IOR.org.uk
REFRIGERATION AIR CONDITIONING HEAT PUMPS

The knowledge hub for refrigeration, air conditioning and heat pumps

Heat Networks in Rural Areas

Dylan Betts

What you will learn

- The paper describes a pioneering rural village district heat network in Cambridgeshire using high temperature ammonia air to water and ground to water heat pumps to provide 2MW heat to 300 buildings including houses, school and two churches.
- The scheme is intended to provide space heating at 72°C water temperature to existing radiators through a Heat Interface Unit in each building and replaces mainly oil-fired boilers.
- The heat pumps are contained within a separate Energy Centre and include back-up electrode boilers and large thermal stores to provide resilience. Electrical Power is drawn from the Grid and a PV farm.
- The paper describes the issues experienced including community liaison, installation of the heat network distribution pipework and resolving unexpectedly high noise from the Energy Centre.

1. Introduction

The concept of rural heat network at the village of Swaffham Prior near Cambridge was first proposed in 2016 by the Swaffham Prior Community Land Trust (SPCLT). This was originally set up by members of the village to deliver housing for people living in Swaffham Prior who struggled to rent properties at typical market rental prices, or who needed to rent a different type of home.

Bouygues Energies & Services were appointed by CCC following the initial feasibility study to develop the technical feasibility of the project, before being appointed as Principal Designer to develop the detailed design and later as Principal Contractor. The Swaffham Prior Heat Network was conceived to represent an innovative method of renewable energy retrofit engineering and addressing not only the growing environmental and financial concerns surrounding oil and gas usage for domestic heating, but also the distinctive heating requirements of rural communities. The project developed around the concept of delivering hot water through a network of below ground pipes installed throughout the village to each property for both space heating and hot water. Heat pumps were selected as the preferred technology to supply the heat using both ground and air source technologies.

Two 750kW Ground Source Heat Pumps (GSHP), and one 500kW Air Source Heat Pump (ASHP) procured from GEA Refrigeration UK Ltd and operating on Ammonia (R717) refrigerant have subsequently been installed in a new purpose-built Energy Centre built upon the site of a previous agricultural building.

The GSHPs are served by an array of 103 boreholes, located in the adjacent field to the Energy Centre. Four 50m^3 thermal stores sit outside the building, these enable the decoupling of energy production from time of use, enabling the heat pumps to take advantage of time of use tariffs of the availability of cheap electricity. As a further innovation, Bouygues proposed to provide an electrical connection from a nearby proposed Solar PV farm to the Energy Centre, provide renewable electricity for the heat pumps. The network will have the capacity to supply 2MW heat generating capacity of heat from the heat pumps at around 72°C to around 300 properties in the village. This value had been determined using previous years' energy consumption from a sample of the properties in the village. The majority of the properties are domestic dwellings, but the village also includes two churches, a school and a pub. Despite the use of previous years' consumption data from various properties in the village, baseline data could not be accurately measured due to the lack of metered data, the variability in use across properties and a distinct lack of reliable assessment techniques for rural buildings. Additionally, pro-active decisions had to be made regarding the best method of predicting future energy usage of the village over the 60 year life-span of the project. However, fluctuations which will arise dependent on demographic, age, and familial nature of future residents provides a huge variability in predictive energy consumption for the future. As such, the thermal buffer tanks serve as additional heat generation capacity for the network, providing a further 2MW of peak heat as required by the village. The design was put together following appropriate design philosophies and guidelines set of in CIBSE CP1, however this didn't include for rural challenges, and thus, suitable alterations had to be made.

It is necessary to contextualize the significance of this endeavour within the broader environmental landscape. Rural households contribute 25% more CO_2 emissions from heating fuels than their urban counterparts, amounting to an additional 1.5 tCO_2 per household per annum [1]. This stark contrast accentuates the pressing need for innovative solutions, such as the Swaffham Prior Renewable Heat Network, to mitigate the environmental impact of rural communities.

