T4 Sustainability Ltd

Church of the Good Shepherd:

Sustainable Energy Review Of Options

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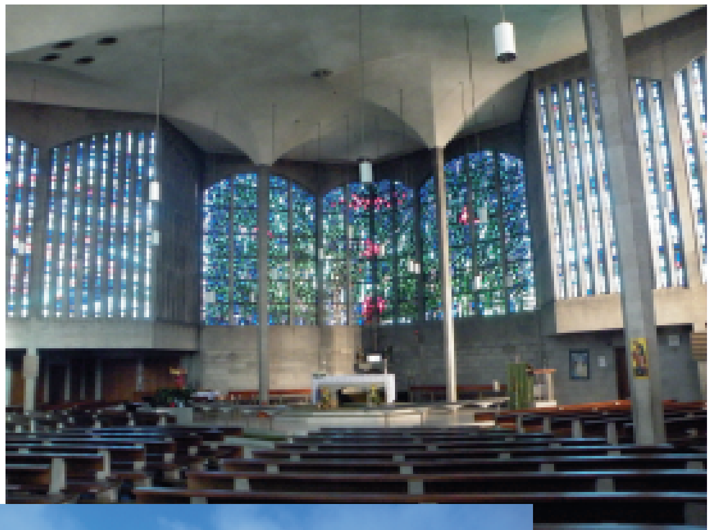

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N. B. Any costs given in this document or the finance model spreadsheet are indicative only, to allow early stage comparison of equipment, fuel costs and carbon emissions, with those from other heating plant. They do not constitute detailed costings for any scheme.

1 - Executive Summary

In their present form neither society as a whole, nor the activities of the church and its congregation are sustainable.

Moving towards a sustainable state of living requires many changes of outlook and expectation, and affords us all the opportunity to set an example in the wider community.

This document considers the meaning of sustainability, and looks specifically at opportunities to make the use of the Church of the Good Shepherd building more sustainable. Because most of the energy used on site is used for space heating, much of the document deals with possible modifications to the heating system.

Starting from the baseline that most of the energy used on site is being used to power electric underfloor heating, natural gas would offer a considerable improvement in financial and environmental performance, but the use of renewable energy, albeit requiring considerable capital outlay, offers both further improvements in environmental performance, and is likely to reduce life-cycle costs, though it is accepted that interest charges arising from the loan required to pay the capital cost of a renewable energy installation would substantially erode the life cycle cost advantage.

Taking account of the problems that arise from the various heat pump based renewable energy options, the conclusion has been reached that the options most worthy of detailed consideration are natural gas and biomass heating.

Biomass heating has a far higher installation cost than gas, though taking account of the Renewable Heat Incentive, may achieve a lower running cost. Although interest on the loan may make the life cycle cost of using biomass similar to using gas, it is hoped that some weight may be given to the benefit of reduced fossil carbon emissions from biomass plant, and the benefit that this brings to all who are affected by climate change, the acidification of sea water, and the other effects of releasing fossil carbon into the atmosphere.

Having considered all of the common renewable energy technologies in addition to biomass heating, photovoltaic electricity production could contribute towards the electricity used on site, and any excess electrical energy generated would be exported to the buildings in the surrounding area through the grid connection. PV would make a useful and financially viable contribution to the sustainable development of the site.

The financial cases for the possible space heating technologies (natural gas, heat pump or biomass) are not simple, as they depends on funding arrangements which are still evolving. A spreadsheet has been provided to allow exploration of the relationship between annual heat demand, peak heat output, and the available

Renewable Heat Incentive payments.

To get the best out of any of the new space heating options, heat demand should be minimised. The listed status of the building makes external or internal insulation of the building envelope very difficult, but if heat loss from the building can be reduced enough, not only would energy consumption, revenue cost, and emissions be reduced, but it might be possible for the new heating system to be smaller which would reduce capital costs.

In particular it may be worth adding insulation to the underside of the aisle ceilings, especially if these ceilings will be above new emitters such as fan assisted radiators. Heat losses through the roof and the plain glass in the mullions are also significant, so if the roof can have any insulation added, or the glass in the mullions can be double glazed or secondary glazing added, these would be a significant improvements.

To date, the building has had underfloor heating, and in terms of getting heat as directly as possible to the congregation, this appears to have been effective. We advise that the new heating system should now use wet underfloor heating in those parts of the building where it is possible to install it. This would result in effective heating of the congregation, even if the proportion of the floor area that can be heated is too small to heat the building as a whole.

Given the requirement to conserve the original flooring, it is accepted that the use of fan assisted radiators may be the best way to heat the bulk of the church, but if this may be less effective at heating the congregation, checks should be made to see if this will increase the length of time and amount of energy required to bring the church up to temperature.

There is little indication of insulation under the elements of the old underfloor heating system, but Ideally the new wet underfloor heating system should be mounted over at least 80mm of rigid foam insulation which would significantly reduce the amount of heat which is lost to the ground under the building.

It would also be interesting to consider the temperature to which the church should be heated. It is understood that the church should be a welcoming and comfortable place, but as a rule of thumb, each degree centigrade reduction in thermostat setting might be expected to reduce energy costs by around 10%.

2 - Aims and Objectives

T4 understands that the Church of the Good Shepherd wishes to operate in as sustainable a manner as possible, and seeks to identify opportunities to improve the building and associated plant during the refurbishment of the church building over the next year.

As electric heating is used in the church, operating costs and carbon emissions are currently very high, and the church seeks more sustainable options with lower operating costs and carbon emissions.

This report then, aims to consider,

what constitutes sustainability and why it should matter to us,

energy supply and carbon issues on a 20 year time scale,

which renewable energy technologies may be rejected, and which explored in more detail,

how the space heating within the church might be improved, and

with a spreadsheet based tool, to consider the various space heating life-cycle costs and carbon savings.

3 - What Is Sustainability ?

The approaches discussed in this section give context to discussions about what constitutes the most sustainable course of action when decisions are made.

3.1 - Theological Perspective And Definitions of Sustainability

Theological Perspective:

One theological perspective is that as Christians, we have a duty "To Strive to Safeguard the Integrity of Creation and Sustain and Renew the Life of the Earth".

This statement of mission appears to fit well with the more technical / ecological definitions of sustainability.

Technical Perspective:

Simply, an activity, process or system is sustainable if it can continue indefinitely in equilibrium with its surroundings, without change of mode of operation or scale.

Sustainability is a very general concept which implies different prerequisites and conditions to the various communities that use it.

On March the 20th 1987, The Brundtland Commission of the United Nations defined sustainable development as follows,

> “sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs”.

This suggests that a sustainable system must operate within the constraints of those natural resources which are available to it, consuming them at a rate which does not degrade the sources of any raw material on which it depends, or the sinks to which spent materials are returned.

The 2005 World Summit further considered what this meant for humanity by noting that this requires the reconciliation of environmental, social equity and economic demands, sometimes referred to as the "three pillars" of sustainability, or the "triple bottom line". This model of sustainability now forms the basis of a number of standards and certification protocols.

The World Summit definition has been queried by some academics. While modern humans may see themselves as depending on the environment, society and the economy, it has been pointed out that society and the economy depend on the environment, there will always be an environment of some kind, regardless of society and the economy.

