overall, the first two weeks helped us identify several of the practical, technical and regulatory challenges associated with installing geothermal heating systems in historic buildings. These included listed-building and conservation restrictions, difficulties in finding suitable locations for wells, the presence of cemeteries around historic churches, a lack of reliable building information, the need to estimate materials and dimensions, and our initial lack of experience with software such as Excel. Although these setbacks made the project more difficult, they also required us to develop alternative methods, make justified assumptions, conduct additional research and learn new skills. This allowed us to continue progressing with the project while producing the most accurate results possible from the information available to us.

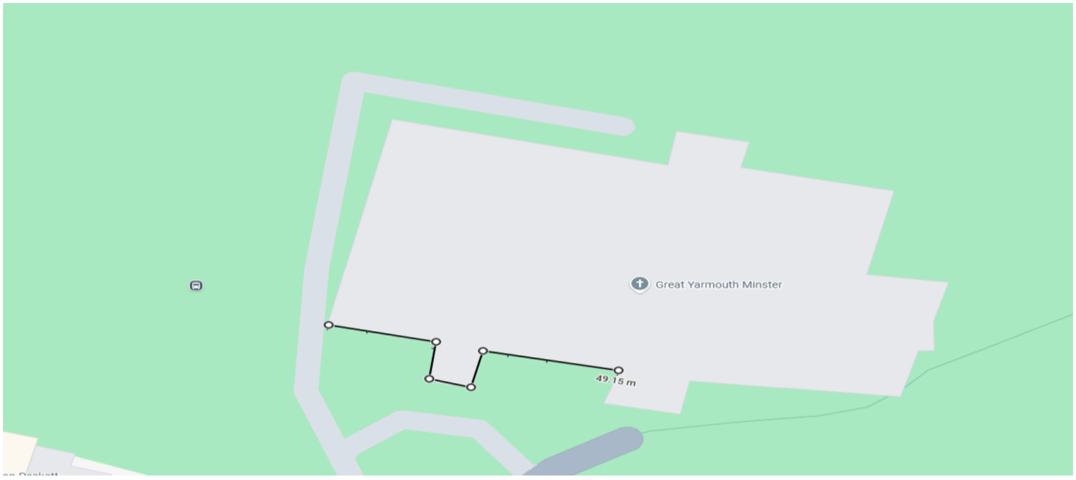


Figure 8- Great Yarmouth Minster measured on Google Maps

All of the different buildi	Ai		Excel	
St Peter-on-the-Wall (Essex, 7th century church)	150 m^2		128	
Great Yarmouth Minster	2,000 m^2		2156	
Marina Leisure Centre (Great Yarmouth)	8,000 m^2		3881	
Royal Naval Hospital (Great Yarmouth)	10,000 m^2		4480	
Dragon Hall, Norwich	1,200 m^2		216	
Westminster Hall	1,500 m^2		3294	
Holkham Hall	8,000 m^2		5900	
Felbrigg Hall (Norfolk)	4,500 m^2			
St Peter & St Paul Church (large 1400s parish church)	1,000 m^2		432	
Castle Rising Castle (entire keep and enclosed buildings)	2,500 m^2		420	
Norwich Cathedral	5,500 m^2		4450	
Caister Roman Fort (internal occupied buildings only)	6,000 m^2			
Norwich castle				
St Georges Hall			4450	

Figure 9- Comparison of AI and Excel formulas

Appendices

Norwich Castle- Norwich

Ordered to be built in 1067 AD by William the Conqueror, it was used as a prison, now serving as a museum. Its materials mainly consist of Caen limestone ashlar facing with flint/rubble core

St Georges Hall- Liverpool

Built between 1841 and 1854, it housed both Civil and Crown Courts but now is used for public events, tourism and weddings. Its mainly constructed of Solid sandstone ashlar masonry.

Saints Peter and Paul Chapel- London

Completed in 1751, the chapel was built as a place of worship and remains a place of worship. The building was reconstructed in 1789 after a brutal fire. Its primary materials consist of solid Barnack and limestone masonry.