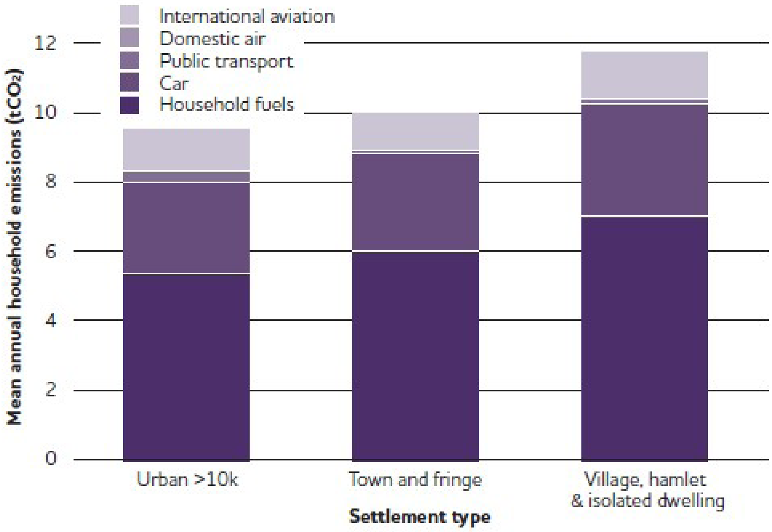

Figure 1: Mean Household Emissions by Settlement Type [1]

This paper aims to delve into the utilisation of Heat Pumps within the Swaffham Prior renewable heat network and aims to shed some light into the complexities and challenges associated with attempting a large-scale retrofit of heating systems in a village of approximately 300 properties. By examining the lessons gleaned from this groundbreaking initiative, the paper will explore the potential of referencing Swaffham Prior as a compelling case study for analogous village retrofit programs throughout the UK. Through a comprehensive analysis of the technological, logistical, and social considerations underpinning the project, this paper seeks to offer valuable insights into the viability and implications of integrating further sustainable heat networks in rural areas throughout the UK, thereby contributing to the necessary advancement of sustainable heating practices nationwide as per both the "Building for 2050" initiative [2] and the UK Government national carbon emission reduction targets of 2030 and 2035.

2. Project Background

The Heating Swaffham Prior project was kick-started by Swaffham Prior Community Land Trust to give residents the opportunity to cost-effectively replace their oil-fired heating systems with a low-carbon alternative. In 2018, the trust commissioned a feasibility study, funded through a £20,000 grant under the Rural Community Energy Fund, into alternative heating options from sustainability charity Bioregional, which identified the potential for a village-wide heat network. A range of heat sources was considered – including burning biomass from local straw – but the key to unlocking the project was a land parcel on the edge of the village owned by Cambridgeshire County Council (CCC). This opened up the possibility of generating heat using a GSHP system.

The Phase 2 Rural Community Energy Fund grant was only available to district and parish councils, as a result, the Community Land Trust presented the heat network concept to Cambridgeshire County Council with a view to persuading the Council to apply on their behalf for a grant towards project design and development. Following this, Cambridgeshire County Council approached Bouygues E&S through the existing REFIT 3 Energy Performance Framework to develop the project further.

The project was initially intended to utilise Ground Source Heat Pumps only, with approximately 267 boreholes, however the project scope was altered as a result of a sharp decrease in the previously preferential Non-Domestic Renewable Heat Incentive (NDRHI) tariff rates alongside an significant increase in the cost of borehole installation and commissioning. The addition of the single 500kW Air Source Heat Pump for use in the summer months was incorporated to give time for the residual heat underground to recover, so that, as the 20+ year programme continues on, the thermal low point of the ground from which the boreholes extract heat will be considerably higher year-on-year relative to a system which only operated Ground Source Heat Pumps throughout the year.

2.1 Community Engagement through the Swaffham Prior Community Land Trust

Community engagement has been vital throughout the project development process, the construction phase and ongoing operation of the heat network, and as such, a lot of time and effort was invested in engagement work to boost the confidence and trust of the community who were being asked to commit to switching to a new type of heating provision which the majority had little knowledge of. As part of this effort, regular stakeholder meetings were held with representatives from CCC, Bouygues E&S and the SPCLT in an attempt to respond to concerns and answer any questions from the village residents. Regular surveys were conducted to gauge resident opinion of relating to the quality of customer service, specifically regarding knowledge transfer on how the heat network was intended to operate, the technologies that would be employed, receptiveness to resident complaints and queries, and full transparency as to what negative effects could be experienced as a result of the installation of the heat network. To further improve stakeholder relationships, a stakeholder engagement consultant was engaged through the Community Land Trust to further educate the residents as to the benefits of the project.

