ABSTRACT

Lifestyles and resources including labour, fuel, space and accessibility impact on wood-fuel system design. In this paper, modelling of occupancy in conjunction with thermal demand demonstrated the difficulties in designing a system based on a single boiler for buildings of highly variable thermal demand.

2 log-batch boilers sized at about 33kW and 24kW combined with a thermal store of 2,000l would service the variable load efficiently at a fuel cost of 2.9p/kWh.

Standard methodology for predicting annual energy demand is likely to be prone to large errors for zone-heated buildings subject to intermittent use. An alternative energy demand prediction can be based on simple modelling of thermal loss, zone occupancy and predicted external temperatures.

The health effects and global warming potential of wood fuelled boilers are of concern but these can be minimised by buying an efficient boiler and following best practice combustion procedures.

Keywords: thermal demand, logs, woodchip, pellet, boiler sizing

INTRODUCTION

Hill Holt Woodland Community (HH) is off-grid and located in 13.8ha of woodland west of Lincoln. The woodland provides a safe walking environment for the public and the community aim to demonstrate sustainable living in a woodland setting. It derives income from the training of teenagers who have been excluded from school and a wood supply from forestry contracting services.

HH is building an energy efficient community hall complex (Fig 1) to include a circular auditorium, cafe, kitchens, WC and offices which will be used to enhance their services to the wider community.

All heating systems can be defined in terms of plant, fuel, people and procedures. Wood fuels are bulky and some fuels arrive unprocessed, so it is vital to consider fuel availability, processing and storage, alongside thermal demand.

Fine particle and gas emissions from wood combustion are of concern because of damage to health and contribution to global warming. The burning of all fuels

Figure 1 - Hill Holt Community Hall

can cause harmful emissions, so procedures to minimise these, based on a review of recent literature, have been included.

Aims

To design a wood-fuelled thermal district heating system for the new community hall, existing office block and IT suite. To enable the system to become part of the islanded community demonstration /education project.

Objectives

- Calculate thermal characteristics of the new community hall based on building specification and calculate boiler size to heat the community hall and the existing offices and IT suite.
- Model annual energy demand of district heating system based on weather statistics and predicted use.
- Compare fuel options by availability, cost, processing and storage requirements.
- Review evidence on emissions from modern wood-fuelled boilers and relate this to operational best practice and impact on system design.
- Provide system design and operation recommendations.

METHODS

Thermal Demand

Hill Holt community hall will be constructed of local timber and mud and will have an internal area of 260m^2.

It will consist of a 2-story timber frame building (kitchen, plant room and WCs), a fully-glazed cafeteria area and a round compacted mud auditorium. Each room will be separated by doors and will be heated by separately zoned under-floor wet heating.

Thermal demand calculations were completed by heating zone for the new community hall and compared with those provided by the sponsor. Thermal demand for the existing IT suite and office block were taken from data supplied by HH.

Fabric heat loss rate was calculated by $\Sigma U_i A_i$, where U_i is the thermal transmittance of an element ($Wm^{-2}K^{-1}$) and A_i is the area of the element (m^2). Ventilation heat loss rate was calculated by 0.33NV, where N is the number of air changes per hour and V is the volume of the room (m^3). Calculations were based on the building specifications with reference to Conventions for U-Value Calculations [1].

The community hall was defined by 8 heating zones and the heat loss was calculated in two ways assuming that

1. adjacent zones were heated
2. adjacent zones were unheated

Design U-values were given by the sponsor (Appendix 1).

Number of Air Changes per Hour (N) were calculated with reference to Building Regulations [2] where values were specified (Appendix 2). However, details for some areas, specified in CIBSE guidelines, were not freely available.

Opening windows in the cafe and the glass in the cupola in the roof of the auditorium were assumed to have U-values in line with standard double glazing, with the cupola value increased by 0.3 due its slope.

U values for walls and ceilings adjacent to unheated spaces were calculated using $U = \frac{1}{\frac{1}{U_0}+R_U}$, where U_0 is the U value of the wall or ceiling, and R_U =0.5 based on rule of thumb for a loft room [1].

Boiler Sizing

The thermal load was increased by 15% to account for system losses and the need to heat the building from cold [3]. 2kW was added for the hot water demand, as suggested in sponsor figures.

Annual Demand Model

Mean monthly temperatures

Measure, correlate and predict methodology was used to predict mean monthly temperatures for HH. Daily data for January to March and October to December 2007 were obtained from the Meteorological Office for Waddington (nearest weather station), along with monthly data for 2007. Monthly averages for Waddington were correlated with concurrent data for Central England and product moment correlation coefficient (r) calculated.

The significance was tested against the null hypothesis r=0 using the T distributed statistic, $t = \frac{r}{\sqrt{\frac{1-r^2}{N-2}}}$, where N is the sample size (12), with N-2 degrees of freedom.

Energy Consumption

Likely occupancy of the community hall, office and IT suite consists of:

- office and IT suites used during office hours
- first floor offices in community hall used by 5-6 people during office hours
- kitchens and cafeteria for lunches during the week and all day on weekends
- auditorium and cafe used for conferences for up to 50 people
- auditorium evening use for clubs, e.g. Scouts, plays, concerts

Energy consumption was estimated in 2 ways. Firstly, using standard methodology(CREST Solar 1),

$$Q_{Month}(kWh) = \frac{(\sum UA + 0.33NV) \times 24 \times D_{Month}}{1000}$$

where Q_{Month} is the estimated energy consumption over a month (in kWh), D_{Month} is the number of degree days in month. $D_{Month} = \sum_{Days\ in\ month}(t_b - t_o)$, where t_b is the base temperature taken as the industry standard value of 15.5°C and t_o is the outside temperature taken as the monthly average outside temperature predicted above.

As zones are used intermittently, the energy consumption estimate calculated by this method was likely to be a significant overestimate. In view of this, a second method was adopted, based on the estimated occupancy of each zone (Appendix 3), the zone design temperatures (t_{zdes}) and the monthly average outside temperatures ($\bar{t}_d$). For each day, d, and zone,z, the energy used was calculated by:

$$\sum_{d,z}(H_{dz}+W_z)\left(\frac{\sum U_z A_z + 0.33 N_z V_z}{1000}\right)(t_{zdes}-\bar{t}_d)$$

where H_{dz} is the number of hours that the zone is used in the day, W_z is the warm-up period for the zone.

Fuel

Annual energy demand

Assuming 85% boiler efficiency,

$$\text{Annual energy demand} = \frac{Q_{Year(kWh)}}{0.85}$$

LHV at moisture content

Lower heating value (LVH) at w% moisture content (mc), q_w, is given by $q_w = \frac{(q_d - 0.2183H_d)(100-w)}{100} - \frac{2.442w}{100}$, where 2.442 is the latent heat of evaporation of water at 25°C, q_d is the LHV of dry fuel and H_d is the dry weight percentage of hydrogen [4].

Weight of fuel

$$W(tonnes) = \frac{\text{Annual energy demand (kWh)}}{278\, q_w}$$

Volume of wood

Following the approach described in “Wood for Energy Production”, chapter 4 [5], volume, $V = \frac{\text{Weight of solids}}{SD}$, where S=the ratio of solid matter in $1m^3$ taken as 0.65 for stacks of 1m lengths of wood and D is the weight of dry matter in a cubic metre given as 0.51 tonnes/m3 for birch.

Volume of woodchip, pellet

Several web sites give volume factors based on the volume of heating oil. They vary considerably, but a woodchip factor of 11.5 and pellet factor of 3.7 were selected from a known and respected source of wood fuel system knowledge [6].

Emissions

Published work on the emissions from modern domestic/small commercial scale wood boilers [7,8,9,10] was reviewed alongside Boman et al’s paper[11] reviewing recent studies on adverse health effects relating to wood combustion, the latest World Health Organisation guidelines on air pollution [12,13] and IARCs assessment of substance toxicity [14].

Boiler Operation and Thermal Store

For efficient combustion a thermal store is included, capable of absorbing any excess heat during firing to be released once the boiler is switched off. Based on the times that each zone was heated (Appendix 4), the thermal load of the zone and the predicted monthly average temperature, thermal load for each hour was estimated. Five scenarios were examined to determine the mode of running the boiler and the implications for the size of the thermal store (Appendix 5).