From a modern human perspective, the triple bottom line aspects of sustainability are not at odds with one another, but are mutually interdependent. Society can only form if the availability of natural resources allows a population to develop, and an economy can only evolve within a self organising society. Once an economy is established, the individuals that comprise society quickly come to depend on it. In turn, the expansion of the human society and the economy increase demand on resources from the environment, and the needs of the population and opportunism may give rise to excessive consumption of resources and production of waste products. Materials may be consumed at much greater rates than these materials can naturally be replenished, or wastes be accommodated within ecosystems. Potentially this gives rise to ecosystem failure, and creates a significant risk of both shortages of key natural resources, and environmental damage arising from pollution and waste.

Our society in its current form is clearly not sustainable, to pick just two examples, either in terms of its dependency on fossil fuels, or in terms of the fate of greenhouse gasses emitted as a consequence of human activity.

To be sustainable, a more or less steady state equilibrium has to be established with nature such that our world wide demand for resources and disposal of waste can be accommodated by the available natural resources (sometimes referred to as global commons). Further, in order to meet the social equity and economic requirements of sustainability, equitable means must be found to achieve this equilibrium, and this links to the objectives of Christian Mission. See Appendix 1.

While this churches project can not make society sustainable on its own, society as a whole cannot become sustainable unless changes are made throughout, by all organisations and individuals. To help bring this about, the Church is not just in a position to assume responsibility for its own sustainable development, but is also in a position to lead by example, and influence society and individuals more widely.

4 - Technology Issues And Options

4.1 - Long Term Energy Source Issues

4.1.1 - Environmental Impacts

Carbon:

Assessments of the future environmental impact of systems which use energy requires information about the future environmental performance of each of the energy supply options. This is notoriously difficult to establish, though some observations follow.

The UK government has indicated that the carbon intensity of the UK electricity supply (the amount of carbon dioxide emitted per kWh of electricity supplied), will fall over the coming years.

Natural gas is widely perceived as the low carbon option for space heating. For sites which can connect to a natural gas supply, it currently sets a carbon emissions benchmark, though it should be noted that future changes to building regulations may require lower carbon heating in new buildings.

Although natural gas has a lower carbon intensity than coal, oil, LPG and resistive electric heating, it is still a fossil fuel, i.e. the carbon dioxide released when it burns comes from geological sites where it would have remained trapped, out of the atmosphere, on a geological time-scale. Further, as 'easy to extract' natural gas reserves are depleted, more energy must be expended to extract the same volume of gas, and it seems likely that techniques such as hydraulic fracturing (fracking) will increase the carbon intensity of natural gas in the UK.

By contrast to natural gas, wood based fuels are of non fossil origin, i.e. the carbon they contain has been recently captured from the atmosphere by plants. This means that while burning these fuels releases carbon dioxide, their combustion does not transfer carbon which is stored in geological formations to the atmosphere. In practice the amount of fossil carbon that is emitted as a result of the use of biomass is not zero because of the fossil fuels used in growing, processing and transporting biomass products. None the less wood fuels have a small fossil carbon footprint compared to other fuels.

It is worth noting that while it may be possible to extract natural gas, albeit at increased energy and financial cost for a long time, it is ultimately a finite resource. By contrast, wood is a renewable resource, albeit that there isn't enough space on the Earth to grow enough of it to meet all of mankinds energy needs. Electricity can be made by the combustion of fossil fuels, from nuclear energy, and from renewable sources including photovoltaic generation, wind turbines, hydroelectric turbines, and tidal turbines. It is the diverse range of renewable and nuclear generating options which may enable us to reduce the carbon intensity of electricity.

The UK government has a target of reducing carbon emissions by 80% by 2050. It would be pleasing if this project could exceed that target, and much sooner.

Transport:

Because wood fuels have a high moisture content, as a rule of thumb, they should not be regarded as carbon neutral unless they have travelled less than 20 miles between the cutting of the tree, and the point where they are used.

Over the last decade, wood pellet production plants have opened in the UK, but care should be taken when selecting a supplier, to choose one which is locally based and will not transport the fuel you use an excessive distance.

4.1.2 - Financial Impacts

Future financial impacts are also difficult to assess. UK energy prices tend to track world energy prices, either because of the sale of energy or fuels produced in the UK (the price to UK markets won't fall below the price that other countries will pay for UK fuels), or because of the UK having to buy at global market prices.

Global politics makes energy prices volatile, though depletion of finite fossil energy resources, increasing wealth in developing countries, and increasing population are all likely to contribute to energy scarcity and cost increases over the coming years.

Natural gas is now shipped round the world as liquefied natural gas (LNG), as well as transported by pipeline. Although new techniques for extracting gas, such as fracking have reduced gas prices in North America, it is widely suggested that even if the UK produces gas by this method, that prices will not fall - at best they will stop increasing, or increase less quickly.

Electricity prices seem set to rise because of a lack of generating capacity which is expected due to the decommissioning of old nuclear plant, and old coal plant which is affected by new emissions regulations. These factors may account for the high prices offered to the developers of new nuclear power plants.

Biomass prices depend on the type of material selected. Solid biomass is generally available in the form of logs, wood chips or wood pellets. As the chipping and pelletisation processes require energy, their production has a somewhat larger environmental footprint than logs, and they tend to be more expensive, but chips may be a by-product of wood disposal, and pellets are frequently made from saw mill waste rather than whole trees. In general, chips are more expensive than log wood, and pellets are more expensive than chips.

Despite the cost difference, pellets and wood chip are popular as they can be handled automatically by augers. Augers handling wood chip are more prone to jam than those carrying pellets, so pellets tend to be the premium product with the highest price. Pellets may also be blown through pipes to move them from store to burner.

4.2 - Peak Energy Requirement And Annual Demand

The view is taken that heating the church to a comfortable temperature helps to engage the congregation, and for some of the more frail members of the church, may make the difference between their being able to participate in winter services and not. It is important then, that it be possible to deliver enough heat, even on the coldest days to keep the church at an acceptable temperature.

Annual energy demand figures have been estimated from historic utility bills, and the peak power consumption from the measured energy consumption of the under floor heating system in its present state of repair, which is 120 kW.

As the present output from the electrical underfloor heating is regarded as barely adequate, it seems likely that systems in the 150 to 200 kW range be sought, especially if underfloor heating cannot be used.

Peak energy requirement and annual demand figures have been used in the finance model spreadsheet, which allows the effect of changing these and other parameters to be explored.

4.3 - Resources On And Around The Site

The site itself is relatively crowded with most of the land area covered in buildings or hard surfaces. There are however some features in the surrounding area which might offer opportunities, see view on next page taken from Google Earth.

Because of the shortage of space on site, consideration was given to using the bank between the church car park (top right on picture) and the council park (to the left in the picture) to accommodate plant and equipment. This would always have been difficult because of the need for significant earthworks and underpinning of the car park, but access is also restricted by a substation transformer, and it is believed that an 11kV power cable which feeds this substation is also embedded in this bank. The idea of using this space then has been rejected.

Day Brook and the water attenuation ponds and tanks have been considered as possible energy sources for a water source heat pump. As the attenuation pond and tank will presumably be kept empty most of the time, these offer little opportunity, but the brook itself could be a significant low grade heat resource. It has neither the fall


Attenuation pond
Football pitch under which it may be possible to drill bore holes which diverge from the church site
Day Brook
Area of flat ground that might offer a site for a shallow ground source collector
Underground attenuation tank
Bank between car park and rear site entrance levels
Substation traformer
Bank between church site and playing field, containing burried high voltage cable
Main church building

Bank between the councils park to the left and the church car park upper right.

in level or the flow rate to offer any potential for hydroelectric generation however. It should be noted that Day Brook rises nearby, and the temperature is relatively warm in winter. While the park may be flooded by the Brook, it is unlikely that surges of water would wash boulders or other objects down the water course which would damage equipment installed in it.