2.2 Community Reaction and Further Engagement

As of January 2024, there are approximately 70 properties connected to the network and “on-heat” with an additional block of properties in the planning phase. Of those connected, the vast majority have been very satisfied with the level of heat provided and the ease of use of the newly installed Heat Interface Unit (HIU) which essentially takes the place of their previous boiler. This serves as the ‘interface’ between the heat network and the tertiary heating distribution system in the property. In addition, due to the majority of the properties in Swaffham Prior originally operating on an oil fed system, the absence of an unsightly oil tank is a welcome sight in their back gardens. Community support post-installation is equally important to the success of the project, and to that end Equans E&S operate a 24-hour hotline for Swaffham Prior residents in the event of a loss of heat, similarly, the operation of the energy centre is monitored for 24 hours a day.

There have been some unforeseen issues regarding the construction of the network which the community has fed back to Equans E&S, CCC, and the SPCLT. These concerns are being addressed by the team dedicated to the operation and maintenance of the network, located on-site at the Energy Centre. In summary, these issues are:

1. The visual impact where grass verges have been poorly re-filled following groundworks.
2. The visual intrusion of the Energy Centre for homes in the village (although this is approximately 0.5km from the village centre).
3. The original footpath which passed through the borehole field, has only recently become available for use.
4. Difficulties caused as a result of necessary easements through unconnected properties.

The residents of connected properties have also experienced some issues concerning recent works post-installation of the HIU and connection onto the heat network. These have often reflected a limited knowledge of the new system from the residents and have affected water circulation related works, for example one resident reported flow issues following a bathroom re-fit. This, as is the case with many resident queries can be addressed with a higher level of focus on resident education for the future.

Furthermore, the case of responsibility delineation has been prevalent in the 18 months since the network was turned on and the first connections made; an example of ongoing discussions between the project partners concerns the replacement of ‘failed' heat emitters within homes subsequent to connection to the network. Equans E&S are of the opinion that if no modifications have been made to the existing physical emitters and pipework during the installation works, it is the duty of the homeowner and/or CCC to resolve, unless clear evidence can be provided that the installation works that cause the damage that has been reported. These are often complex and difficult conversations where it is of paramount importance for all parties to work together to reach an amicable solution. Clear delineation of responsibility, before any works were started, could potentially be improved to prevent such issues from happening.

3. Energy Centre

A purpose-built Energy Centre has been constructed to locate the 2x 750kW GSHPs, 1x 500kW ASHP, 3x 500kW auxiliary electric boilers, dedicated ventilation equipment (due to the use of ammonia as a refrigerant), and all other heating ancillary equipment. Due to their size, the thermal stores are sited externally with the dry air coolers which extract heat from the ambient air for the ASHP. The Energy Centre is situated on the eastern side of the village and was designed and procured by CCC independently although works were sequenced and coordinated with the design packages managed by Bouygues E&S in our role as PC/PD.

Figure 2: Energy Centre (left) and Thermal Stores (right)

The Energy Centre was built with a $12m^2$ roller door installed on the northwestern face of the building, a factor which has proved to have a negative impact upon noise levels, and contains internal access to the Northeast of the building. Within the energy centre there are three separate fit-for-purpose control rooms alongside the bulk of the Energy Centre where the heat pumps are located, along with 3x 500kW Electrode Boilers which were included in the overall heating design to provide additional resilience. These can provide the thermal stores with heat if the heat pumps are offline. Although these are clearly inferior in terms of overall efficiency relative to the GSHPs and ASHP, the opportunity to secure a significantly sized electrical connection (via the Cambridgeshire Private Electricity Network) made this a viable and practical option. Fig.2 shows an external view of the Energy Centre where the 4x $50m^3$ (200,000 litres total volume) thermal stores are located. These are used to buffer thermal heat at 72/75ºC from the heat pumps / electric boilers to meet demand from the network.

An agricultural building used to be located on the site previously and as such, planning permission did not have to be sought in order to complete the build. We acknowledge that there have been a number of issues to address regarding the Energy Centre since system operations have begun; perhaps the most pertinent of which has been the noise level at the border of the single adjacent property. The noise levels tend to be more noticeable as a result of operation of the Ground Source Heat Pumps at night. Noise levels were planned to be approximately 25dB initially, with this rising to 45dB during the project planning phase. Actual noise levels can exceed this, and a review of acoustic absorption methods was considered.