Scenario 1 - basic January weekday with the offices and IT suite in use during office hours, the cafe and kitchen open during the lunch time period, no auditorium or evening use.

Scenario 2 added the evening use of the auditorium for 3 hours. The additional constraint of not running the boiler out of office hours was added to avoid unnecessary out of hours working.

Scenario 3 - January weekend day with the cafe open and heated during daylight hours, along with the kitchen, WC, lobby and plant room.

Scenario 4 – April weekday.

Scenario 5 - April weekend.

Sizing of thermal store

$$\text{Store Volume}(l) = \frac{\text{Energy}(kWh)\times 1000}{1.16(t_f - t_r)}$$

where 1.16 E-3 is the specific heat capacity of water in kWh/l.

RESULTS AND DISCUSSION

Thermal Demand

Heat losses by zone are presented in Table 1. Total heat loss, based on the heating of adjacent areas, was 45.8kW compared with the sponsor figure for the same buildings of 41.1kW. The main differences were due to changes in N, which were set at BR values in the figure calculated here.

The heat load calculated by assuming the adjacent spaces were unheated was not significantly higher, due to the high insulation specification.

Table 1 -Thermal Demand

Heating Zone	Design temp (when heated)	Design temp (when unheated)	Heat Loss W (adjacent zones heated)	Heat Loss W (adjacent zones unheated)
Auditorium	21	5	6506	6552
Cafe	21	5	4581	4772
Office 1	21	5	809	874
Office 2	21	5	1231	1315
WCs	21	5	623	689
Lobby	21	5	1709	1895
Kitchen	18	5	1493	1621
Plant/furniture store	21	5	401	509
Offices	21	5	14459	14459
IT Suite	21	5	13969	13969
Outside		-1		
Unheated stores		-1		
Ground		5		
Total			45782	46655

As the building materials were designed to minimise heat loss, the larger part of the thermal demand was generated by the ventilation losses. However, some of the U-values quoted may be optimistic, e.g. the U value for the internal doors was 0.25 and triple glazed windows at 0.8. In addition, the performance for multifoil insulation has not yet been proven.

Annual Demand Model

Mean monthly temperatures

The Product Moment Correlation Coefficient, r= 0.998 (Fig. 2) indicated a very high degree of positive correlation between the temperature data from Waddington and Central England (highly significant),

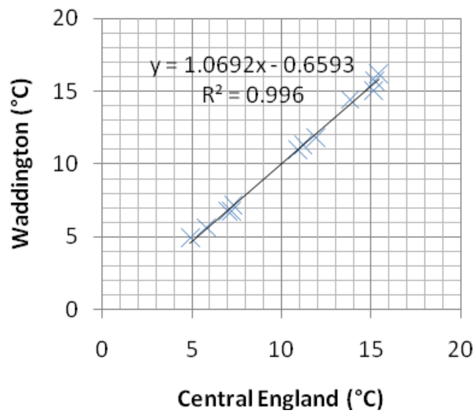

Figure 2 - Waddington and Central England Mean Temperatures

from which it was deduced that the long term data available in the Central England data set could be transformed using the linear regression coefficients specified on the graph, y=1.069x-0.659 to predict the monthly temperatures for Hill Holt site (Table 2).

Table 2 - Predicted Monthly Temperatures

	Monthly Mean Temperatures °C		
Month	Central England 2007	Central England 1987-2006	Long Term Predicted for Waddington
Jan	7.0	4.6	4.3
Feb	5.8	5.0	4.7
Mar	7.2	6.8	6.6
Apr	11.2	8.6	8.6
May	11.9	11.8	12.0
Jun	15.1	14.5	14.9
Jul	15.2	16.8	17.3
Aug	15.4	16.7	17.2
Sep	13.8	14.2	14.5
Oct	10.9	10.8	10.9
Nov	7.3	7.1	7.0
Dec	4.9	5.0	4.7

This should be viewed with caution as 12 monthly means only were examined over the year. A comparison of daily data could be usefully analysed to find individual regression relationships for each month.

In addition, the Hill Holt site is protected by the trees surrounding it which may moderate the local temperatures, so a comparison between Hill Holt and Central England is likely to be more reliable than that with Waddington.

Energy consumption

The annual energy requirement using method 1 was almost double that using method 2 (Table 3), where the intermittent nature of the building occupancy was taken into account. Method 2 has the additional virtue that it could be used as the basis for a predictive model of energy consumption and firing schedule for the boiler, based on actual building bookings and historical or forecast temperatures.

Table 3 - Energy Use by Month

Month	Degree	Energy (kWh)

	Days in Month	Method 1 - using degree days, heating only	Method 2 - using occupancy and design temp, water included
Jan	347.2	17,964	7,882
Feb	303.2	15,691	7,465
Mar	274.9	14,226	6,783
Apr	208.5	10,788	6,017
May	108.7	5,626	3,776
Jun	19.4	1,006	2,437
Jul	-56.0	-2,896	1,578
Aug	-51.8	-2,682	1,507
Sep	30.0	1,553	2,689
Oct	143.0	7,401	5,069
Nov	255.6	13,228	6,318
Dec	334.9	17,329	8,141
Year total (no heating Jun-Sep)		**102,253**	**51,452**

Note: Cafeteria is unheated and solar thermal provides hot water from May to Sep inclusive.

Fuel

Wood-based fuel was pre-requisite for this project because the Hill Holt Community aims to be an exemplar woodland based socio-economic unit. The options for fuel are therefore logs, wood chip and wood pellet.

Very little fuel wood is extracted from the site but roundwood worth £5,000 is generated through contracting which might be available for heating. There is little woodland in this part of Lincolnshire so bought fuel wood in the form of logs, woodchip or pellets would have to be supplied by neighbouring counties. The site is accessed directly from the A46, with turning room for lorries enabling bulk deliveries.

Weight, volume and cost comparison

The weight, volume and price of wood fuels are compared with that of heating oil in Table 4.

Based on the purchase of green roundwood at commercial rates, fuel costs of wood (2.8-2.9p/kWh) and chip (3.5p/kWh) are about half those of oil (6.6p/kWh) with wood pellets (4.3p/kWh) between the two. Full table and notes are found in Appendix 7.

Woodchip varies considerably in chip size and mc which can have detrimental effects on combustion quality, so should be bought only from a specialist wood-fuel supplier.

Pellet prices vary considerably and one price from a local supplier was more expensive than oil. However, it is likely that pellet prices will reduce over time as more local supplies become available.

Table 4 - Annual Fuel Weight, Volume and Cost

Fuel	Beech	Spruce	Pellet	Chip	Oil
LHV (GJ/dt)	18.7	19.7	19	19.2	43.9
Combustion mc (%wet)	20	20	7.6	20	
Combustion LVH (GJ/t)	13.4	14.2	16.2	13.8	
Weight (t) 20%mc	16.5	15.5	13.6	16.0	5.01
Weight (t) 44%mc	23.4	22.1			
Volume (m3) 20%mc	44	53	23	72	6.25
Unit cost	£31/ wt	£29/ wt	£160/ t		£553 for 1000l
Processing cost (£)	733	891		1163	
Processing hours	49	60		68	0
Total annual cost (£)	1459	1532	2244	1804	3454
Fuel cost(p/kWh)	2.8	2.9	4.3	3.5	6.6

Stoking

Batch log burners are fuelled manually. Chip and pellet boilers can be fed manually via hoppers or have automatic feed systems. Chip and pellet handling systems are often specific to the boiler model/manufacturer and so have not been reviewed.