Castle Rising- Kings Lynn

Built in 1138 by the Norman lord William d’Aubigny II, the Castle served many purposes from a lavish hunting lodge to a royal residence, to a prison, to military preparedness, and is now currently a historical landmark. Its main construction materials are Solid Norman Carstone rubble with limestone ashlar facing

Holkham Hall- Wells-Next-The-Sea

Built in 1764, it was a private family home and showcased a staggering collection of Roman sculptures, currently it remains a family home to the Coke family and tourist attraction.

Caister Roman Fort- Caister-On-Sea

Built around 200 AD, it acted as a coastal defence and naval base protecting a local river estuary. It now remains as a public heritage site and a tourist attraction to the public.

Dragon Hall- Norwich

Built around 1430, for the initial purpose of a house before Robert Toppes died and turned into a pub and shops. Now it serves as a home to the National Centre for Writing. Its main construction materials are Flint rubble with brick ground floor and timber framed upper wall.

Norwich Cathedral- Norwich

Built in 1096, originally designed as a monastery and a seat of power, it now serves a purpose as being the Anglican Cathedral and a major cultural language. Mainly built from Medieval stone masonry with later Gothic alterations.

Felbrigg Hall- Norwich

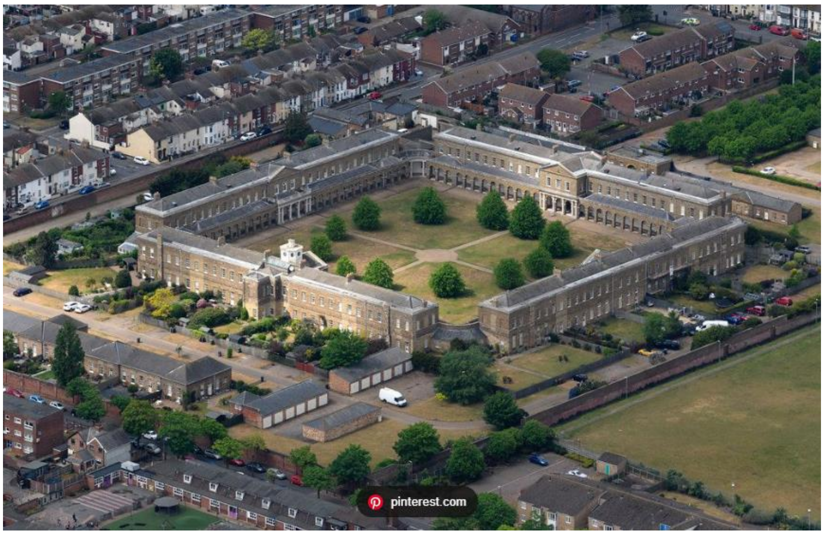
Built in 1624, it was originally a private country estate and family home but now it is owned by the National Trust and serves as a public heritage site and tourist attraction.

Marina Centre- Great Yarmouth

Built in 1981 it served as a leisure centre for the public before getting demolished in 2020 and a £26 million replacement facility was built in 2022 and still serves the same purpose.

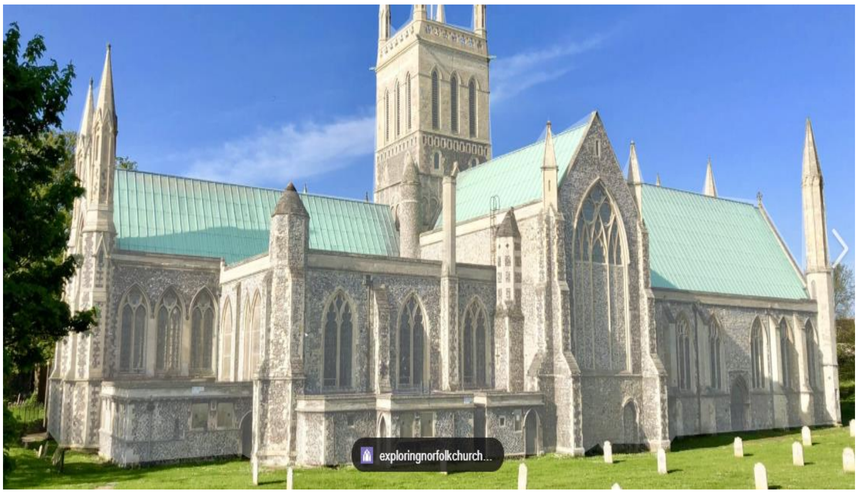
Westminster Abbey- London

Built between 1245 and 1269, it was ordered by King Henry III and served as a place of worship. It now serves as a place of worship, Royal Peculiar, runs state events, and global tourism. Constructed out of Medieval limestone masonry mainly.