As a result, acoustic jackets have been fitted over the compressors to reduce vibrational noise emissions. However, insufficient noise attenuation measures from the building overall, were implemented during the construction phase causing small gaps to be left (for example around the roller shutter door) and a measured noise level at the neighbouring border in the order of 50dB. In addressing these higher-than-expected noise levels relative to the original scheme design, the heat pumps have all been given increased layers of sound absorbent protection and all aforementioned air leaks in the building fabric have been dealt with. Acoustic membrane has been applied to all external doors, with increased layers on any louvre doors; cumulatively these preventative measures are expected to reduce the decibel level at the border of the neighbouring property by 7-9dB and will be an important achievement in ensuring addressing the concerns of all those potentially impacted by the heat network's implementation. Although this was identified as a project risk early on during the development phase, noise levels have proved to be in excess of expectations and serves as an important issue for consideration in any comparable future projects.

4 Heat Pumps and Refrigerants

Ammonia heat pumps have been utilised for the scheme as primary heat sources. These needed to be capable of delivering 75ºC water flow temperatures at a delta T of 15ºC. The heat pumps featured a twin stage compressor circuit comprising of a screw compressor with a reciprocating compressor for high-end temperatures. The 500kW ASHP is connected to a dry air evaporator cooler (located on a plinth directly outside the building) to absorb ambient thermal energy and transfer via the refrigeration circuits to the heat pumps internally.

The possibility of using R717 as a natural refrigerant alternative (with a GWP of 0), came to light through an extensive market evaluation of available commercial heat pumps during the early project design phase. It became clear that in order to get to the necessary temperatures that would align to a conventional fossil-fuelled boiler system as found in the majority of homes, we would need to utilise a slightly more 'unconventional' refrigerant option relative to HFC refrigerants that are more commonly found in commercial applications. After initially looking at HFO refrigerants, these were unable to reach the expected high temperatures at a reasonable compression, which would result in decreased COPs as the required temperatures are met. There are also wider environmental concerns with the use of HFO's. As a result, natural refrigerants with ultra-low GWP's were considered, with CO_2, Propane, Isobutane, and Ammonia as the main options.

CO_2 was deemed unsuitable due to the requirement of a very low return temperature on the heating side in order to maintain the stability of the vapour compression cycle, the refrigerant would not be able to deal with the narrow delta Ts attributed to the Swaffham Prior Project. The use of CO_2 would have required a +40ºC delta T which could not have been retrofitted into the properties on the village without severely impacting the secondary heating systems.

Ammonia was chosen over Propane and Isobutane due to its commercial availability within the heat pump market at the time, however all were suitable refrigerants. The drawbacks of these are that they are hazardous and potentially explosive. Ammonia produces additional risk through its toxic and corrosive nature and the risks associated with inhalation. Due to the safety issues with the ammonia refrigerant, extra precautions were taken in the design and construction of the energy centre in which the heat pumps were housed to ensure full compliance with DSEAR regulation practices. These included ventilation and leak-detection systems as well as various other safety measures to ensure that – in the event of a leak – there is a process set up to keep any personnel safe and avoid an explosion.

The use of both Ground and Air Source heat pumps allows the system to operate using the heat source which provides the best co-efficient of performance at the time as monitored by the BMS in the Energy Centre.

4.1. Borehole Field

The arrangement of the borehole field was altered significantly throughout the project. Initially Bouygues commissioned BA Hydro to conduct hydrothermal geological studies of the site to enable understanding and prediction of heat generation potential of different borehole arrangements. Also undertaken was a thermal resistivity test to determine the volume of heat able to be absorbed from each borehole, this was achieved through the installation of a test borehole with thermal response tests carried out over several weeks to inform the borehole design through improved understanding of the geology. This led to the inclusion of an air source heat pump to relieve the boreholes of their duties over the summer months and replenish and regenerate heat for the following winter.

Subsequently, this led to the ability to have the boreholes dug in a far sparser pattern than originally intended, which in turn also improved efficiency of the boreholes as there was far less interaction between each neighbouring set of boreholes. This allowed a further reduction in the total number installed since each borehole was able to be exploited to its full potential. This iterative process between the M&E designers, energy specialists and thermo-geologists allowed an optimum combination to be arrived at between the use of the air and ground source systems. As a result of our modelling, including the optimisation of design and control philosophies and increasing thermal storage capacities the planned number of boreholes was reduced from 256 to 103.