Fuel Processing and storage

Green timber at a maximum of 60%mc (softwood has higher mc than hardwood) has to be reduced to 20-25%mc for burning in log batch or chip boiler. A review of the guidelines published by DK Vindencenter [5] and Forestry Research [15,16] suggests processing and storage guidelines as follows:

1. Minimise mc in greenwood in by felling in winter, or if cutting in summer leave as whole trees with leaves on to allow transpirational drying.
2. Cut and split(maximum thickness 100mm) freshly felled timber, stack logs north/south in east/west rows, where they are exposed to sun and wind, off the ground(2 logs as rails, or pallets have been suggested), with the top of the pile covered to maximise drying. Drying takes at least one summer, preferably two. (13-22.5%mc achieved for split wood in a covered store 12-16 month after felling [16]. Once dry, ensure that logs are covered (more important for softwood which soaks up more moisture than hardwood).
3. If the space allows, wood for 3 years should be stored (occupying about 150m^3), fresh felled, one year and two year piles. The fresh and one year piles would be in the drying site, with the two year pile stacked close to the boiler house for immediate use. The site for the boiler house and fuel store is about 10m by 10m, about 20m from the Community Hall which would allow for a 1 year supply to be stored close to the boiler.

Wood chip boilers require particular chip specifications, particularly respecting size. Wood can be chipped fresh, but this increases the size variability [17] and the chips compost, reducing dry matter content and thus heating value[18]. Chips can be dried after chipping but this is usually energy consuming and not recommended.

If chips are required, chip dry fuel as required and cover to prevent dry matter losses.

- Note that wet chips can spontaneously combust, so if chips are to be stored for more than a week or two, they would be best stored under cover, some way from buildings [19].
- Handling of wood chips can be hazardous to health due to dust and the presence of fungal spores [19].

Wood pellets are delivered in small bags, 1tonne bags or loose in bulk. They must be kept dry, so storage of loose pellets (including 1 tonne bag) must be in grain-type silos or purpose built stores. Currently most pellets in the UK are imported from Sweden or Canada and delivery charges are not insignificant.

Processing Equipment

If green roundwood is sourced, then two specialist pieces of equipment are worth considering:

- Firewood processor to cut logs and split logs to size [20,21].
- Wood chipper to chip dry logs, if a chip boiler was selected [22,23]

Forestry and Agriculture carry the highest accident rates in UK industries, so there are numerous publications from the HSE about the use of all forestry and wood processing equipment. Some are noted in the references [24,25].

Comparison of Fuels

Characteristics of wood fuels are summarised in table 8. HH have a high availability of low skilled labour and a ready supply of wood from contracting, suggesting the use of log or chip. As a number of staff living on-site are available to light boilers, then logs would best provide the community needs.

If wood were to be sourced externally then a one year supply could be provided by a single lorry load, thus minimising cost and environmental effects of transporting bulky fuel.

Table 5 - Fuel Comparison

Fuel	Pros & Cons
Log - pros	• Cheapest fuel, large labour resource available • Staff living on site available to light/ monitor boiler • Simple system - less to go wrong, • Good selection of efficient boilers - domestic and small commercial scale • Room on-site for fuel storage • Single delivery of fuel for year
Cons	• 150m2 storage space required for 3 year supply • Considerable processing effort

	• H&S risk associated with fuel handling and processing equipment • Manual boiler operation • Large thermal store to enable efficient running
Chip - Pros	• Choice of manual hopper or automatic feed • More controllable than log boiler • Room on-site for fuel storage • Single delivery of fuel for year
Cons	• Additional processing • Extra processing plant • Requires dry storage after chipping • Additional H&S risks (dust, fungal growth, spontaneous combustion) • Domestic scale boilers unavailable so limited savings from mass production
Pellet - Pros	• Very efficient boilers available • Efficient burning down to 50% of rated capacity • Fuel cheaper than oil • Controllable, much smaller thermal store • Good selection of efficient boilers available on domestic and small commercial scale
Cons	• Fuel more expensive than log or chip • Dry storage vital • Not able to use fuel available from contracting

Emissions

Emissions from modern wood boilers with thermal stores run according to best practice, and pellet boilers running at 50-100% capacity are low compared with those of older appliances [9,7]. However, wood burning does produce higher levels of some harmful emissions than oil burning. These are summarized in Appendix 8.

Best practice to minimise emissions

Although it was challenging to compare emission data from the published literature because measurements are recorded in a number of ways, the way a wood-based boiler was run was shown to greatly affect the emissions profile. Slow combustion led to incomplete combustion which led to increased concentration of particles [7,9,10] and 6-fold gaseous emissions [10] but interestingly, best practice combustion gave a larger number of particles [10], with 80% at PM1 than slow combustion. As yet there is little medical data to examine the effect of very small particles on human health [13]. Particles from both best-practice combustion and slow combustion deposit mainly on the alveoli in the lungs, but it is thought that the particles from slow combustion are more toxic [26].

In addition, Olsson concluded that efficient wood/pellet burning lowers the CH_4 concentration in smoke to the same occurrence as in ambient air (CH_4 emission factor 0.04g/kg dry fuel).

For complete combustion the most important factors are high combustion temperature, sufficient air supply, adequate mixing of combustion air and fuel gas [27].

- Fuel – all similar, no treated wood. Bark increases NOx due to increased N and ash content.
- Moisture content – dry, at least 25%. In Johansson study, little difference was noted between the combustion of dry and 26%mc logs, but at 38%mc, VOCs(mainly CH_4 and ethene), PAH (polycyclic aromatic hydrocarbons) and particle counts rose dramatically, probably due to the reduction of combustion temperature.
- Size – roundwood diameter <100mm, best split to increase the surface area adjacent to the flame and thus the gasification rate of the fuel [10], and thus increase combustion efficiency. Woodchip and pellets should be sized for boiler.
- Appliance – modern log batch or pellet boiler, designed to prolong burning time and maintain high combustion temperature.
- Combustion practice
  - sufficient air for complete combustion AFR>1.5
  - logs not packed too tightly
  - High temperature – maintained by ceramic liners and air-fuel ratio (AFR) not too high (increases CO, CH_4 VOC, PAH)
  - No slow burning of log or woodchip boilers
  - Pellet boilers to be run at >50% capacity [7]

- Thermal store for log boilers– large enough to allow the boiler to be run efficiently in batch mode.

Boiler Size, Operation and Thermal Store

Boiler size, based on thermal demand, was calculated to be 55kW. To enable the boiler to be run efficiently, a thermal store must be included in the system which is capable of absorbing the excess heat to be released once the boiler is switched off. The scenarios examined produced boiler firing patterns with resulting maximum energy storage requirements in table 6.

On a typical January weekend day, the boiler was fired only for one 1 ¾ hour period, and for that short firing time 79kWh accumulated in the thermal store. Clearly, this issue would be exacerbated in warmer months as indicated in scenario 5 when the boiler needed to be lit for 1 ½ hours only. This indicates that the demand could be better satisfied by two smaller boilers as it might be unrealistic to fire the boiler for 2 hours or less. In addition, no account was taken of the solar thermal input which could offer a significant contribution to the thermal store in April.

Table 6 - 55kW Boiler Scenarios

Scenarios	55kW boiler	Boiler firings (hrs)		Max energy stored
		am	pm	kWh
1	Jan week day	3	3 3/4	79
2	1 +auditorium	3	5	78
3	Jan w/e day	2		79
4	Apr week day	2	3	70
5	Apr w/e day	1 1/2		69

Adopting the same scenarios with boilers sized at 33kW and 24kW (Table 7) reduced the storage requirement to 45kW.

Table 7 - 2 Boiler Scenarios

Scenario		Boiler firings (hrs)		Max energy stored
		33kw	24kW	kWh
1	Jan week day	9.5	2	45
2	1 +auditorium	7	8	44
3	Jan w/e day	0	4	31
4	Apr week day	4	6	40
5	Apr w/e day	0	3	45

The under floor heating design was based on a flow temperature(t_f) of 85°C and a return temperature(t_r) of 65°C (these seem a bit high for underfloor heating but the 20°C differential is standard), giving a thermal store size of 3,405l for a 55kW boiler design. This is a large thermal store, but it compares favourably with the Dulas Ltd. specification for a 50kW boiler installation at Cwmbiga [27].

The two boiler design reduced the thermal store size to 1940l.

In the sponsor provided figures the boiler was sized to provide 60% of the load. This reduction was made to ensure that the system was not oversized which could be dangerous in a batch fuel system and to account for wood and woodchip boilers being run continuously, unlike gas/oil boilers that are run intermittently [29].