The ground under the park potentially offers a heat resource to ground source heat pumps. Subject to the consent of the council's legal department, the parks department are willing to consider the use of horizontal trenches in the ground to the south west of the football pitch as a heat source for the church, as long as the football pitch would not be disturbed. They are also willing to consider the drilling of bore holes on the church site which would diverge under the pitch to extract heat from a greater volume of earth.

One of the few areas of exposed earth on the church site is immediately to the north of the church. This area is grassed, and falls between the level of the upper entrance to the site and the lower car park. While nothing could be installed on this grass surface in front of the church windows, it may be possible to set a plant room and equipment into the bank with appropriate retaining walls, with access via the lower car park.

4.4 - Technology Options

4.4.1 - Rejected Technologies

4.4.1.1 - Hydroelectric Generation

The generation of significant amounts of hydroelectric power requires higher flows and drops in height that are found on Day Brook. The power that can be extracted on a hydro site is given by the following equation.

Power = Head x Flow x Gravitational force

As the head (drop in height) is very small, and the flow small, this site is not suitable for hydroelectric development.

4.4.1.2 - Wind Power

The site is crowded, and located in an urban area. There is no ground on site which would not be affected by turbulence caused by trees or buildings, and as the site has a large number of visitors, and noise would be a nuisance to the church and neighbours, it seems unlikely that any conventional stand-alone wind turbine could be used.

Turbines are available which mount onto buildings, but these generally have low electrical outputs, can impose significant structural stresses on the building, and may transmit noise and vibration into the buildings on which they are mounted.

Given the constraints of the site and the available wind turbines, the use of on site wind power cannot be recommended.

4.4.1.3 - Solar thermal

Solar thermal for heating domestic hot water has been considered, but little hot water is consumed on site, and pipe runs from any central heat store to points of use would be rather long, giving rise to significant heat loss from the pipes. Under these circumstances then, the use of solar thermal seems unlikely to offer either useful environmental or financial returns.

4.4.1.4 - Air Source Heat Pump

See Appendix 2, "Introduction to Heat Pumps".

In heating mode, air source heat pumps extract energy by cooling the air around them, and transferring that heat to the inside of a building.

Air source heat pump systems have the problem that on the coldest days of winter when most heating is required, the outside air temperature is low, so the coefficient of performance (COP) is poor. Ice may build up around heat exchange surfaces in air source systems on cold days, and the need to defrost these when the air is cold also reduces efficiency. On cold winter days air source machines may have COPs little higher than 1, so may be little better than resistive electric fires or resistive electric under floor heating under these conditions, and it may not be possible to deliver sufficient heat to the building.

As air source heat pumps obtain heat by blowing air through heat exchangers with large fans, see picture below, they may be relatively noisy, especially as they age. Given the proximity to the church and adjacent housing this could become a significant issue.

Given the relatively poor performance of these machines in cold weather and the possibility of noise nuisance, this type of heat pump is not being recommended on this site.

4.4.1.5 - Ground Source Heat Pump

See Appendix 2, "Introduction to Heat Pumps".

In heating mode, ground source heat pumps extract energy by cooling soil, rock and water in the ground with chilled fluid in buried pipes, and transferring the heat that is collected to the inside of a building.

Ground source systems have to be large enough that the available thermal capacity of moisture, soil and rock can meet short term peaks in heat demand without excessive cooling, but also large enough that adequate amounts of heat can flow into the ground source system over the course of a year to avoid excessive ongoing local cooling of the ground heat source. The success of a ground source system then, depends on the thermal capacity and conductivity of the surrounding soil and rock, but is also influenced by the mass flow of water through the ground (advection), as water brings relative warmth into the cooled heat source region. The formation of ice due to over cooling should be avoided around the pipework of ground source systems, as less heat will reach the ground source pipe work if ice prevents the flow of water through the ground near the pipes. As a precaution, the pipework of ground source heat pumps is generally filled not with pure water, but with water containing about 33% of a glycol based antifreeze. Ethylene glycol (similar to the antifreeze used in many cars) has been used in this application, but we prefer to use propylene glycol, as in the event of leaks or accidental contamination, this is much less toxic to humans, and to most organisms in the environment.

In winter then, air source systems typically have to operate with very low COPs in frosty conditions, but while well sized ground source systems should always operate with source inlet temperatures above freezing, heat source operating temperatures may sometimes not be far above freezing by the end of the winter heating season.

The pipework embedded in the ground to extract the heat can be in any arrangement which allows the heat transfer fluid to be heated by the ground by the necessary amount at the necessary flow rate. Broadly speaking, ground source pipework divides into systems that use shallow trenches one or two metres deep, or boreholes which range from a little over forty to over a thousand metres deep.

Shallow trenches may be set up using buried coils of black MDPE plastic pipe. As a rule of thumb, ten metres of trench is required per kilowatt of heat pump installed capacity, and each ten metres of trench will contain sixty metres of coiled MDPE pipe. Energy yields per metre decline if trenches are longer than a hundred metres, but multiple trenches can be run with parallel flows. These parallel trenches should be no less than five metres apart. Given these constraints on space, it seems that no more than two hundred and thirty metres of heat source trench could fit to the south west of the pitch. Such shallow trenches then could only make a small contribution to the space heating requirements of the church building.

Boreholes can also accommodate closed loop heat exchangers, but as these become deeper the static pressure in the heat exchange loop increases, so materials which can withstand this must be chosen. It is normal to backfill such boreholes with a thermally conductive material such as bentonite grout rather than conventional concrete, though the use of some lime based mixtures may also be possible which may reduce the 'embedded' carbon footprint.

Unless very deep, the vast majority of the energy reaching a ground source heat pump will be solar energy which has fallen on the surface of the earth and been conducted into the ground. This will reach the heat collection pipework by process of both heat conduction through the matrix of solid particles and the water in the pores between them, and heat advection (mass flow) by moving groundwater.

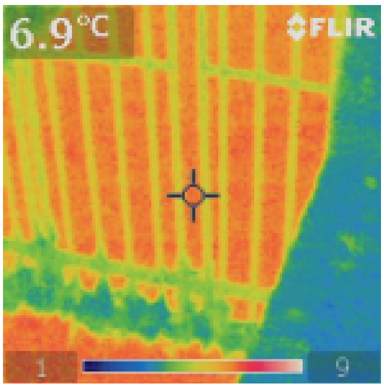
4.4.1.6 - Water Source Heat Pump

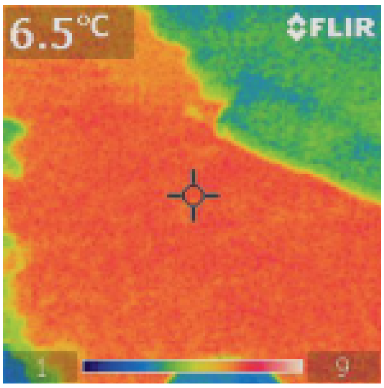
See Appendix 2, "Introduction to Heat Pumps".

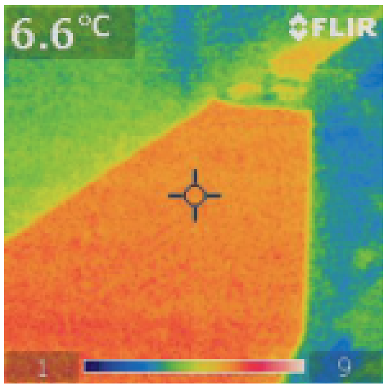
Where available, moving water, or large bodies of still water may be used as heat sources. A range of water source systems are available. Closed loop systems may draw heat from moving water in streams or rivers, or from lakes, passing antifreeze mixtures through pipes which are warmed by the surrounding water. Open loop systems may use a pair of wells or boreholes, drawing water from one and discharging to another.