Royal Naval Hospital- Great Yarmouth

Built between 1809-1811, it served as a hospital to the wounded soldiers out on the North Sea before becoming a Lunatic Asylum and then an NHS St Nicholas Hospital. Currently now, it is a Grade II listed private residential development.



Great Yarmouth Minster- Great Yarmouth

Built in 1101, the Minster served as a place of worship. Currently, it now serves as a place of worship still but also hosts events and fund raising.

Week One

During the first week of our internship at CeraPhi, we were focused on collecting the thermal performance data for 13 historic buildings which included the Great Yarmouth Minster, The Royal Naval Hospital, Norwich Cathedral and others from similar time periods. This involved researching the U-values of walls, roofs, floors, windows and doors as well as estimating the surface areas of each building element. The aim was to calculate the overall heat loss of the building and understand how suitable they would be for geothermal heating systems.

Geothermal systems provide low carbon heating by supplying heat at relatively low temperatures, reducing heat loss is critical to improving efficiency. We also visited the Great Yarmouth Minster which provided a good view of the challenges that are faced with geothermal energy, for example where can we dig the wells? Where can the pipes be fed through? The cost? And countless others that come with doing these assessments on historic buildings that have been listed and are not allowed any changes to them. Also seeing the building helped me understand the large internal volume of the building which needed to be heated so we were thinking of many different heating techniques to heat such a tall building with such internal volume, and we decided on floor heating. This is because the floor is warm and as heat rises the heat will be trapped in an area close to the seating area which will be one of main parts of the building to be heated this will reduce the amount of heat energy needed for the building as we will only be heating where people are going to be and not the whole building. From week one we realised that the historic construction materials and preservation requirements that can make the installation of renewable heating technologies more complex than in modern buildings.