These reasons do not apply to a modern log, chip or pellet system supported by a correctly-sized thermal store. However, to reconcile boiler efficiency with highly variable demand, the options are to install:

1. a single boiler sized to meet thermal demand (55kW) and a large thermal store (3,500-4,000l).
2. 2 smaller boilers (about 33kW and 24kW), reducing thermal store size to 2000l. Note that the smaller boiler could be LPG or oil.
3. a single boiler sized at 60-70% of peak load with additional space heaters(probably in IT suite and old offices) providing additional heat in times of very cold weather, smaller thermal store.

Two boilers are likely to be more expensive than two smaller ones, although smaller domestic-scale boilers may be available at lower cost (increased production numbers). Extra costs would be incurred by extra control gear, piping etc. and installation costs but there would be a cost reduction in downsizing the thermal store. In addition, redundancy would facilitate scheduled and unscheduled maintenance.

Boilers with sophisticated combustion control moderate more efficiently, so the option could be between one expensive boiler and two cheaper ones.

CONCLUSIONS

System design

Resources (labour, fuel, space, accessibility) and lifestyle impact on wood-fuel system design.

2 log-batch boilers sized at about 33kW and 24kW combined with a 2,000l thermal store would service the variable load most efficiently, at a fuel cost of 2.9p/kWh.

Health & safety risk assessment would need to be made and procedures would need to be put in place to cover the processing and storage of fuel.

CHP is not yet available on this scale, but may be worth considering in the future.

Demand modelling

Traditional thermal demand calculations are not sufficient for the sizing of a wood-fuel system (and probably not a traditional system either). Thermal losses can be combined with occupancy and predicted temperatures to sense check calculations and determine the size of the thermal store.

When fabric heat loss is very low, the thermal demand calculations become very sensitive to ventilation rates which are often difficult to determine before building.

Standard methodology for predicting annual energy demand is not appropriate in this case because of the variability of occupancy of individual zones.

A model could be developed to determine boiler firing schedules and fuel requirements based on building bookings.

Minimising Emissions

The health effects and global warming potential of wood fuelled boilers are of concern but these can be minimised by buying an efficient boiler (log, chip or pellet) and following best practice combustion procedures.

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APPENDIX 1 – MATERIALS AND U-VALUES SPECIFICATION FROM SPONSOR FOR COMMUNITY HALL

Area	Element	Description	U-Value WK/m²
Office	Wall	(optional plasterboard or wall tiles or not finished in storage spaces) VB layer, 12mm ply sheathing, 125mm jute/cellulose or hemp fibre batts, 25mm airspace, ACTIS TS 10 radiant insulation, 25mm ventilated air space breather membrane, 25x35mm SW battens and counter battens, ship lapped cladding in pine.	0.10
Office	Roof	plasterboard, VB layer, 12mm ply sheathing, breather membrane, 125mm jute/cellulose or hemp fibre batts, 25mm airspace, ACTIS TS 10 radiant insulation, 25mm ventilated air space specialist batten angles with PV80 by Lafarge tiles with either reclaimed tiles or redland manufactured tiles on the north facing part.	0.10
Hall	Wall	400mm rammed earth, two 100mm layers of foamglas mechanically fixed to earth wall, lath and lime render.	0.18
Hall	Roof	38mm T&G cladding vapour barrier, 25mm airspace, two layers ACTIS TS 10 radiant insulation, 25mm ventilated air space breather membrane battens, counter battens and ash shingles.	0.08
Cafe	Wall	walls/doors entirely glazed as windows above, approx 80% of wall would be open able area. Triple glazing (low E=0.05, argon filled) with hard wood timber frame 12mm gap between panes.	1.6
Cafe	Roof	38mm T&G cladding, separation felt, vapour barrier, Foamglas rigid insulation 300mm at ridge, 200mm at thermal eaves, separation felt, butyl rubber pond liner on underlay felt and sedum mat covering on 50mm soil.	0.13
All	Floor	blinded hardcore, 250mm foamglas, 100mm lime crete with embedded heating pipes, and quarry or terracotta tiles.	0.16

Table 1: *Materials specifications and the Calculated U-values*

APPENDIX 2 – AIR CHANGES PER HOUR FOR COMMUNITY HALL

Zone	ACH	Notes
Auditorium	2	Regulation covered by CIBSE guide B2 which is not freely available so this is an estimate.
Cafe	2	Regulation covered by CIBSE guide B2 which is not freely available so this is an estimate. Actual ACH is likely to be higher depending on number of people using it.
Office 1	1.5	Based on BR for 6 people in 2 offices, assumed no accountable use of printers/copiers
Office 2	1.5	As for office 1
WCs	2	Based on BRs for 3 WCs. This may be less overall due to intermittent nature of BR requirement
Lobby	3	Used continually for access to WCs, offices and kitchen
Kitchen	3.1	Based on extraction requirements related to kitchen volume
Plant/furniture store	1	May be higher depending on the plant to be kept.

APPENDIX 3 – ESTIMATED USE OF EACH ZONE IN DISTRICT HEATING SCHEME (JANUARY)

		Hours used in Day (heating up times not included)										
Date	Day	Zone 1 Auditorium	Zone 2 Cafe	Zone 3 Office 1	Zone 4 Office 2	Zone 5 WC	Zone 6 Lobby	Zone 7 Kitchen	Zone 8 Plant room	Zone 9 Office block	Zone 10 IT Suite	Hot water
01/01/2008	Tue											
02/01/2008	Wed		3	9	9	9	9	3	9	9	9	1.5
03/01/2008	Thu		3	9	9	9	9	3	9	9	9	1.5
04/01/2008	Fri		3	9	9	9	9	3	9	9	9	1.5
05/01/2008	Sat		9			9	9	9	9			4.5
06/01/2008	Sun		9			9	9	9	9			4.5
07/01/2008	Mon		3	9	9	9	9	3	9	9	9	1.5
08/01/2008	Tue	3	6	9	9	12	12	3	9	9	9	3
09/01/2008	Wed	3	6	9	9	12	12	3	9	9	9	3
10/01/2008	Thu		3	9	9	9	9	3	9	9	9	1.5
11/01/2008	Fri		3	9	9	9	9	3	9	9	9	1.5
12/01/2008	Sat	9	9			9	9	9	9			4.5
13/01/2008	Sun		9			9	9	9	9			4.5
14/01/2008	Mon		3	9	9	9	9	3	9	9	9	1.5
15/01/2008	Tue	3	6	9	9	12	12	3	9	9	9	3
16/01/2008	Wed	3	6	9	9	12	12	3	9	9	9	3
17/01/2008	Thu		3	9	9	9	9	3	9	9	9	1.5
18/01/2008	Fri		3	9	9	9	9	3	9	9	9	1.5
19/01/2008	Sat		9			9	9	9	9			4.5
20/01/2008	Sun		9			9	9	9	9			4.5
21/01/2008	Mon		3	9	9	9	9	3	9	9	9	1.5
22/01/2008	Tue	3	6	9	9	12	12	3	9	9	9	3
23/01/2008	Wed	3	6	9	9	12	12	3	9	9	9	3
24/01/2008	Thu		3	9	9	9	9	3	9	9	9	1.5
25/01/2008	Fri		3	9	9	9	9	3	9	9	9	1.5
26/01/2008	Sat		9			9	9	9	9			4.5
27/01/2008	Sun		9			9	9	9	9			4.5
28/01/2008	Mon		3	9	9	9	9	3	9	9	9	1.5
29/01/2008	Tue	3	6	9	9	12	12	3	9	9	9	3
30/01/2008	Wed	3	6	9	9	12	12	3	9	9	9	3
31/01/2008	Thu		3	9	9	9	9	3	9	9	9	1.5

APPENDIX 4 – ENERGY USE BY DAY (JANUARY)