The use of water source systems is contingent on the amount of water available being large enough to deliver the necessary thermal energy at the available temperature.

In this instance, the Day Brook offers the possibility of water source heating for the church. Thermal imaging was used to check the temperature of the brook on a number of occasions in winter, and temperatures of over 6°C were observed, even during weeks when there was snow on ground. Similar temperatures were observed







by Ernest Dale using a conventional thermometer.

The flow of streams is notoriously difficult to measure with great accuracy, but based on the motion of immersed objects in the brook and the cross sectional area of the stream, it would appear that there is sufficient water at a high enough temperature to provide energy to a water source heat pump to deliver space heating to the church. In discussion with the congregation via Ernest Dale it was noted that while the brook sometimes rose in level and might flood parts of the playing field, it had never been seen to dry up or freeze in winter.

Given that most of the annual space heating requirement will be between October and May, it seems likely that there will be an adequate supply of water in the brook, which should offer a higher temperature heat source than trench or most borehole ground source systems, making a water source system the heat pump solution of choice.

The extraction of heat from the brook might involve pumping water from the brook to a heat exchanger elsewhere, then returning the water to the brook. Alternatively, a closed loop of pipe laid on the bed of the brook might be used as the heat exchanger. In the UK, the use of a closed loop system has the advantage that the cost of an abstraction license which must be paid when water is abstracted from wells or watercourses can be avoided. The source heat exchanger must be generously sized however to give the best possible inlet temperature for the heat pump, and therefore the best COP.

The heat exchanger in the brook might be made from MDPE plastic or flexible stainless steel. Both these materials are supplied in very long coiled lengths and could be attached to a frame, in turn attached the bed of the brook. As these materials are uncoiled, they naturally tend for form a flat 'slinky' of overlapping loops, see picture top of next page, which allows more metres of pipe to be installed than metres of framework are used. This increases the amount of surface area available for heat transfer, and to increase this further multiple 'slinkies' can be mounted on the same frame with parallel flows. If the heat transfer fluid flows in the opposite direction to the water of the brook, a contraflow heat exchanger would be set up which would offer best performance.

Again it would be necessary to run pipes across the south west side of the football pitch, avoiding the newly constructed levee flood defence and the 11kV power cable buried in the church boundary. On toxicity and environmental grounds we would again suggest the use of 33% propylene glycol in water as the heat transfer fluid antifreeze mixture.

Discussions with Nottinghamshire County Council, Gedling Borough Council and the Environment Agency have indicated that as the brook is classified as a Sealed Main River, the Environment Agency is the only significant stakeholder in the use to which the brook might be put.

Coiled flexible stainless steel tube which could be used to form a heat exchanger on the bed of the brook.

Good Morning John,

I have received some comments from some of my colleagues and the general consensus is that the use of a water source heat pump would be a good method of heating the church and we would probably raise no initial objections to the proposal, however how the project would go ahead would need to be discussed at the stage where consent is applied for.
After speaking to the Biodiversity team, they raise no objections to the proposal but would probably recommend that you get an ecologist to survey the site to make sure that there are no protected species in the vicinity. They also said that there are plans for improving the watercourse at that site therefore if the water source heat pump project is to go ahead then you should wait until the watercourse improvements are finished and the channel is stabilised. If you wish to know more about that project then they have recommended that you speak to Paul Crawford in Ground works at Nottingham.

I am still waiting for a final group of colleagues to get back to me with any comments that they may have but they are currently short on staff so said that they will get back to me near the end of the week.

I'm sorry for the delay so far and will let you know the final comments as soon as I find out.

I hope this helps you in your feasibility study.

Kind regards

Sally

Preliminary informal discussions with the Environment Agency have been positive as indicated by this email response from sally.andrews@environment-agency.gov.uk, see text at bottom of previous page.

One key disadvantage of this scheme is the risk of vandalism and theft of metal. This might have been an acceptable risk with the original vertical sided concrete banks of

the stream, see top two pictures on the previous page, but after the improvements to the water course by the Environment Agency and Groundwork, access to the stream is much easier, making it more likely that members of the public would find the heat exchanger, and also making it easier to vandalise and remove, see bottom picture previous page.

Although the use of a water source system appears technically feasible, given the risk of vandalism and metal theft, the use of the brook as a heat source now seems less advisable.

4.4.1.7 - An Additional Problem With Heat Pumps

An additional problem has arisen with the use of heat pumps on this site. While the entire church floor was originally heated by underfloor heating, conservation of the flooring materials now requires that most of the floor area not be disturbed.

With one of the proposed under floor heating options, it has recently been suggested that the amount of heat that could be delivered via under floor heating systems might be a little under 10% of the total required. While this heat might be very well targeted, clearly other emitters would need to be used, and for the heat pump to deliver a good COP, these would need to operate at the lowest possible temperature.

Fan assisted radiators might be used, but these can be noisy, and to minimise the amount of noise per unit of heat delivered, it may be an advantage to run these at a higher temperature than would optimise the efficiency of the heat pump. The benefit of increasing the operating temperatures of fan assisted radiators is hard to assess though, as increasing the operating temperature will make the hot air released more buoyant, so it may tend to heat the roof of the church rather than the congregation and clergy.

Use of a heat pump to provide only a small part of the thermal load would be hard to justify, so if higher emitter temperatures are required for emitters other than underfloor heating, it may be appropriate to use a higher temperature heat source such as biomass or natural gas. These could still power underfloor heating in appropriate parts of the church using three port mixing valves to deliver water to the underfloor heating at the required temperature.

4.4.1.8 - Use Of Harvested Rain Water

Where the demand for non potable water is significant, rain water may be used for example, to flush toilets, wash surfaces and vehicles, and water plants. Having considered the amount of water used on site however, it seems unlikely that the cost and environmental footprint of the necessary equipment and works could be justified.

4.4.2 - Technologies To Consider

Of the thermal technologies, in the previous section, air source heat pumps have been rejected as they may be noisy (particularly as they age), and a significant amount of plant would be required to meet the heat requirements at the coldest times of year. Ground source heat pumps have been rejected because (even if the adjacent sports field was included in the scheme), there is insufficient land area available for the extraction of heat from the top two metres of soil (a minimum of 10,000m^2 required), and the price of a borehole system appears to be prohibitive. Water source heat pumps have also been rejected, because particularly now that banks of Day Brook have been landscaped, theft of the water source heat exchanger would be particularly easy, and leaked antifreeze would drain into the brook.

The efficiency of all the heat pump based solutions is contingent on the heat pump input temperature being as warm as possible and the emitters within the church being as cool (and large) as possible. The lack of opportunity to use wet under floor heating raises likely emitter operating temperatures, which also contraindicates the use of heat pumps.

This leaves two options for the space heating of the building, namely natural gas and biomass fuelled boilers.

4.4.2.1 - Thermal Emitters

It has been suggested that all space heating energy might be emitted via fan assisted convectors, perhaps with no under floor heating used at all. It is accepted that the need to conserve historic floors limits the amount of floor area which might be committed to wet underfloor heating, and that this would only allow the dissipation of between 10 and 20% of the total amount of heat required to maintain the temperature of the building. Heat emitted at floor level immediately under the congregation might however be of great value if it heats the congregation more effectively than hot air which is blown into the body or roof of the church. I thus suggest that the installation of under floor heating still be considered where it is possible.