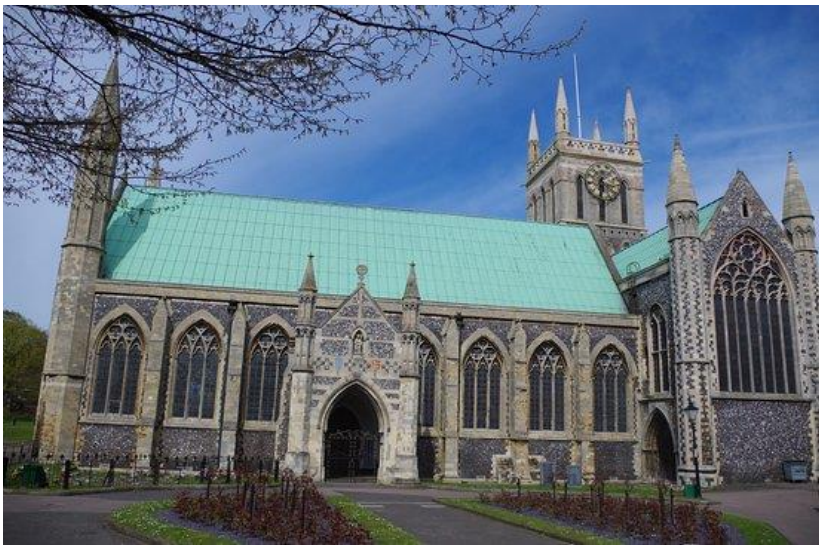


Figure 10- Picture of Great Yarmouth Minster

Week Two

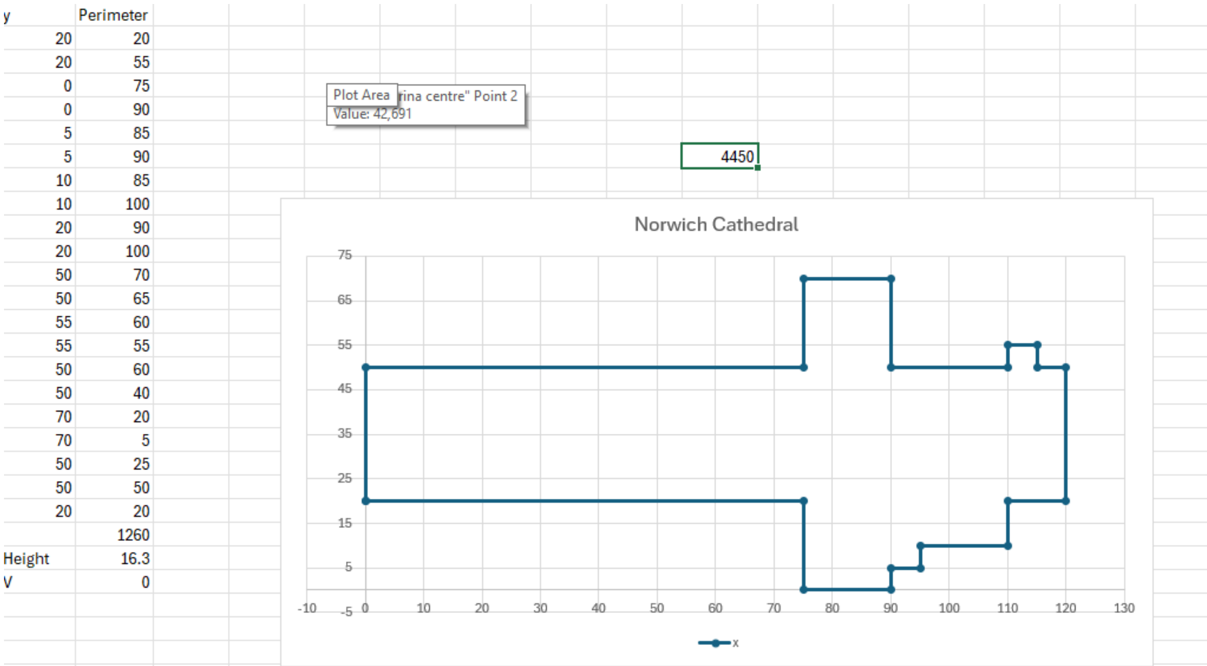
In the second week, the remaining buildings data was completed and organised in preparation for some data analysis. To improve the accuracy of our calculations, floor plans were created for each of the buildings using Excel and Google Maps. These plans allowed us to estimate surface areas and heat loss paths more effectively. A key part of this stage was comparing building dimensions and data generated by artificial intelligence with measurements and estimates obtain through Google Maps. The comparison revealed a significant margin of error within the AI generated data, particularly for older and more historic buildings.

This was likely due to the irregular shapes found within the buildings and lack of standardised information associated with the buildings. The findings emphasised the importance of verifying data before it is used for geothermal feasibility studies, as an inaccurate building dimension can lead to an incorrect heat load calculation and ultimately affect the cost of the geothermal project depending on how big the mistake is. During our time inputting all our data and preparing to analyse it we learnt a lot of new skills on Excel that will be very useful in the future. Towards the end of the week, we were provided climate data by CeraPhi which we then briefly looked at the different amounts of energy needed to heat the buildings at different times of the year.