	Energy used in Day (kWh)											
Zone	1	2	3	4	5	6	7	8	9	10		
Date	Auditorium	Cafe	Office 1	Office 2	WC	Lobby	Kitchen	Plant room	Office block	IT Suite	Hot water	Total kWh
01/01/2008	0	0	0	0	0	0	0	0	0	0	0	0
02/01/2008	0	19	7	10	6	16	5	4	121	117	3	307
03/01/2008	0	19	7	10	6	16	5	4	121	117	3	307
04/01/2008	0	19	7	10	6	16	5	4	121	117	3	307
05/01/2008	0	41	0	0	6	16	12	4	0	0	9	88
06/01/2008	0	41	0	0	6	16	12	4	0	0	9	88
07/01/2008	0	19	7	10	6	16	5	4	121	117	3	307
08/01/2008	25	30	7	10	7	21	5	4	121	117	6	353
09/01/2008	25	30	7	10	7	21	5	4	121	117	6	353
10/01/2008	0	19	7	10	6	16	5	4	121	117	3	307
11/01/2008	0	19	7	10	6	16	5	4	121	117	3	307
12/01/2008	55	41	0	0	6	16	12	4	0	0	9	144
13/01/2008	0	41	0	0	6	16	12	4	0	0	9	88
14/01/2008	0	19	7	10	6	16	5	4	121	117	3	307
15/01/2008	25	30	7	10	7	21	5	4	121	117	6	353
16/01/2008	25	30	7	10	7	21	5	4	121	117	6	353
17/01/2008	0	19	7	10	6	16	5	4	121	117	3	307
18/01/2008	0	19	7	10	6	16	5	4	121	117	3	307
19/01/2008	0	41	0	0	6	16	12	4	0	0	9	88
20/01/2008	0	41	0	0	6	16	12	4	0	0	9	88
21/01/2008	0	19	7	10	6	16	5	4	121	117	3	307
22/01/2008	25	30	7	10	7	21	5	4	121	117	6	353
23/01/2008	25	30	7	10	7	21	5	4	121	117	6	353
24/01/2008	0	19	7	10	6	16	5	4	121	117	3	307
25/01/2008	0	19	7	10	6	16	5	4	121	117	3	307
26/01/2008	0	41	0	0	6	16	12	4	0	0	9	88
27/01/2008	0	41	0	0	6	16	12	4	0	0	9	88
28/01/2008	0	19	7	10	6	16	5	4	121	117	3	307
29/01/2008	25	30	7	10	7	21	5	4	121	117	6	353
30/01/2008	25	30	7	10	7	21	5	4	121	117	6	353
31/01/2008	0	19	7	10	6	16	5	4	121	117	3	307

Notes:

1 Cafe not heated from May to Sept incl

2 When any part used, then Lobby, WC and Plant room heated
3 No value included for the energy to heat up building, just the energy to maintain design temperature

APPENDIX 5 – BOILER FIRING SCENARIOS – SINGLE 55KW BOILER

1. Typical Jan weekday, no evening use, cafe heated

	Hour	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	0000
Zone 1	Auditorium																			
Zone 2	Cafe					4.3	4.3	4.3	4.3	4.3										
Zone 3	Office 1			0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8							
Zone 4	Office 2			1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2							
Zone 5	WC			0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6							
Zone 6	Lobby		1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7							
Zone 7	Kitchen					1.4	1.4	1.4	1.4	1.4										
Zone 8	Plant room			0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5							
Zone 9	Office block		12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6							
Zone 10	IT Suite		12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2							
	Hot water					2.0	2.0	2.0	2.0											
	Total power required	0	26.5	29.6	29.6	37.3	37.3	37.3	37.3	35.3	29.6	29.6	29.6	0.0	0	0	0	0	0	0
	Boiler power output		55	55	55			55	55	55	55									
	Energy to store (kWh)	0	28	25	25	-37	-37	17	17	19	25	-30	-30	0	0	0	0	0	0	0
	Cumulative energy stored	0	28	53	78	41	4	21	38	58	83	53	23	23	23	23	23	23	23	23

2. Typical Jan weekday, auditorium used for 3 hours in evening, cafe heated

	Hour	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	0000
Zone 1	Auditorium												5.8	5.8	5.8	5.8	5.8			
Zone 2	Cafe					4.3	4.3	4.3	4.3	4.3			4.3	4.3	4.3	4.3	4.3			
Zone 3	Office 1			0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8							
Zone 4	Office 2			1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2							
Zone 5	WC			0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6			
Zone 6	Lobby		1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7			
Zone 7	Kitchen					1.4	1.4	1.4	1.4	1.4										
Zone 8	Plant room			0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5							
Zone 9	Office block		12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6							
Zone 10	IT Suite		12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2							
	Hot water					2	2	2	2					2						
	Total power required	0	26.5	29.6	29.6	37.3	37.3	37.3	37.3	35.3	29.6	29.6	39.7	14.4	12.4	12.4	12.4	0	0	0
	Boiler power output		55	55	55			55	55	55		55	55							
	Energy to store (kWh)	0	28	25	25	-37	-37	17	17	19	-30	25	15	-14	-12	-12	-12	0	0	0
	Cumulative energy stored	0	28	53	78	41	4	21	38	58	28	53	68	54	41	29	16	16	16	16

3. Jan weekend, Cafe, no offices, auditorium or IT suite

	Hour	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	0000
Zone 1	Auditorium																			
Zone 2	Cafe		4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3								
Zone 3	Office 1																			
Zone 4	Office 2																			
Zone 5	WC			0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6								
Zone 6	Lobby		1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7								
Zone 7	Kitchen			1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4								
Zone 8	Plant room			0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5								
Zone 9	Office block																			
Zone 10	IT Suite																			
	Hot water			2	2			2	2	1										
	Total power required	0	6.0	10.5	10.5	8.5	8.5	10.5	10.5	9.5	8.5	8.5	0	0	0	0	0	0	0	0
	Boiler power output		55	41																
	Energy to store (kWh)	0	49	30	-11	-9	-9	-11	-11	-10	-9	-9								
	Cumulative energy stored	0	49	79	69	60	52	41	30	21	12	4								

4. April weekday, no evening use, cafe heated

	Hour	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	0000
Zone 1	Auditorium																			
Zone 2	Cafe					3.2	3.2	3.2	3.2	3.2										
Zone 3	Office 1			0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6							
Zone 4	Office 2			0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9							
Zone 5	WC			0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5							
Zone 6	Lobby		1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3							
Zone 7	Kitchen					1.0	1.0	1.0	1.0	1.0										
Zone 8	Plant room			0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4							
Zone 9	Office block		9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4							
Zone 10	IT Suite		9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1							
	Hot water					2	2	2	2											
	Total power required	0	19.8	22.1	22.1	28.2	28.2	28.2	28.2	26.2	22.1	22.1	22.1	0	0	0	0	0	0	0
	Boiler power output		55	55				55	55	55										
	Energy to store (kWh)	0	35	33	-22	-28	-28	26	26	28	-22	-22	-22	0	0	0	0	0	0	0
	Cumulative energy stored	0	35	67	45	17	-11	15	42	70	48	26	4	4	4	4	4	4	4	4

5. Apr weekend, Cafe, no offices, auditorium or IT suite

	Hour	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	0000
Zone 1	Auditorium																			
Zone 2	Cafe		3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2								
Zone 3	Office 1																			
Zone 4	Office 2																			
Zone 5	WC			0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5								
Zone 6	Lobby		1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3								
Zone 7	Kitchen			1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0								
Zone 8	Plant room			0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4								
Zone 9	Office block																			
Zone 10	IT Suite																			
	Hot water			2	2			2	2	1										
	Total power required	0	4.5	8.3	8.3	6.3	6.3	8.3	8.3	7.3	6.3	6.3	0	0	0	0	0	0	0	0
	Boiler power output		55	27																
	Energy to store (kWh)	0	50	19	-8	-6	-6	-8	-8	-7	-6	-6								
	Cumulative energy stored	0	50	69	61	55	48	40	32	25	18	12								

APPENDIX 6 – BOILER FIRING SCENARIOS – 2 BOILERS, 33KW AND 24KW

1. Typical Jan weekday, no evening use, cafe heated

	Hour	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	0000
Zone 1	Auditorium																			
Zone 2	Cafe					4.3	4.3	4.3	4.3	4.3										
Zone 3	Office 1			0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8							
Zone 4	Office 2			1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2							
Zone 5	WC			0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6							
Zone 6	Lobby		1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7							
Zone 7	Kitchen					1.4	1.4	1.4	1.4	1.4										
Zone 8	Plant room			0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5							
Zone 9	Office block		12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6							
Zone 10	IT Suite		12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2							
	Hot water					2.0	2.0	2.0	2.0											
	Total power required	0	26.5	29.6	29.6	37.3	**37.3**	37.3	37.3	35.3	29.6	29.6	29.6	0.0	0	0	0	0	0	0
33	Boiler 33 output		33	33	33	33	33	33	33	33	33	17								
24	Boiler 24 ouput							24	24											
	Energy to store (kWh)	0	6	3	3	-4	-4	20	20	-2	3	-13	-30	0	0	0	0	0	0	0
	Cumulative energy stored	0	6	10	13	9	5	24	44	42	45	32	2	2	2	2	2	2	2	2