While it is accepted that underfloor heating needs to be started some hours before the building is used in order to be warm in time for the start of services, the same may be true of fan assisted convector heaters if these heat the congregation less directly, only bathing the congregation in warm air once the building has filled with buoyant hot air from the top down. A system based on fan assisted convector heaters would require careful design to heat the congregation evenly.

4.4.2.2 - Natural Gas

Natural gas offers a simple to control heat source, which is compact, and offers a good range of output powers from a given boiler or set of boilers. Two sites have been considered for the installation of gas boilers. One site might be the top of the wall where the electrical switch gear for the old under floor heating is currently located. Access for air inlets and flues would be via the ceiling and roof.

The other location which has been suggested as a plant room for a gas boiler is the garden tool store, entrance pictured on the right below. To make this into a useful space, the far end of the staircase outside would need to be demolished to allow the necessary extension to the store.

This would allow a plant room of 3.6 by 1.85 metres to be realised. Again access to for balanced flues would most likely be via the roof, though many gas boiler flues could be routed to run through vertical surfaces.

Without wishing to suggest this specific manufacturer or model, the picture on the next page shows an array of Broag Remeha Quinta 115 boilers, each with a maximum output of 107kW. As the church has a heat requirement of between 150 and 200 kW, only two such boilers would be required, and smaller models might be used. None the less, this gives an idea of how compact gas heating might be.

In general there may be an advantage to using two or three small boilers to heat the site rather than a single larger unit, in that if a boiler fails, one or more working

boilers will continue to be available, and there is a greater chance that near normal operation of the building will be possible.

While the church has an existing gas supply, checks should be made with the supplier about any necessary upgrades to the supply pipe or meter which might be required to service the additional 200 kW of demand.

Despite the many advantages of gas heating, the fact remains that over its life, a gas system will consume large amounts of a fossil fuel, and will release the fossil carbon that this contains from the fuel into the atmosphere. While far more efficient in its use of primary fuel than the electric under floor heating which is currently nearing the end of its service life, (roughly two and a half times more efficient), the use of gas is still not sustainable, and much more can be done to improve the sustainability of the fuel if a non fossil fuel heating system can be identified.

Gas is currently deemed to produce 0.184 kg CO_2 per kWh of heat delivered, but it is possible that this may rise if more gas is imported, and it has also been suggested that the use of hydraulic fracturing to extract 'unconventional' or shale gas may further increase this emissions factor figure. The environmental damage per kWh of heat delivered from gas may increase over time then, but it is not possible to say by how much with any certainty.

4.4.2.3 - Biomass Heat

The use of biomass (in this case wood), offers a more sustainable fuel for space heating than gas, but more space is required to implement a biomass system. The boilers are larger, on site fuel stores are required, and in the general case, a buffer tank (heat store) will be required.

Wood can be burned in three forms which are broadly classified as logs, chips and pellets. The use of logs would be labour intensive and has been discounted. The operation of both chip and pellet systems can be automated however. In order to operate these boilers automatically, it is necessary to move fuel from store to burner, and this can generally be done with a screw auger. Augers can only move fuel over limited distances however, so particularly for pellet systems, it is common practice to use blowers to move fuel through wide pipes from store to burner. Pellet systems then, have more design flexibility, and of late have achieved higher levels of market penetration and lower prices than chip burning systems. Chip systems have thus also been discounted, but if an appropriate model was identified, this could be reconsidered.

Wood pellets are typically made from saw-mill waste, though as the market grows, other woody material may be included. The dimensions and content of the various grades of wood pellet are tightly specified, but the appearance below is typical.

It should be noted that blowing pellets to move them degrades them to some degree, so the shorter the distances they are blown, the better. When pellets are delivered to systems of this size, they are usually blown from a tanker into the users store. The maximum possible distance pellets can be blown will depend on the equipment fitted to the tanker, and any change of height between the tanker and the users store - it is much easier to blow pellets down hill than up hill. It is generally accepted that 20 metres is likely to be an absolute maximum distance that it would be sensible to blow pellets on a horizontal delivery, but 12 or 15 metres would be preferred. It is then possible to blow pellets from the fuel store to the burner, a distance which again should be under 20 metres. Along with constraints relating to where delivery trucks can manoeuvre and park, these distances that fuel can be blown impose significant constraints on where plant is located.

Fuel deliveries are made from large vehicles. The more fuel can be delivered at one time the lower the cost of the fuel is likely to be, so there is an advantage to having as big a fuel store as possible on site. While deliveries could be made to a small fuel store every two or three weeks, it may not be unreasonable if enough space can be found, to aim for one to three deliveries per year. Less frequent deliveries would help to reduce the risk of urgent deliveries having to be made during periods of cold weather.

However frequently deliveries are made, it is essential that delivery vehicles do not get bogged down in soft earth. It has been noted during site visits by prospective suppliers, that the ground to the immediate north of the church is quite soft, and at a minimum, an are area of hard standing would need to be put down here to allow delivery tankers to operate with confidence.

As delivery tankers would need to deliver while parked immediately to the north of the church, it will be essential to check that the weight of the trucks can have no adverse structural impact on the walls of the church, and that deliveries can be scheduled with some precision to eliminate the risk of disturbance to services. The rear church gates could perhaps be locked during services on delivery days to eliminate this risk altogether.

Tanker deliveries would be made by trucks driving forwards into the site, then reversing the back end of the vehicle around the north side of the church to park. The further back the trucks can reverse, the less far the pellets will need to be blown, and the less the pellets will be degraded. Once the pellet delivery has been made, the truck would drive forwards out onto the road. There would be no need for vehicles to linger on the road while deliveries are made.

Fencing has recently been added to the north east corner of the church roof to reduce the risk of vandalism, see pictures on the top of the next page, but these will have the useful side effect of making the edge of the flat church roof very obvious for tanker divers who are not familiar with the levels of ground around the site. See Appendix 4 - Practicalities Of Fuel Supply.

The lower picture on the previous page shows the view west north west across the north side of the church building. It would reduce the distance that pellet has to be blown if the fence to the rear of this picture could be moved back a few metres, and some of the grass replaced with hard standing. Beyond the edge of the grass visible in this lower picture, the ground falls away very steeply (see pictures on next page), to the level of the church car park, roughly a storey lower, see picture below, the view from the church car park.

To make a plant room available for biomass, it is proposed to set it into the side of the bank between the surfaced childrens play area at car park level, and the ground at the upper level of the site.

From the childrens play area, the doors to this plant room would need to be immediately behind the current location of the green fence and the brick wall on which it stands, see picture below.

This plant room would need to be constructed between retaining walls, but discussion with architect Robert Reynolds indicates that it may be possible to achieve a width of 4.5 metres, a depth of 7 metres, and a height of up to 4.5 metres, but see indicated requirements in section 5. This should allow pellets to be blown from a tanker located to the north of the church to a store in the plant room even if the fence is not moved, though as noted above, moving the fence a few metres west north west would be desirable.

Equipment in the plant room would include the burner or burners, buffer cylinder, and expansion vessel, with the rest of space largely given over to fuel storage. The buffer cylinder is likely to have a footprint of at least $1m^2$, and while it could be smaller, it may be appropriate to assume a similar figure for the expansion vessel.

The space taken up by the boiler or boilers will vary from model to model. A boiler of the size pictured below could heat the church on its own, but when judging the size, note the ash bins at the front, and the pellet feed equipment to left. The total footprint would be about 2 by 2 metres, but allowing for maintenance access, 3 by 3 metres might be a more typical requirement.