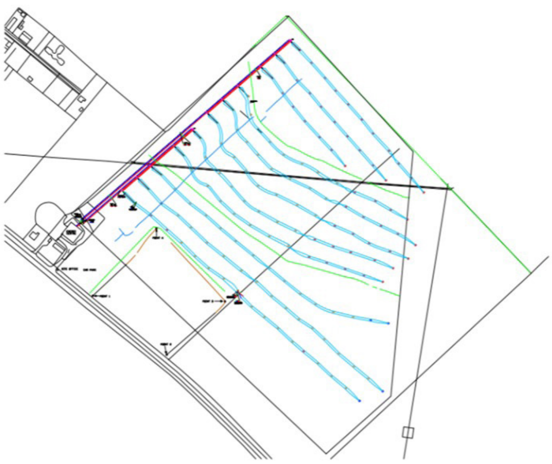

Figure 3: Borehole Field Layout

The boreholes are connected to the energy centre and heat pump exchanger via a main branch of flow and return pipework which is fed by individual strings (rows) of pipework stemming from each row of boreholes – as seen above (Fig.3). The control of each junction between the main branch of pipework and the individual strings house a manifold which has the capability to manage flow rates and pressure through the system.

5. Heat Network and North Angle Solar Farm

5.1 North Angle Solar Farm (NASF) / Cambridgeshire Private Electricity Network (CPEN)

The increase in electricity prices in recent years and the design and construction cost for the network had a substantial impact on the feasibility of the project and placed a strain on the economics case, given that the price of the commodity being relied upon to deliver this work was increasing to north of 60p/kWh. An additional strain to the project consisted of UKPN costs to upgrade the connection to the national grid from the Energy Centre. Rural villages do not typically have large existing connections to the grid – and not enough to draw an additional 2,500 kVa that was required to the new Energy Centre. As a result, Bouygues E&S proposed connecting to the North Angle Solar Farm - which at the time was an independent Bouygues E&S project. A cost-plan and business case were developed for the installation of a private wire connection from the North Angle Solar Farm to the Energy Centre to supply the electricity demands of heat sources. Using electricity with 'zero carbon' emissions, when compared with the carbon emissions contributing to grid electricity, is extremely beneficial and it was agreed to include this in the overall project proposal.

CPEN is an 8km long stretch of 33kV private wire with a central substation directly connecting NASF with a new transformer just outside the Energy Centre. Anything downstream of the central substation is private, linking directly to the energy centre but allowing for surplus export to the network when there is little demand, and shortfall import from the network in the event of increased demand during periods of low solar absorption.

5.2 Heat Network Layout

Bouygues E&S contracted with Pinnacle Power Ltd for design and build of the heat network. Designing and installing a new heat network is an unprecedented challenge when retrofitting an ancient parish which contains houses built as far back as the 1700's [3]. The DHN was designed with a 70ºC/55ºC degrees Celsius flow/return design operating temperature, to ensure efficient operation of the heat pumps and thermal stores, however design of a flow/return system with a delta T of 15ºC presented a unique challenge with regards to the arrangement of the older residential properties. Typically installed heating systems in the village operated at 10ºC delta T, which resulted in the return of water through the network at 5ºC more than designed. To mitigate this, Bouygues E&S considered replacement of the pipework distribution system in the properties in order to satisfy the 15ºC delta, however the high costs and potential disruption involved made this an unsuitable option. The network itself – as shown in Figs.4 and 5 comprises of an intricately laid series of flow and return pipes throughout the roadways of the parish. The network design allowed for future connections in all homes in the village as well as the small number of existing non-domestic properties. The wider project team including CCC felt this was important since it would provide the opportunity to connect to the network at a later date. At each property line a t-connection was installed for later use as a branch off to the property line.

The network itself – as shown in Figs.4 and 5 comprises of an intricately laid series of flow and return pipes throughout the roadways of the parish. The network design allowed for future connections in all homes in the village as well as the small number of existing non-domestic properties. The wider project team including CCC felt this was important since it would provide the opportunity to connect to the network at a later date. At each property line a t-connection was installed for later use as a branch off to the property line.