2. Typical Jan weekday, auditorium used for 3 hours in evening, cafe heated

	Hour	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	0000
Zone 1	Auditorium												5.8	5.8	5.8	5.8	5.8			
Zone 2	Cafe					4.3	4.3	4.3	4.3	4.3			4.3	4.3	4.3	4.3	4.3			
Zone 3	Office 1			0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8							
Zone 4	Office 2			1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2							
Zone 5	WC			0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6			
Zone 6	Lobby		1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7			
Zone 7	Kitchen					1.4	1.4	1.4	1.4	1.4										
Zone 8	Plant room			0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5							
Zone 9	Office block		12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6							
Zone 10	IT Suite		12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2							
	Hot water					2	2	2	2					2						
	Total power required	0	26.5	29.6	29.6	37.3	37.3	37.3	37.3	35.3	29.6	29.6	**39.7**	14.4	12.4	12.4	12.4	0	0	0
33	Boiler 33 output		33	33	33	33	33	33	33											
24	Boiler 24 output							24	24	24	24	24	24	24	24					
	Energy to store (kWh)	0	6	3	3	-4	-4	20	20	-11	-6	-6	-16	10	12	-12	-12	0	0	0
	Cumulative energy stored	0	6	10	13	9	5	24	44	33	27	22	6	15	27	15	2	2	2	2

3. Jan weekend, Cafe, no offices, auditorium or IT suite

	Hour	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	0000
Zone 1	Auditorium																			
Zone 2	Cafe		4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3								
Zone 3	Office 1																			
Zone 4	Office 2																			
Zone 5	WC			0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6								
Zone 6	Lobby		1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7								
Zone 7	Kitchen			1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4								
Zone 8	Plant room			0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5								
Zone 9	Office block																			
Zone 10	IT Suite																			
	Hot water			2	2			2	2	1										
	Total power required	0	6.0	10.5	10.5	8.5	8.5	10.5	10.5	9.5	8.5	8.5	0	0	0	0	0	0	0	0
33	Boiler 33 output																			
24	Boiler 24 output		24	24				24	24											
	Energy to store (kWh)	0	18	13	-11	-9	-9	13	13	-10	-9	-9								
	Cumulative energy stored	0	18	31	21	12	4	17	31	21	13	4								

4. April weekday, no evening use, cafe heated

	Hour	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	0000
Zone 1	Auditorium																			
Zone 2	Cafe					3.2	3.2	3.2	3.2	3.2										
Zone 3	Office 1			0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6							
Zone 4	Office 2			0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9							
Zone 5	WC			0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5							
Zone 6	Lobby		1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3							
Zone 7	Kitchen					1.0	1.0	1.0	1.0	1.0										
Zone 8	Plant room			0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4							
Zone 9	Office block		9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4							
Zone 10	IT Suite		9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1							
	Hot water					2	2	2	2											
	Total power required	0	19.8	22.1	22.1	28.2	28.2	28.2	28.2	26.2	22.1	22.1	22.1	0	0	0	0	0	0	0
33	Boiler 33 output		33	33	33	33														
24	Boiler 24 output						24	24	24	24	24	24								
	Energy to store (kWh)	0	13	11	11	5	-4	-4	-4	-2	2	2	-22	0	0	0	0	0	0	0
	Cumulative energy stored	0	13	24	35	40	36	31	27	25	27	29	7	7	7	7	7	7	7	7

5. Apr weekend, Cafe, no offices, auditorium or IT suite

	Hour	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	0000
Zone 1	Auditorium																			
Zone 2	Cafe		3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2								
Zone 3	Office 1																			
Zone 4	Office 2																			
Zone 5	WC			0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5								
Zone 6	Lobby		1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3								
Zone 7	Kitchen			1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0								
Zone 8	Plant room			0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4								
Zone 9	Office block																			
Zone 10	IT Suite																			
	Hot water			2	2			2	2	1										
	Total power required	0	4.5	8.3	8.3	6.3	6.3	8.3	8.3	7.3	6.3	6.3	0	0	0	0	0	0	0	0
33	Boiler 33 output																			
24	Boiler 24 output		24	24	24															
	Energy to store (kWh)	0	20	16	16	-6	-6	-8	-8	-7	-6	-6								
	Cumulative energy stored	0	20	35	51	45	38	30	22	15	8	2								

APPENDIX 7 – CALCULATION OF ANNUAL FUEL REQUIREMENT AND STORAGE SPACE

Annual Energy Demand (kWh)	61,176						
Fuel	**Beech**	**Pine**	**Spruce**	**Birch**	**Pellet**	**Chip**	**Oil**
LHV (GJ/tonne dry wt)	18.7	19.4	19.7	19	19	19.2	43.9
Combustion mc (%wet wt)	20	20	20	20	7.6	20	
LHV (GJ/tonne at combustion mc)	13.4	13.9	14.2	13.6	16.2	13.8	43.9
Moisture Content (%wet wt)	44.0	44.0	44.0	44.0	7.6	44.0	
Weight (tonnes) at 20%mc	16.5	15.8	15.5	16.2	13.6	16.0	5.01
Weight (tonnes) at 44%mc	23.4	22.5	22.1	23.0			
Volume (m3) at combustion mc	44	44	53	49	23	72	6.25
Unit cost	£31/green tonne	£29/green tonne	£29/green tonne	£31/green tonne	£160/ tonne		£553 for 1000l
Processing cost (£)	733	737	891	819		1163	
Processing time (hours)	49	50	60	55		68.1	0
Total annual cost (£)	1459	1389	1532	1532	2244	1804	3454
Fuel cost(p/kWh)	2.8	2.7	2.9	2.9	4.3	3.5	6.6

Notes

1. Annual energy requirement assumes boiler efficiency of 85%
2. LHV for Pine, Spruce, Birch from Wood for Energy Production Ch 6 [5], Oil LHV from DUKES 2007
3. Oil conversion of tonnes to litres from DUKES 2007 (burning oil)
4. OilPriceCheck.co.uk for heating oil price, includes VAT
5. Woodchip processing costs included log processing costs plus chipping costs, as it was assumed that roundwood would be cut to length and split prior to drying to maximise drying efficiency, then chipped dry. From forestry research technical note [31], About 4m^3 of solid wood can be chipped per hour with an industrial machine, costing £8.50/m^3, assumes no payment for equipment hire.
6. Price of softwood, based on £29/green tonne (mc 43-44% this year in Midlands, North-East, 38-40% last year), hardwood £31/green tonne) delivered, in 2 or 3m lengths, 26 tonnes on an artic lorry. Current prices from Iwan Williams, UPM Tillhil [32], include delivery.
7. Pellet price of £160/tonne bulk from Howard Towns at English Woodfuels ltd, Leics, 20kg bagged price £265/tone, includes delivery.
8. Softwood mc of 44% was used for mc of hardwood, as no hardwood figures were available. Hardwood moisture contents are generally lower and dependent on species, so the weight calculated for hardwood is an overestimate.
9. Seasoned logs should be bought by volume as this is largely independent of mc, whereas weight varies considerably.

10. Processing costs for logs were based on old figures for firewood processor trials, based on labour costs of £7.50/mh and did not include capital or hire costs. However, if processing is carried out by in-house labour, this cost is probably realistic.

APPENDIX 8 –WOOD FULE EMISSIONS – HEALTH AND GLOBAL WARMING

Health

Emissions of concern to health are classified as particles, gases and aromatic compounds:

Particles

Inhaled fine particles PM10 are related to acute asthma, with relative risk(RR) of hospital admission of 1.01-1.12 and the RR of asthma symptoms of 1.03-1.105 (Boman 2003). It is important to note that these RRs are small and that there is little data to identify the particular particle property or component responsible. WHO recognised minimum level of documented health effect is 10ug/m3 annual mean for respiratory and cardiovascular effects.