To take another example, a system using three boilers might use three units of similar size to that pictured at the top of the next page, each unit producing up to 60kW. These might each have a footprint of 1.5 by 2 metres, but it may be necessary to allow more space for maintenance. Space in the plant room will be tight, so a single larger boiler with a smaller footprint might be the better approach, though this is subject to detailed design.

The fuel store or stores should be as large as possible to minimise the frequency of deliveries. Fuel stores generally have provision to blow pellets in at the top, and an auger at the bottom to collect pellets which can then be transferred to the burner.


PELLEMATI

With careful design, pellet stores can be built in structures, and this might enable the best use of the available space to be made. Clues to one possible form of construction may be gleaned from the internal design of the unit shown on the bottom of the previous page. Note however, that the design will need to keep the pellets dry, allow annual cleaning, and take account of the weight of the tonnes of pellets contained in the store.

An alternative would be to use one or more free standing stores. As the picture below illustrates, all stores have a connection at the top to allow filling, and a connection at the bottom to allow pellets to be passed on to the burner.

Note that one or more flues will be required by a biomass system, and to operate correctly these must meet or exceed the requirements specified by the manufacturer. These flues are generally twin wall stainless steel types, and it should not be assumed for example, that if three boilers are installed, that the combustion gasses that arise from these can be directed into a single flue. Flue design is covered under Part J of the building regulations in conjunction with manufacturers guidance, so should be undertaken as part of the detailed design process. Note however that the flue or flues may have a recommended length of several meters, and turbulence arising from nearby trees and buildings may result in these lengths being extended. It may however be possible to have the flue(s) coated or painted to help them blend in with their surroundings, and it may sometimes be necessary to use guy lines to secure flues in place.

It should also be noted that in some circumstances pellet stores may generate small amounts of carbon monoxide which is a highly toxic gas. Pellet stores then, should always be well ventilated, and access should be restricted to staff who are aware of the risk this creates and will manage it appropriately.

4.4.2.4 - Gas vs Biomass Conclusion

It appears to be practical to implement space heating powered from either gas or biomass plant on this site, but more work will need to be undertaken to create a plant room for a biomass system.

To aid in choosing between gas and biomass, a very simple life cycle numerical model has been passed to the church in the form of a spreadsheet, to allow various scenarios to be explored. The church is free to extend this spreadsheet to take account of additional issues should it wish to.

I cannot advise either one of these solutions over the other for a number of reasons. A numeric model can never capture all of the nuances of convenience or environmental benefit that might be offered by one system or the other, and there is significant uncertainty around key data such as fuel prices, ten, fifteen, or twenty years hence.

This tool then, allows decision makers and the congregation to explore 'what if' questions, but cannot predict financial benefit with great accuracy. The tool also attempts to work out carbon emissions performance, but decision makers should keep in mind that while carbon emissions are the only environmental indicator that the tool attempts to quantify, these emissions are not the only environmental indicator that we should try to keep under review. Sustainable sourcing of biomass material is bound to become a more important issue in the future for example.

Gas offers a solution which is cheaper in the shorter term, requires less borrowing, and thus gives rise to less financial risk. It only partially addresses issues relating to carbon emissions and climate change however, and decision makers will have to decide if the additional carbon emissions savings that might be achieved by the use of biomass, justify the additional financial risk arising from the purchase of biomass plant.

Ultimately this is a subjective decision based on personal values. If anybody would like to talk to me about the technical or more subjective issues, please call me.

Whichever type of heating is selected, if agreement between the various stakeholders can be reached, insulation of the building should be improved where possible. In particular, it may be worth adding insulation to the underside of the aisle ceilings, especially if these ceilings will be above new emitters such as fan assisted radiators. Heat losses through the roof and the plain glass in the mullions are also significant, so if the roof can have any insulation added, or the glass in the mullions can be double glazed or secondary glazing added, these would be a significant improvements.

4.4.2.5 - Photovoltaic Electricity Generation

Photovoltaic (PV) generation of electricity offers an opportunity to generate electricity using panels on the roof of the building. It is possible to mount panels on pitched or flat roofs, and the church has a number of roofs which are either flat, or close to flat.

Not all this space is readily usable for PV as use of the rear edge would obscure the church window, panels near the front edge would be visible from the road, and various roof lights and shadows from buildings also limit where panels might usefully be placed. Gaps must also be left between rows of panels so that the rows don't shadow each other. Despite these complications it has been estimated that approximately 7kW of panels might be fitted on the roofs visible above.

The roof of Marian Hall (the building to the rear, roof not visible) has not yet been assessed as it is not easily accessible. The view from Google Earth however suggests that the roof surface is not a simple V shape, and an analysis of the roof structure and shape would be required to assess its potential as a platform for PV, see picture from Google Earth at the top of the next page.

Image © 2014 Google, © 2014 Infoterra Ltd & Bluesky

Panels may either be mounted through the roof to structural elements within the building, or on flat roofs, may also be mounted on weighted frames or containers, which are held in place solely by the mass of the ballast.

On a flat roof, the use of ballast to hold panels in place avoids the need to penetrate the roof membrane, but requires the roof to be able to withstand the weight of the ballast as well as the static and dynamic loads (weight and wind forces) exerted by the PV panels. Mounting on flat roofs should generally be subject to structural survey.

The picture at the top of the next page shows ballasted containers on which PV panels are mounted. In this instance virgin sand was used as the ballast, but any dense inert material can be used, as long as the necessary weight of material can be packed into the volume of the container. A number of recycled building materials can be used with environmental benefit. These include reused bricks, breeze blocks, concrete, roof tiles etc.

The financial case for PV currently depends on the Feed In Tariff (FIT) and payments for electricity generated, and the electricity you won't have to buy as a result of on site generation. As time goes by, PV panels and inverters are getting cheaper, but the FIT rate is also being reduced over time. This has meant that the cost of systems has come down, but so has the income they produce. The consequence of this is that the payback time for a typical PV system has remained in the range eight to twelve years depending on the characteristics of the site. The FIT is index linked and

payable for twenty years.
The use of PV has been discussed with Bev.Pearson@gedling.gov.uk, Planning Officer at Gedling Borough Council. Bev commented that GBC were unlikely to object to the use of PV on the flat roofs to the front of the church, as long as it was not visible from the road. As long as it is not installed close to the front edge of the roof, this requirement appears to be easy to meet.

Any excess electrical energy generated would be exported to the buildings in the surrounding area through the sites grid connection. The church would receive FIT payments for this generation, and environmental benefit would accrue, as less electrical energy generated from fossil fuels would be consumed in the area.

5 - Lifecycle Financial Model And Its Limitations

A spreadsheet has been provided to model the financial life-cycle of the space heating options.

This allows various scenarios to be explored in relation to energy use, fuel costs, and Renewable Heat Incentive rates. It must be understood however that future fuel prices cannot be predicted with certainty. Note however that the RHI payments are index linked so will increase over time to retain their original financial value, and that the cost of wood pellet will depend on the size of delivery which favours having a larger pellet store if possible.

Ultimately though, the decision is not just about finding the cheapest solution, and some value must be placed on lower carbon solutions which is an inexact process (see Appendix 3 - Financial Value Of Emissions).

It is not easy to ascribe a financial benefit to reducing carbon emissions as the cost incurred is not a fee that we are charged. Rather, cutting emissions is a harm we can avoid doing, i.e. the placing financial and other burdens on those affected by the climate change we cause.

This cannot easily be reflected in a spreadsheet, so in addition to the numeric uncertainty about the future costs of the competing options, our conclusions must be based to some degree on how we value our impacts on other people.