Floor	Target Temp	Length	Width	Floor Space	Floor Type	U-Value							Total U-Value	Cum ▲	kWh
Great Hall Floor (First Floor)	20	27	7	189	Heavy oak floorboards on oak beams and joists	1.9							359.1	77,313	27,763
Undercroft Floor	20	12	8	96	Brick/stone flags laid on compacted earth	1.1							105.6	77,313	8,164
Warehouse Ground Floor	20	15	7	105	Stone slabs with lime mortar over compacted fill	1.1							115.5	77,313	8,930
Hall House Ground Floor	20	12	8	96	Brick and stone paving	1.1							105.6	77,313	8,164
Screens Passage	20	8	3	24	Stone paving	1.1							26.4	77,313	2,041
Rear Yard Access Floor	20	9	4	36	Stone setts on compacted sub-base	1.7							61.2	77,313	4,732
Modern Extension Ground Floor	20	12	8	96	Reinforced concrete slab with rigid insulation and damp-proof membrane	0.18							17.3	77,313	1,336
Roof	**Target Temp**	**Length**	**Width**	**Roof Space**	**Roof Type**	**U-Value**							**Total U-Value**	**Cum ▲**	**kWh**
Great Hall Roof	20	27	7	189	Oak timber brown-post trusses, rafters, originally thatch	2.1							396.9	77,313	30,686
South Hall House Roof	20	12	8	128	Timber rafters with clay plain tiles	2.5							320.0	77,313	24,740
North Service Block Roof	20	10	6	80	Timber rafters with clay plain tiles	2.5							200.0	77,313	15,463
Rear Warehouse Roof	20	9	6	72	Timber rafters with clay tiles	2.8							201.6	77,313	15,586
Modern Extension Roof	20	12	8	128	Timber/ steel deck with rigid insulation and waterproof membrane	0.15							19.2	77,313	1,484
Wall	**Target Temp**	**Length**	**Height**	**Wall Size**	**Wall Type**	**U-Value**	**Window Percentage**	**Window Type**	**U-Value**	**Door Type**	**U-Value**	**Number of Doors**	**Total U-Value**	**Cum ▲**	**kWh**
North Elevation	20	27	8	216	Flint rubble with brick ground floor and timber framed upper wall	1.9	20%	leaded single glazed in oak frames	5.1	Solid oak timber double door	3	1	550.8	77,313	42,587
South Elevation	20	27	8	216	Flint rubble, brick and timber framing	2.1	20%	leaded single glazed in oak frames	5.1	Solid oak panelled door	2.5	1	584.0	77,313	45,151
East Gable Wall	20	7	8	56	Timber frame with close studd Vertical (Value) Axis ary base	2.1	20%	leaded single glazed in oak frames	5.1	Solid timber plank door	2.8	1	152.6	77,313	11,798
West Gable Wall	20	7	8	56	Timber frame with masonary base	2.1	20%	leaded single glazed in oak frames	5.1	Solid timber door	2	1	151.0	77,313	11,674
North Extention Wall (modern)	20	12	8	96	Insulated cavity wall (2005 extension)	0.3	20%		0	-	0	0	23.0	77,313	1,781
South Extension Wall (modern)	20	12	8	96	Insulated cavity wall (2018 extension)	0.3	20%		0	-	0	0	23.0	77,313	1,781
Courtyard Wall	20	18	3	54	Historic flint and brick boundary wall	2.1	20%		0	-	0	0	90.7	77,313	7,014
River-side Wall	20	27	8	216	Flint rubble with brick lower section	2	20%		0	-	0	0	345.6	77,313	26,719

Summary	U-Value	Cum ▲	kWh			
Floor	790.7	541,191	61,130			
Walls	1920.8	618,504	148,506			
Roof	1137.7	386,565	87,959			
	3849.2	1,546,260	297,595	5.195857862	deg/kWh	
		FLEQ	4400			
		kW	67.6	351.4227273		
		BTU	230.8			541.0813561

Figure 11- Data collection of Dragon Hall



y	Perimeter
20	20
20	55
0	75
0	90
5	85
5	90
10	85
10	100
20	90
20	100
50	70
50	65
55	60
55	55
50	60
50	40
70	20
70	5
50	25
50	50
20	20
	1260
Height	16.3
V	0

Figure 12- Floor plan of Norwich Cathedral

Week Three

During the third week, we moved from data collection to analysis. We had also started to investigate the climate data, using each building and the region, we could find the climate data also leading to the use of degree days. Using the U-values and surface-area calculations from the previous weeks, we estimated the total heat loss of each of the 13 buildings and compared their thermal performance. This helped identify which buildings were most likely to benefit from geothermal heating and which would present greater challenges. Some historic buildings had much higher heat losses than newer buildings, despite having similar internal volumes. Its lower U-values indicated that heat loss and heating demand depend more on construction materials and thermal performance than on building size alone. Using Ceraphi's geothermal modelling tools, we then estimated the number of wells needed to heat each building and assessed seasonal demand.

The results showed that more wells are required to meet higher winter heating loads than summer demand. These findings emphasised the value of improving a building's thermal performance, where possible, before installing a geothermal system. Reducing heat loss can increase system efficiency, lower energy demand and reduce the infrastructure required, thereby improving the project's economic viability.