In best practice combustion, <80% of particles are PM1 (Tissari). It is thought that particles from combustion deposit mainly on alveoli in the lungs but little research has addressed the effect of these small particles. An unpublished study parallel to the Tissari study, suggests that the particles emitted from slow combustion are more toxic(Tissari personal communication).

For comparison wood combustion emits 12-32mg/MJ compared to 6-12mg/MJ for oil (Johansson).

Gases

Emission gases known to have respiratory effects are Ozone and NO2 (WHO).

Ozone is not produced by combustions but the precursors NOx and volatile organic carbons(VOCs) are. Minimum levels to affect health are 100ug/m3 (8h mean) for Ozone and 40ug/m3(annual mean) for NO2. Relative concentrations of the constituents of NOx vary with temperature and so most studies measure NOx rather than constituents, wood combustion produced 62-125mg/MJ compared to 37-41mg/MJ in oil (Johansson). Output is affected by the composition of the fuel (increased in bark) and the combustion temperature.

ACs

Out of the aromatic compounds (ACs) in wood smoke (Olsson 2005) known to be harmful to health, Benzene is clearly the most important. It is known to be carcinogenic to humans (IARC), haematotoxic and mutagenic (WHO). There is no safe threshold for Benzene and 17ug/m3 gives RR of leukaemia of 1.0001 (WHO). Efficient combustion of wood/pellets produces about 0.36mg/m3 (Olsson), 0.1-5.8mg/MJ (Johansson) compared with 0.01-0.04mg/MJ for oil (Johansson). However, WHO recognises that the most likely exposure routes are smoking, filling up your car and sitting for long journeys in cars with elevated air benzene levels.

Toluene (Methylbenzene) is not classifiable as carcinogenic to humans (IARC), but is known to damage cells. Efficient wood combustion level is about 0.12mg/m3(Olsson) which is less than the WHO minimum level of proven health effect at 0.26mg/m3.

Naphthalene causes haemolytic anaemia, cataracts and is classified as possibly carcinogenic to humans (IARC). Minimum health effect levels have not been determined as there is not enough data to separate Naphthalene effects from companion pollutants. Efficient wood combustion level is about 13mg/m3 (Olsson).

Global Warming Gases

Sustainably produced wood fuel can be considered to be CO_2 neutral as CO_2 released in burning is equivalent to that fixed in the growing process. As a percentage, CO_2 makes up about 9-13% of emission fraction for wood, pellet and oil fired boilers (Johansson). However, that does not take into account the CO_2 released in fertilising, harvesting, processing and transporting the wood. Wood is a bulky fuel in comparison to oil and so it is important to identify local sources of fuel to minimise the effect of fuel transport on global warming.

In addition to CO_2, the combustion of wood produces methane (CH_4) and Nitrous Oxide(N_2O) which have Global Warming Potentials (GWP) of 25 and 298 respectively over 100 years. [33]. The CH_4 produced by modern wood boilers in the Johansson study ranged from 0.8-14 mg/MJ (excluding MC=38%), modern pellet boilers <0.55-5.3 mg/MJ (excluding <27% capacity), compared with oil fired boilers in the range 0.46-0.52 mg/MJ [7] N_2O was not explicitly measured in the studies examined but total NO_x levels in wood/pellet boilers were 1.5-3.5 times those of the oil boiler at 37-41 mg/MJ [7].

APPENDIX 9 - WOODCHIP BOILERS

Manufacturer	Model	Output (kW)	Price (ex VAT)	Efficiency	Contact	Postcode	Tel no	Email/web	Notes
Binder	RRK 80-175	75		73-82	Wood Energy Ltd	EX16 9EU	1846 0707339	sales@woodenergyltd.co.uk	
Binder	RRK 22-49	22-49		73-82	Wood Energy Ltd	EX16 9EU	01845 0707339	sales@woodenergyltd.co.uk	
Biotech	HZ100	31-99.5	19,438		ICE Renewables	LE12 8UE	0845 4727498	icerenewables.com	
Biotech	HZ35	35	11,470		ICE Renewables	LE12 8UE	0845 4727498	icerenewables.com	
Biotech	HZ50	50	13,293		ICE Renewables	LE12 8UE	0845 4727498	icerenewables.com	
Dunster	Moderator 1	20-32			Dunster Wood Fuels	TA24 6NY	1649 821188	info@dunsterwoodfuels.co.uk	
Dunster	Moderator II	60-200			Dunster Wood Fuels	TA24 6NY	1650 821188	info@dunsterwoodfuels.co.uk	
Froeling	Turbomatic	28		N/A	Bioenergy Tech Ltd	TN22 5RU	01825 890140	sales@bioenergy.org	
Froeling	Turbomatic	35		N/A	Bioenergy Tech Ltd	TN22 5RU	1826 890140	sales@bioenergy.org	
Froeling	Turbomatic	48		N/A	Bioenergy Tech Ltd	TN22 5RU	1827 890140	sales@bioenergy.org	
Froeling	Turbomatic	55		N/A	Bioenergy Tech Ltd	TN22 5RU	1828 890140	sales@bioenergy.org	
Froeling	Turbomatic	85		N/A	Bioenergy Tech Ltd	TN22 5RU	1829 890140	sales@bioenergy.org	
Gilles	HPK-RA	15, 20, 25, 30, 35, 40, 45, 49, 61		90	Energy Innovations	IP16 4SE	845 8006805	info@energyinnovationsuk.com	
HDG	Compact	50	11045		Euroheat	WR6 5AY	01885 491112	www.euroheat.co.uk	
HDG	Compact	65	11867		Euroheat	WR6 5AY	01885 491112	www.euroheat.co.uk	

Herz	Firematic 50	25-50	27,300	N/A	Rural Energy	LE15 8DH	1668 454989	info@ruralenergy.co.uk	includes 4m Diameter agitator, 1500l buffer tank, basic control gear but not flue
KWB	USV 15	15		90	Econergy	SG19 2SH	0870 0545554	sales@econergy.ltd.uk	
KWB	USV 25	25		90	Econergy	SG19 2SH	871 0545554	sales@econergy.ltd.uk	
KWB	USV 30	30		90	Econergy	SG19 2SH	872 0545554	sales@econergy.ltd.uk	
KWB	USV 40	40		90	Econergy	SG19 2SH	873 0545554	sales@econergy.ltd.uk	
KWB	USV 50	50		90	Econergy	SG19 2SH	874 0545554	sales@econergy.ltd.uk	
KWB	USV 60	60		90	Econergy	SG19 2SH	875 0545554	sales@econergy.ltd.uk	
KWB	USV 80	80		90	Econergy	SG19 2SH	876 0545554	sales@econergy.ltd.uk	
Talbot	C1	50	30000		Talbotts	ST16 3HS	01785 213366	enquiries@talbotts.co.uk	installed, includes fuel hopper, screw feeds, control and simple flue
Twinheat	M40i/A2	29 pellet, 24 chip		88	Rural Energy	LE15 8DH	1665 454989	info@ruralenergy.co.uk	Installed cost. Includes small hopper, basic control, but not flue, fill hoper every 2-3 days
Twinheat	M40i/A4	48 pellet, 37 chip	12,700	86	Rural Energy	LE15 8DH	1665 454989	info@ruralenergy.co.uk	Installed cost. Includes small hopper, basic control, but not flue, fill hoper every 2-3 days
Twinheat	M80i/A8	80 pellet, 64 chip	15,650	89	Rural Energy	LE15 8DH	1666 454989	info@ruralenergy.co.uk	Installed cost. Includes small hopper, basic control, but not flue, fill hoper every 2-3 days