Based on discussions with Organic Energy (OkoFen boilers) and Rural Energy (Herz boilers), it is suggested that the following figures be used in the financial model as guide prices for the cost of the boilers(s) and plant room equipment.

Option 1

OkoFen 168 kW cascade system (3 X 56 kW pellet boilers). Approximate floor area requirement for the PETS 168 would be 6.5m x 5m internal footprint. Note that this cost excludes delivery.	£66,583

Option 2

OkoFen 192 kW cascade system (4 X 48 kW pellet boilers). Approximate floor area requirement for the PETS 192 would be 7.5m x 5m internal footprint. Note that this cost excludes delivery.	£82,106

Option 3

Herz 199 kW (single boiler system, pellet fuelled). Note this price excludes flue. Assume £12,000 more for the flue, subject to survey and detailed design. Note that this cost includes delivery.	£42,282

Option 4

Herz 155 kW (single boiler system). Note this price excludes flue. Assume £10,000 more for the flue, subject to survey and detailed design. Note that variants of this system could burn wood chip or pellet, but this must be selected when the system is commissioned. Wood chip would offer lower fuel costs, but possibly lower reliability than a similar pellet system. The pellet variant may have a slightly lower installation cost because of cheaper fuel handling equipment. Note that this cost excludes delivery.	£105,891

Option 5

Herz 199 kW (heat pod prefabricated plant room system). Note this price excludes flue. Assume £12,000 more for the flue, subject to survey and detailed design. Note that variants of this system could burn wood chip or pellet, but this must be selected when the system is commissioned. Again, wood chip would offer lower fuel costs, but possibly lower reliability than a similar pellet system. The pellet variant may have a slightly lower installation cost because of cheaper fuel handling equipment. Indicative dimensions, 8m x 3.2m x 3.4m (H), fuel storage room capacity 21m^3. Note that this cost excludes delivery.	£79,909

Note that these costs exclude VAT, and assume that the earth bank will have been dug out by the church, with retaining walls built, the space roofed (except for the heat pod option), electrical power provided, water and drainage supplied to the plant room location, and that the plant room or heat pod stand would be finished with a suitable concrete base.

The manufacturers claimed efficiencies of these boilers are in the range 90 to 93% depending on operating conditions and the degree of modulation.

T4 believes that the above models are of good quality, would meet the requirements of the church (subject to detailed design), and give an indication of typical prices for this type of equipment. None the less, other manufacturers also offer quality products which would be appropriate to the needs of the building. If the church and diocese wish to explore the biomass option further, other manufacturers products should also be evaluated.

Appendix 1 - Global Context, A Wakeup Call

Environmental footprint is an indicator that allows us to compare humankind's resource use to the resource the planet makes available. It is calculated in terms of the amount of area required to deliver the things we consume, in such a way that there is no net use of non-renewable resources. In the context of Environmental Footprint calculations, 'area' means biologically the viable land or sea required to grow the resources we live on, and to incorporate the waste produced as a consequence of their consumption back into that biological system.

The area units used are hectares with world average productivity. This area may be analysed in terms of requirements for cropland, grazing land, forest to grow raw materials, sea for fish and seafood production, land for housing, work and infrastructure, and land to fix carbon dioxide emissions arising from energy use. Because the area of available land and sea habitats are known, this indicator enables comparison between the footprint space required by individuals or populations, and that available locally or globally.

Footprint calculations show that environmental footprint has risen over the last three decades at about one and a half percent per year, and this trend is continuing. Humanity as a whole passed the point where it could live on the Earth without ongoing consumption of finite resources in the nineteen seventies. By 1996 this figure had reached about a hundred and thirty percent of the Earth's carrying capacity, and some estimates suggest that it has now more than doubled since 1970.

Further, footprint calculations can be used to highlight the distribution of wealth around the world. Among the different nations of the world there is a wide range of sizes of footprint. The US has the highest score at about 12 area units per person, about twice the value for Western Europe and nine times the level of a typical citizen of India. The US level of consumption is enjoyed by about three hundred million citizens. By contrast, a level of consumption of around two area units is experienced by three and a quarter billion people in the Asia/Pacific region. Clearly poverty is far more common than wealth, and Western Europe is relatively well off.

As a whole this situation is not sustainable, and the matter, already well out of hand, has to be addressed soon to avoid catastrophe. It is tempting to continue the discussion by enumerating problems arising from the impending crises arising from the lack of fossil fuels, and the damage done to our atmosphere and climate by the use of fossil fuels. It is also tempting to discuss greed, inequity and overpopulation, extinction of species and loss of habitat, but if the points made so far alone are enough to bring us to the question "what can we do to improve the situation?" this is perhaps unnecessary.

Threats and opportunities

So far, these issues may seem abstract and hard to relate to, but a brief review of energy and food price increases that you have experienced over the last few years should indicate that major changes are occurring in the world, and this is entirely consistent with an ever greater number of consumers competing for an ever smaller pool of available resources, with little notion of how to share what we need equitably. The need for ‘contraction and convergence’ is clear, though how to bring it about is unclear in a political democracy if the bulk of the population don’t want their use of resources to contract, and the government are chosen by the population as a whole. On the face of it there may be no way forward. Economics and ‘game theory’ seem to suggest that economic ‘growth’ will occur until it lacks the resources to continue, and biology suggests that when populations run out of resources, their failure can be catastrophic. This may be all the more true in a species that lives as a socially and technologically complex network of mutually dependent but competing societies.

So much for the threats, what of the opportunities ? We cannot pretend that as Christians we have immediate solutions to these problems. The contribution we can make perhaps relates to dogged attitude and determination to find meaningful and equitable ways forward. Where we fail to succeed in finding solutions to these problems, we are responsible for the consequences of our actions.

Given the gravity of the threats humanity faces, and our responsibility for many of these, there seems to be ample justification to strive to deal with these issues and make this a big part of our lives’ work. Perhaps a sensible starting point would be to acknowledge that each of us has a duty to live within God’s creation without causing its destruction, a duty to other people to allow them reasonable use of resource similar to that which we might reasonably consume, and a duty to future generations, not to consume resources at a rate which will render their survival difficult or impossible.

Although our resources are finite and we frequently regard our budgets as spent, from a global perspective we are well resourced. As an affluent nation, and let us hope an ethically minded one, we can surely find little excuse for not addressing environmental problems head on in order to make a difference now. If we don’t address these issues, who will do it for us? We must make the opportunities to improve our use of resources, and as far as possible, live sustainably. Put simply in the words of the World Commission on the Environment and Development, we must achieve

> “... development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”

We need to strive continuously to learn more about what this means, and to consider sustainability in every decision we make.

Taken from Derby Diocese "Faith In Action" Chapter 4.

Appendix 2 - Introduction to Heat Pumps

A heat pump is a device that transfers thermal energy from one location and medium to another, though more importantly for our present purpose, it has the property that the heat energy delivered by the system can be at a higher temperature than the heat source.

As heat is moved from one place to another, the heat source is cooled, and the destination, usually referred to in the terminology of thermodynamics, as the heat sink, is warmed.

Common examples of heat pumps include refrigeration systems where the heat source is the inside of an insulated box (the interior of a fridge) which is cooled, and the heat sink is the 'radiator' at the back of the fridge which feels warm to the touch.

When used to heat buildings, heat is moved the other way, from some medium outside the building, normally the ground, the air, or water, to the inside of the building, the 'insulated box'. Here, the heat is typically distributed by radiators or an under floor heating system. In the process, the ground, air or water outside is cooled, and the temperature inside the building is increased.