In figure 13, you can see that the climate data is shown for Wales, using the highlighted box, the region can be changed to see that specific regions climate data broken down into each month. Figure 14 shows a chart with some other sections colour coded, this is used to determine how many wells will be needed within those months and then it will give you the number of wells needed to match the energy demand within that period. However, the downside to this is that during the other months that the energy demand is lower, the well could be generating more energy than needed so therefore it needs a different channel to be distributed to allowing other local households or businesses to be supplied by this system.

Wales	Climate Data for Wales											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min	2.4	2.4	3.6	5.3	7.9	10.7	12.5	12.4	10.5	7.5	4.6	2.8
Max	8.2	8.5	11.4	14.9	19.1	22.1	23.7	23.5	20.5	16.3	10.9	8.4
Mean	5.3	5.45	7.5	10.1	13.5	16.4	18.1	17.95	15.5	11.9	7.75	5.6

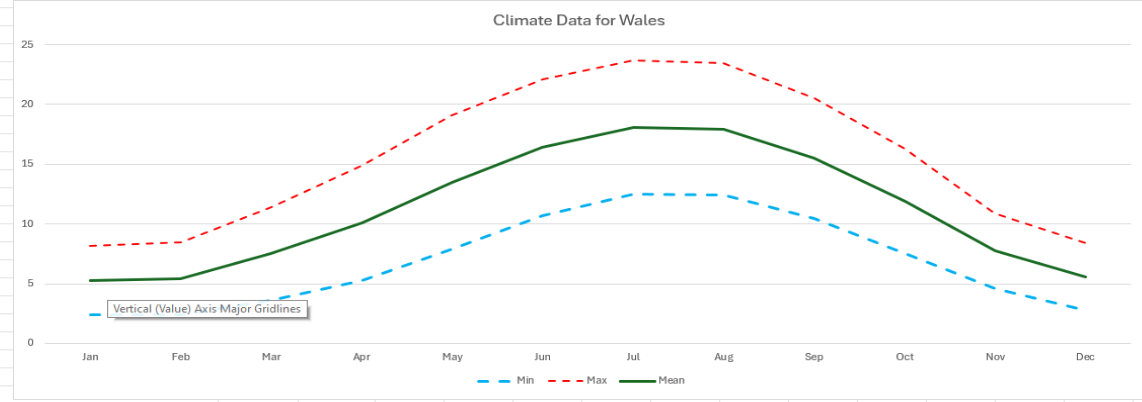


Figure 13- Climate data for Wales

AYR inc Heat Pump	35.1	kW
Sesonal inc Heat Pump	40.3	kW
Working Temp	2	°C

AYR inc HP (kW)	35.13	CeraPhi 500	126.27	CeraPhiWell
Sesonal inc HP (K	40.33	CeraPhi 500	153.33	CeraPhiWell
Working Temp	2	CeraPhi 500	6	CeraPhiWell

Please Chose the number of each well to match blue curve on chart

AYR Wells	1
Seasonal Well Aug start	0
Seasonal Well Sep start	1
Seasonal Well Oct start	0
Seasonal Well Nov start	1
Seasonal Well Dec start	1
Seasonal Well Jan start	0
Total Wells	4
Well Coverage	101.3%

Well Selection

Month	AYR well output	Seasonal Aug Start Output	Seasonal Sep Start Output	Seasonal Oct Start Output	Seasonal Nov Start Output	Seasonal Dec Start Output	Seasonal Dec Start Output
Jan	26,135	0	30,007	0	30,007	30,007	0
Feb	23,606	-	27,103	0	27,103	27,103	0
Mar	26,135	-	-	0	30,007	30,007	0
Apr	25,292	-	-	-	29,039	29,039	0
May	26,135	-	-	-	-	30,007	0
Jun	25,292	-	-	-	-	-	0
Jul	26,135	-	-	-	-	-	-
Aug	26,135	0	-	-	-	-	-
Sep	25,292	0	29,039	-	-	-	-
Oct	26,135	0	30,007	0	-	-	-
Nov	25,292	0	29,039	0	29,039	-	-
Dec	26,135	0	30,007	0	30,007	30,007	-
Total	307,716	0	175,200	0	175,200	176,168	0