APPENDIX 10 – LOG BOILERS

Manufacturer	Model	Output (kW)	Price (ex VAT)	Efficiency	Contact	Postcode	Tel no	Email/web	Notes
Baxi	Solo Innova	14	4431	90	Baxi, Plumbcentre				
Baxi	Solo Innova	32	4961	90	Baxi, Plumbcentre				
Baxi	Solo Innova	48	6098	90	Baxi, Plumbcentre				
Bio Log	60	60		N/A	Bioenergy Tech Ltd	TN22 5RU	1826 890140	sales@bioenergy.org	
Bio Log	35	20-40		N/A	Bioenergy Tech Ltd	TN22 5RU	01825 890140	sales@bioenergy.org	
Dunster	Moderator	15	1670		Dunster Wood Fuels	TA24 6NY	01643 821188	info@dunsterwoodfuels.co.uk	
Dunster	Moderator	20	1865		Dunster Wood Fuels	TA24 6NY	1644 821188	info@dunsterwoodfuels.co.uk	
Dunster	Moderator	25	1965		Dunster Wood Fuels	TA24 6NY	1645 821188	info@dunsterwoodfuels.co.uk	
Dunster	Moderator	32	2323		Dunster Wood Fuels	TA24 6NY	1646 821188	info@dunsterwoodfuels.co.uk	
Dunster	Moderator	50	3500		Dunster Wood Fuels	TA24 6NY	1647 821188	info@dunsterwoodfuels.co.uk	
Dunster	Moderator	75	5269		Dunster Wood Fuels	TA24 6NY	1648 821188	info@dunsterwoodfuels.co.uk	
EdilKamin	Energy W Boiler	21.2	1250	63.3	Cambria Green Fuels			info@cambriagreenfuels.co.uk	
EdilKamin	Power WG Boiler	24	2400	78.4	Cambria Green Fuels			info@cambriagreenfuels.co.uk	
EdilKamin	Energy W Boiler	26.2	1285	63.3	Cambria Green Fuels			info@cambriagreenfuels.co.uk	
EdilKamin	Energy W Boiler	30.5	1350	63.1	Cambria Green Fuels			info@cambriagreenfuels.co.uk	
EdilKamin	Power WG Boiler	33	2475	77.1	Cambria Green Fuels			info@cambriagreenfuels.co.uk	
EdilKamin	Energy W Boiler	35.2	1450	63.3	Cambria Green Fuels			info@cambriagreenfuels.co.uk	
Froeling	FHG turbo 3000	20	4035	91.8	Highland Wood Energy	PH33 6SW		info@highlandwoodenergy.co.uk	
Froeling	FHG turbo 3000	30	4215	91.8	Highland Wood Energy	PH33 6SW		info@highlandwoodenergy.co.uk	

Froeling	FHG turbo 3000	40	4970	91.8	Highland Wood Energy	PH33 6SW		info@highlandwoodenergy.co.uk	
Froeling	FHG turbo 3000	50	5126	91.8	Highland Wood Energy	PH33 6SW		info@highlandwoodenergy.co.uk	
HDG	Navora	20	7770	91	Euroheat	WR6 5AY	01885 491112	www.euroheat.co.uk	
HDG	Bavaria	22	4495	N/A	Euroheat	WR6 5AY	01885 491112	www.euroheat.co.uk	
HDG	Navora 25 BC	25	6580	N/A	Euroheat	WR6 5AY	01885 491112	www.euroheat.co.uk	
HDG	Navora	25	7770	91	Euroheat	WR6 5AY	01885 491112	www.euroheat.co.uk	
HDG	Bavaria	29	4495	N/A	Euroheat	WR6 5AY	01885 491112	www.euroheat.co.uk	
HDG	Navora	30	7770	91	Euroheat	WR6 5AY	01885 491112	www.euroheat.co.uk	
HDG	Euro	30	9150	91	Euroheat	WR6 5AY	01885 491112	www.euroheat.co.uk	
HDG	Bavaria	35	4495	N/A	Euroheat	WR6 5AY	01885 491112	www.euroheat.co.uk	
HDG	Bavaria	38	5535	N/A	Euroheat	WR6 5AY	01885 491112	www.euroheat.co.uk	
HDG	Euro	40	9150	91	Euroheat	WR6 5AY	01885 491112	www.euroheat.co.uk	
HDG	Bavaria	49	5535	N/A	Euroheat	WR6 5AY	01885 491112	www.euroheat.co.uk	
HDG	Euro	50	9150	91	Euroheat	WR6 5AY	01885 491112	www.euroheat.co.uk	
HDG	Turbotec L	50	10875	90	Euroheat	WR6 5AY	01885 491112	www.euroheat.co.uk	
HDG	Turbotec L	60	10875	90	Euroheat	WR6 5AY	01885 491112	www.euroheat.co.uk	
Herz	Firestar 50	25-50	15,200	93	Rural Energy	LE15 8DH	1666 454989	info@ruralenergy.co.uk	inlcudes, basic control gear and 400l buffer tank, but excludes flue
Hoval	Agrolyt	20							
Hoval	Agrolyt	25							

Hoval	Agrolyt	35						
Hoval	Agrolyt	45						
Hoval	Agrolyt	50						
Mescoli	Gaselle GLQS 29VF	14-28		90	Bioenergy Tech Ltd	TN22 5RU	1828 890140	sales@bioenergy.org
Mescoli	Gaselle GLQS 39VF	23-37		90	Bioenergy Tech Ltd	TN22 5RU	1829 890140	sales@bioenergy.org
Mescoli	Gaselle GLQS 45VF	35-55		90	Bioenergy Tech Ltd	TN22 5RU	1830 890140	sales@bioenergy.org
Mescoli	Gaselle GLQS 70VF	53-84		90	Bioenergy Tech Ltd	TN22 5RU	1831 890140	sales@bioenergy.org
Vimar	Vigas 18DP	28 wood, 18 pellets			Dunster Wood Fuels	TA24 6NY	01643 821188	info@dunsterwoodfuels.co.uk
Vimar	Vigas	25		85	Dunster Wood Fuels	TA24 6NY	01643 821188	info@dunsterwoodfuels.co.uk
Vimar	Vigas	40		84	Dunster Wood Fuels	TA24 6NY	1644 821188	info@dunsterwoodfuels.co.uk
Vimar	Vigas	60		82	Dunster Wood Fuels	TA24 6NY	1645 821188	info@dunsterwoodfuels.co.uk
Windhager	FKU	20.9						info@windhageruk.com
Windhager	FKU	25.6						info@windhageruk.com
Windhager	HMX 320K	16-32						info@windhageruk.com
Windhager	HMX 400K	20-40						info@windhageruk.com

APPENDIX 11 – PELLET BOILERS

Manufacturer	Model	Output (kW)	Price (ex VAT)	Efficiency	Contact	Postcode	Tel no	Email/web	Notes
Baxi	Multiheat	15			Baxi, Plumbcentre				
Baxi	Multiheat	25, 23 with grain, woodchip			Baxi, Plumbcentre				
Baxi	Multiheat	43, 37 with grain, woodchip			Baxi, Plumbcentre				
Binder En-tech	PK 45	8.6-46.7			Wood Energy Ltd	EX16 9EU	1847 0707339	sales@woodenergyltd.co.uk	
Biotech	PZ100 RL	30-99	15,896		ICE Renewables	LE12 8UE	0845 4727498	icerenewables.com	
Gilles	HPK-RA	15, 20, 25, 30, 35, 40, 45, 49, 60			Energy Innovations	IP16 4SE	0844 8006805	info@energyinnovationsuk.com	
Hoval	Biolyt	10, 15, 21, 26, 50,70							
Mescoli	PPB/CB	28		87.9-90.4	Bioenergy Tech Ltd	TN22 5RU	01825 890140	sales@bioenergy.org	
Mescoli	PPB/CB	34		87.9-90.4	Bioenergy Tech Ltd	TN22 5RU	1826 890140	sales@bioenergy.org	
Mescoli	PPB/CB	50		87.9-90.4	Bioenergy Tech Ltd	TN22 5RU	1827 890140	sales@bioenergy.org	
Twinheat	ME40i	48 pellet, 37 grain	12,700	86	Rural Energy	LE15 8DH	1668 454989	info@ruralenergy.co.uk	Installed cost. Includes small hopper, basic cotrol, but not flue, fill hoper every 2-3 days
Twinheat	ME80i	80 pellet, 64 grain	15,650	89	Rural Energy	LE15 8DH	1669 454989	info@ruralenergy.co.uk	Installed cost. Includes small hopper, basic

cotrol, but not
flue, fill hoper
every 2-3 days