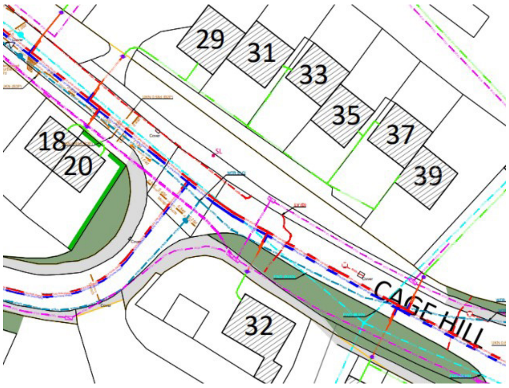

Figure 4: Heat Network - T-connections at property line

Figure 5: Entire Heat Network / Energy Centre (shown in purple)

5.2.1. Network Installation & Traffic Management

Pinnacle were sub-contracted to install the network throughout the village. Traffic management proved to be a particular area of concern throughout the installation process. The rural nature of the village meant that unforeseen challenges arose with respect to planning and reception of right to work permits on the roadway. Where possible permits were acquired in advance for the initial installation, however for end-point customer connections this wasn't possible as the installations were not delivered to every property in the village sequentially, which would have allowed for a more organised approach for installation and traffic management. Instead, permits had to be obtained after residents had signed an "Expression of Interest Form" and several surveys had been carried out on the property to determine pipework routes from the roadway into the home. All traffic management attributed to end-customer connection had to abide by several notable caveats exclusive to projects in rural areas, such as the High Street – main road through the village – being part of an access route for HGV farm deliveries which require additional space on the roadway than do ordinary vehicles.

5.3. End-Point Customer Connection and Internal Installations

The process by which a resident of Swaffham Prior is able to join the heat network and have the pipework routes designed and installed on their property is designed to be as streamlined and un-intrusive as possible for the homeowner. Following a property owner signing an expression of interest form with Cambridgeshire County Council, the process involves Equans E&S conducting an internal and external survey on the property. This includes aspects such as:

1. Determining make, model and age of the existing boiler
2. Determining kW rating, flow and inspection history of the existing boiler
3. Carrying out inspection surveys on the existing boiler controls
4. Performing a visual inspection of building electrical systems to determine the need for a new distribution board on the property as a result of the increased electrical load.

Following this process, a surveyor locates the suitable area for the network pipes to enter the property, this is often where the existing boiler is already located, in order to facilitate a straight swap with the heat interface unit. Then a survey is undertaken to provide pipework routes from the T-piece in the roadway to the home with measurements and costs produced and sent to the Council for review.

Following the review, the property is factored into the construction programme. Works are then carried out later; over the course of 4-5 days the pipework is laid with all mechanical and electrical connections in place and the new HIU installed with a commissioned data logger installed which will send consumption information back to the energy centre to better assess and improve output efficiencies.

6. Swaffham Prior Heat Network as a Case Study for Retro-fit Heat Network

The Swaffham Prior HN is a case-study for retrofitting and rejuvenating ageing villages for them to become more accessible both to newer-generation renters and growing families whose preference is to not reside in a home fuelled by oil/gas. By instead fuelling the homes with zero carbon alternatives such as a mixed Ground and Air Source Heat Pump Network.

An important aspect of the success of the project came through weekly design team meetings involving designers and engineers from a plethora of companies and disciplines. Listed below are the main commercial partners involved in the project:

- Sharman Grimwade (M&E Designers)
- Pinnacle (DHN)
- BAS Hydro (Boreholes)
- GEA (Heat Pumps)
- Bouygues E&S

Whilst the project has largely been a success, the challenges outlined in this paper will serve as a forethought to those who wish to replicate the heat network regarding the logistical and technical issues both foreseen and unforeseen that have had an impact on the development of the SPHN.

About the author

Dylan Betts, BEng (Honours) is a graduate in Energy Engineering from De Montfort University. Dylan has been involved in several large-scale decarbonisation projects over the last year including the implementation and operation of the Swaffham Prior Heat Network project, which is the first of its kind in the United Kingdom, providing the capacity to have up to 300 homes decarbonised with low carbon heating systems

References

1. V. W. J. T. a. T. B. Ian Preston, "Distribution of Carbon Emission in the UK: Implications for Domestic Energy Policy," University of Oxford, Oxford, 2013.
2. E. &. I. S. Department for Energy Security and Net Zero and Department for Business, "Building for 2050," London, 2018.
3. "Swaffham Prior," British History Online, [Online]. Available: https://www.british-history.ac.uk/vch/cambs/vol10/pp273-278#anchorn9. [Accessed 22 01 2024].