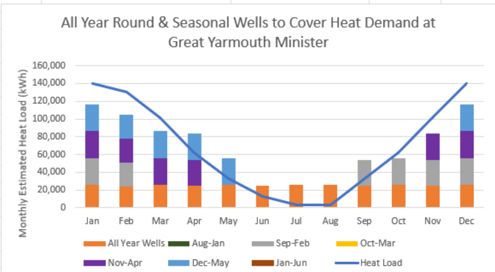


Figure 14- Well calculation sheet

Week Four

In the final week, the focus shifted towards finalising the analysis and beginning the preparation of a report detailing the findings from the project. We reviewed all the calculations, checked data consistency, and summarised the results in a format that clearly communicated the relationship between building characteristics and geothermal feasibility. Particular attention was given to comparing the buildings based on their total heat loss, estimated heat loads and geothermal well requirements. This allowed us to identify the buildings that would be most suitable for geothermal heating considering costs and practicality.

Throughout this process, several conclusions were made. The project demonstrated that accurate building data is essential information when designing renewable energy systems and calculating the heat load needed for a building of any sort and that any assumptions left for AI can lead to significant errors in not tested well. More importantly, the analysis reinforced the critical role of U-values in determining heating demand. Regardless of building size, poor insulation consistently resulted in great energy requirements and increases geothermal infrastructure needs. The project also emphasised the unique challenges that are faced when dealing with old historic buildings that need to be preserved where conservation requirements can limit opportunities for fabric improvements, Overall the 4 weeks at the internship provided valuable experience in building performance assessments, data analysis, heat loss calculations, excel, and geothermal system design. It can also demonstrate how engineering decisions are driven by accurate data and how geothermal energy can play a significant role in reducing carbon emissions when matched with a thorough understanding of a building’s thermal characteristics

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Introduction 1
Method/data collection 1
Data analysis 1
Volume vs U-value 1
Degree days 2
Next 2
Conclusion 3

Introduction

Method/data collection

Looked for many historic buildings

Figured out the u values and the materials that were used

Worked out the area of each buildings wall, floor, roof, door, window

Done this for 12 old buildings and 1 newer (marina centre- good comparison)

Figure 15- Planning of our final report.

Why Data Analysis Is Important

Data analysis is extremely important for our project due to the project involving untouched historic buildings because the quality of the final conclusions depends entirely on the accuracy and interpretation of the data collected. The historic buildings data that we collected were complex structures which included varying materials, ages and size. By analysing the data, we collected we can understand how these differences affected each buildings heat loss and suitability for geothermal energy.

One of the main reasons for carrying out the data analysis was to calculate the heat loss of each building. By combining U-values with the surface area of each wall, floor, roof, door, window we were able to estimate how much heat was escaping and where from. This is essential for geothermal energy because the heating system must be able to replace this lost heat to keep the building at a comfortable temperature.

Data analysis also allowed us to compare the thirteen historic buildings and identify which ones were the best candidates for geothermal systems. By examining the results, we could see which building had the lowest hear losses and which would require more energy to heat. This helped us understand where geothermal systems would be most effective and practical.

Overall, data analysis was essential because it allowed us to accurately calculate heat loss, compare buildings, validate data, determine heating requirements and estimate the number of geothermal wells needed to heat a building at a certain temperature. Without analysing the data, it would not have been possible to determine which historic buildings were most suitable for geothermal heating or to make informed recommendations for future projects.

Executive Summary

This project investigated how geothermal heating could be used to improve the thermal performance and climate resilience of historic buildings while maintaining occupant comfort and protecting their historic significance. The project was carried out over four weeks with CeraPhi and focused on understanding the challenges involved in assessing and heating historic buildings, particularly where conservation requirements restrict changes to the existing building fabric.

The main case study was Great Yarmouth Minster, a historic Grade II listed building. The project began with research into geothermal energy, U-values, degree days, building materials and heat loss. CeraPhi's closed-loop geothermal system was studied, where a working fluid circulates through a deep well and absorbs heat from the surrounding rock before returning to the surface. This heat can then be transferred into a building's heating system. The research highlighted the potential for geothermal heating to provide a lower-carbon alternative to conventional heating systems.