In addition to the thermal energy from the heat source, additional energy is required for a heat pump to operate. The greater the temperature difference between the heat source and sink, the greater the amount of additional energy is required to move a given amount of thermal energy from the heat source to the heat sink. Although practical heat pumps almost invariably use mechanically driven components, they are generally operated from an external electrical energy source which drives an internal electric motor, rather than being driven via a mechanical shaft.

The use of electrical rather than mechanical drive makes it easier to seal the refrigerant gasses in the system. It is important that these do not leak out, as loss of these materials will cause failure of the system, but more importantly, the chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) chemicals traditionally used, either cause damage to stratospheric ozone, are remarkably potent greenhouse gasses, or both. As a consequence of this, heat pumps must be maintained and disposed of with care by competent personnel.

In heating applications, the heat delivered can be assumed to be the sum of the energy obtained from the heat source outside the building to be heated, and the electrical energy provided to operate the heat pump. The performance of such systems is usually indicated by the ratio of heat output power divided by the electrical input power. This is usually termed the coefficient of performance, abbreviated to COP or CoP. By current standards, well designed systems with COP values of over 5 are likely to be seen as good performers, where as those with COP figures of under four should be examined with care to see if the design can be enhanced, or if they are financially and environmentally beneficial at all compared to say natural gas. COP values improve as the difference between the heat source and sink temperatures is reduced.

Maintaining an adequate temperature in a heated building requires that at a comfortable internal temperature, the heat loss from the building on the coldest days can be met by the heat available from the heating system. Where a heat pump is used, this requires that either the heat source medium can be continually replaced as it is cooled, e.g. an air source system in which large fans blow high volumes of air through the machine to act as a heat source, or a ground source system in which the soil and rock around pipes buried under ground have a high thermal capacity so that they cool very little as heat for the building is withdrawn.

Many heat pumps incorporate provision to produce domestic hot water. The heat pump itself may not operate at a high enough temperature to ensure control of Legionnaires' disease, but immersion heaters might be used to eliminate any risk of Legionella build up in the hot water cylinder. As the demand for domestic hot water is very small on this site, and the pipe runs required to distribute domestic hot water would be long, the use of a heat pump to produce domestic hot water appears not be environmentally or economically justified.

Appendix 3 - Financial Value Of Emissions

Carbon trading schemes have been set up to provide incentives for large businesses to cut carbon emissions, but the price of carbon under these schemes reflects the supply of allowances (amount of carbon emissions that government allocates to the market), and the amount of commercial activity which gives rise to emissions, which in turn reflects the state of the wider economy. At the moment, the traded carbon price is neither a significant incentive for business to change its behaviour, nor a good reflection of the cost of addressing the impacts of climate change.

A better indicator might be the Social Cost of Carbon which has now been replaced by the Shadow Price of Carbon. This is now the UK's official basis for incorporating carbon emissions in cost-benefit analysis and impact assessments. It quantifies the damage costs of climate change caused by each additional tonne of greenhouse gas emitted, expressed as carbon dioxide equivalent (CO_2e) for ease of comparison, in line with the Stern Review.

The Stern Review team calculated a range for the price of carbon based on estimates of the damage likely to be caused by climate change, such as floods, changes to agriculture, sea level rise and so on. Stern's conclusion was that "if we don't act, the overall costs and risks of climate change will be equivalent to losing at least 5% of global GDP each year, now and forever. If a wider range of risks and impacts is taken into account, the estimates of damage could rise to 20% of GDP or more".

According to Paul Ekins, professor of energy and environment policy at King’s College London, a low carbon price does not send a strong enough price signal to ensure that the necessary action will be taken. He suggests, as an alternative, that the price of carbon should be based on the "actual cost of abatement ", rather than potential damage, and that the cost of carbon should be as much as £100 or more per tonne.

If such figures which represent the costs of reducing emissions, or dealing with the consequence of emissions were to be factored into our own calculations, they would obviously shift the result significantly in the direction of the lower carbon options.

Appendix 4 - Practicalities Of Fuel Supply

Note that to claim RHI payments from October 2014, fuel will need to be provided by a supplier on the approved biomass supplier list. See https://www.gov.uk/register-biomass-supplier

Supplies should be quality marked to recognised EU quality standards to meet the requirements of the boiler installed, typically EN PLUS A1 grade pellets. Failure to use the correct grade of pellet may damage a boiler and invalidate the warranty.

All of the companies below have been contacted by phone and invited to visit the church to look at the point to which fuel would have to be delivered. These discussions have been undertaken using Google Earth and / or Google Maps to identify the location.

While most expressed the view that the access to the rear gate could be wider, access would still be possible. A minimum gate width of 3m is generally required, and the current gates offer a width of 3.11m. It is understood that widening the gate would not be a simple operation however, as the gates are electrically operated. If the gate were to be widened, larger deliveries of fuel could be made (subject to store size) which would somewhat reduce fuel costs.

Manoeuvring into the gateway is typically easier than it might appear, as many pellet delivery trucks use rear wheel steering to gain access where space is tight. Both companies that visited the site took the view that they would drive in forwards through the gate, reverse back while turning towards the pellet store, unload, then drive out forwards through the gate.

All suppliers indicated that ideally (to minimise the formation of dust), pellets should not be blown more than 15m into the store. 20m should be acceptable if necessary however, especially if blowing the pellets down hill.

Prospective supplier name and details	Comments
High Park Industries http://www.highparkindustries.co.uk/	HPI supply some Nottinghamshire Schools. Generally Nottinghamshire County Council (NCC) have no complaints, the fuel provided seems of good quality. It is understood that HPI manufacturer pellets in Nottinghamshire, which helps to minimise the environmental impact of their supply.

Forever Fuels http://www.forever-fuels.com/content/wood-pellets-east-midlands	Although based outside of Nottinghamshire, Forever Fuels store and deliver fuel from a depot near Retford. NCC "have been very happy with quality of pellet and service from Forever Fuels". Forever Fuels (Chris) visited the site and indicated that their four wheel delivery trucks would be able to access the site, and could deliver up to 10 tonnes of fuel at a time. Forever fuels recommend that as part of the annual maintenance program, fine dust be hoovered out of the pellet store fabric so that blowing pellet into the store continues to be easy.
S J Vicary http://www.jsvicary.co.uk/index.php/biomass-fuel-supply	Their web site only seems to mention wood chip, but they also supply pellet. This company is on YPO framework http://www.ypo.co.uk/contract/detail/900044
Billington Bioenergy http://www.billingtonbioenergy.co.uk/	Roger Pearson has answered questions about access carefully and arranged their site visit. The regards access as "Fairly easy compared to many" as the gate is more than 3m wide. Bilington Bioenergy (Paul) also visited the site and reported that a 6 wheel delivery vehicle with rear wheel steering would be able to access the site, and would be able to drop off 14 tonnes of fuel at a time. This company is on YPO framework http://www.ypo.co.uk/contract/detail/900044
Forest Fuels http://www.forestfuels.co.uk/our-locations/midlands	Forest Fuels have remarked that to keep fuel costs to a minimum it would be appropriate to deliver 18 or 19 tonnes of fuel at a time. The trucks required to do this would however require a 12m turning circle, so deliveries of fuel of this size may not be practical. This company is on YPO framework http://www.ypo.co.uk/contract/detail/900044
CPL Distribution (Wood Pellets 2 U) http://www.woodpellets2u.co.uk/	This company is on YPO framework http://www.ypo.co.uk/contract/detail/900044

Appendix 5 - Project Contacts

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