A major part of the project involved collecting and analysing data from historic buildings. Information was gathered for 13–15 buildings, depending on the stage of the project, including walls, floors, roofs, windows and doors. Approximate dimensions, surface areas, materials and U-values were recorded using Excel. Google Maps was used to estimate building dimensions where accurate plans were unavailable. Due to the lack of reliable information for many historic buildings, assumptions were necessary, and an estimated error margin of approximately 10% was used.

The data was then used to estimate heat loss and heating demand. Degree days were incorporated to investigate how seasonal and regional climate conditions affect energy requirements. The results showed that building thermal performance has a significant effect on heating demand. Buildings with poorer U-values generally required greater amounts of energy and could require more geothermal wells. The analysis also demonstrated that larger building size alone does not determine heating demand, as construction materials and thermal performance are equally important.

The project identified several practical challenges associated with installing geothermal systems in historic buildings. Listed-building restrictions can limit alterations to the building, while cemeteries, archaeological remains and surrounding structures can restrict suitable locations for geothermal wells. Existing heating infrastructure, such as radiators, could potentially be reused to reduce the need for major alterations. Locating equipment so that it does not negatively affect the appearance or historical significance of a building was also an important consideration.

The project produced a numerical building heat-loss and performance model, a material and U-value library, building data tables, charts and visualisations, and a final report and presentation. Overall, the project demonstrated that accurate building data is essential

when assessing geothermal feasibility. It also showed that reducing heat loss, where possible, can improve system efficiency, reduce heating demand and potentially reduce the infrastructure required. The findings suggest that geothermal heating has potential for historic buildings, but its suitability depends on the building's thermal characteristics, available space, conservation restrictions, heating demand and the accuracy of the data used in the assessment. Furthermore, we discovered after comparison between AI and Excel that AI was extremely wrong, proving that AI cannot do the job that is done here at CeraPhi because of how new geothermal heating is. The information on the internet is too new and not accurate enough to reply on compared to a professional within a workplace.

Conclusion

In reviewing our finished project, we evaluated lessons learnt, we have drawn the following conclusions.

Planning:

Initially, we did some small tasks provided by CeraPhi and computer-based research to provide us with a basic understanding of the industry, making us more familiar with the language and terminology used within the industry. On top of this, we produced a small fact file on Great Yarmouth Minster as this building was our main case study and we were unfamiliar with it, so gaining an understanding of its history and its current use helped determine its future of geothermal heating.

Ask questions:

Throughout our project, we had to enquire with our mentor Barry Read at CeraPhi about the different ways of interpreting data. Barry was the main source of our information and helped guide us through our internship journey. The main difficulty we agreed on was building up the courage to keep asking questions. We experienced this because we understood that everyone at CeraPhi was very busy with deadlines and meetings, but further on into the programme, this feeling slowly faded.

Developing new skills and techniques:

Throughout this project, we have learnt many new skills. First, we learnt how to approach common industry software such as Excel. Before this internship programme, neither of us knew how to confidently use Excel, but with the guidance of Barry our mentor, we understood how to use excel more as we used it. For example, we learnt how to fix errors, create charts and graphs using the data we have inputted, and formulas.

Additionally, we learnt and developed our problem-solving, teamwork, project management, and time management skills which all help contribute towards the 15 elements of the CREST project. With the development of these skills, we were able to work efficiently and get tasks completed on time meeting the criteria of each task.

What we would do differently next time

If we were to complete this project again, we would try to collect more accurate information about buildings before starting the calculations, although there is minimal data available, we think this could be an area of improvement. A major challenge was that many historic buildings did not have detailed plans, meaning we had to estimate dimensions and materials using Google Maps and other sources. This meant that some of our calculations could have contained errors that we did account for. Next time, we would spend more time finding more reliable building plans and checking our measurements against multiple sources before entering them into Excel. We would also validate any information produced by AI earlier in the project, as we found that some AI-generated measurements were significantly different from our manually checked data. This would make our heat-loss calculations more reliable and improve the accuracy of our final conclusions.

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