Department of Mechanical and Aerospace Engineering

A Study of Energy Efficiency Improvements and Heating Systems Suitability in Low Occupancy Scottish Rural Community Buildings

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Copyright Declaration

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Signed: Calum Craig Date: 31st August 2014

Abstract

Community buildings within rural situations provide a valuable facility to their local populous yet they are often overlooked with regards improvement. These buildings can be of challenging historical construction styles, suffer detrimentally from a lack of basic routine maintenance and be run by committees who possess little Energy related knowledge. Further, they face difficult heating issues due to very low occupancy rates. With low levels of financial income and ever increasing overheads these facilities often become threaten with closure which would be a loss to the community they serve.

The work presented here investigates the effect of energy efficiency measures upon the level of heat demand required and the suitability of alternative heating systems including renewable energy systems. The measures considered are: Loft Insulation, Under Floor Insulation, Internal Wall Insulation and Improved Air-Tightness.

The effects of the fabric improvements to Solid-Walled and Wooden-Walled buildings are highlighted and the improved buildings are simulated with different occupancy levels and the heat demand variation noted alongside suitable heating system settings.

The work provides a Heating System Suitability Matrix for Rural Community Buildings based upon the post-improvement simulation outcomes and suggested Capacities of Base Load and Boost Load.

The results demonstrate the benefit of Fabric Improvement plus Energy Efficiency measures and show that both alternative and renewable based heating systems can be suitable for the demands of Scottish Rural Community Buildings.

Acknowledgements

I would like to express my gratitude and warm thanks to Dr Nick Kelly, academic supervisor, and Professor Paul Strachan, PostGrad course director, for their input and belief as they maintained my focus during my studies. Without them I would not have a dissertation in which I could publicly thank them.

Rural Community Building committee members within the Strathendrick area require my thanks also. Their patience and time was invaluable and I wish them every success as they fight their individual battles and continue to provide such vital, yet misunderstood and generally under-valued, facilities in our local area.

It is without doubt that I am heavily indebted to Mr Jimmy Bain - Caretaker Extraordinaire. His drive and enthusiasm for the future of his local village hall is second to none. I sincerely wish you every success for your future plans.

To the ladies in my life I owe a huge thank you. They say you can always count on your Mum – well I can confirm the saying holds true. My wife and daughters moved 500 miles, quite literally, to allow me to undertake my MSc studies and I will always be there for them in return. They refer to this as ‘payback time’.

One certain ‘significant other’ requires my thanks too; so here it is - you know who you are.

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1. Introduction

1.1. Rural Community Buildings (RCB)

A 2007 research study and subsequent report, "Community Facilities in Rural Scotland: A Study of their Use, Provision and Condition" (Scottish-Govt, 2007), was a core element of the Scottish Government response to a petition which reflected the recognition that there was a lack of good understanding of the provision, condition and usage of community facilities and their importance in rural areas. The full report is only available through *www.scotland.gov.uk/socialresearch*.

The outcome of work by the Scottish government is summarised in the following section with all points relevant to the:

- featured Base-Case buildings used within the modelling and simulation work in this study,
- additional survey of RBCs in the Strathendrick Area as presented at Appendix A.

An energy efficiency and renewable energy systems focus has been retained to prove:-

- the value of simple Building Modelling and Simulation
- the scope for benefit stemming from Retrofit of Energy Efficient Measures
- the potential, or otherwise, for Alternative and/or Renewable Energy Systems.

Purpose and Value of RCBs

Rural community facilities (RCFs) are local assets which serve as central points or "hubs", and as venues for service provision, from within and out-with the community, sometimes providing for the co-location of multiple services (Scottish-Govt, 2007). Further, RCFs can be categorised as facilities that are owned or managed by the community or voluntary sector and which provide a wide range of leisure, health, social and cultural services for all residents of the community. They are often regarded as essential for modern living, provide important focal points for the local community and are frequently critical for the less advantaged or mobile in society.

Action with Communities for Rural England (ACRE) place a positive spin on RCFs within their 2014 Policy Position Paper by leading with the fact that rural communities benefit from owning well-maintained, multi-purpose facilities that provide opportunities for local social activity, sports, arts and recreation, alongside providing access to services and civic participation. They drive through the message that key factors leading to the realisation of benefit from RCFs is the provision of well resourced advice, information and support that ensures volunteer management committees succeed in helping their rural communities to be vibrant, healthy and sustainable (ACRE, 2014). This is something that is lacking in the Scottish experience but that the research picks up on.

Birth of an RCB

For a building to under-go a change of use is not uncommon and RCBs are typical in that many have served a previous purpose before becoming an RCB. For example, many old church buildings are gifted to the local community to be run 'for the benefit of those living in the local area' by a group of selected trustees or committee members. Similarly, wealthy local business owners funded the building of community facilities in the area where they lived or ran their business as a means of giving something back to the area.

With the high inherent value of an existing building, compared to the financial and carbon cost of a new building, it is not surprising that many RCBs are older, pre 1900 in some cases. With them being older presents issues due to their likely method of construction and material fabric which are now becoming an issue as the "Community Facilities in Rural Scotland" report highlights. Historically energy prices were lower and the buildings were comparatively newer thus less degraded than now thus those operating them could afford the heating and/or electric bills. With the passage of time and the rise in running costs due to fabric degradation and increased energy cost the buildings face new challenges that they must meet if they are to survive and remain open for the benefit of the communities they serve. They could be branded Hard-to-Treat (HTT) and the organisations running them described as in "fuel poverty".

Report Highlights:

Condition + Maintenance

Two-thirds of the surveyed facilities are more than fifty years old and almost two-thirds reported that they require improvements to make them "fit for purpose" or to comply with legislation.

When built	Percentage
Pre 1900	32.7
1900-1944	31.1
1945-1999	28.8
2000 or later	7.4

Table 1: Age of RCBs (Scottish-Govt, 2007)

Rising fuel costs inevitably increase running costs for the buildings. The main source of fuel for two-thirds of surveyed buildings was electricity, with oil used by one-fifth.

Main fuel source	Percentage
Mains gas	12.3
Electricity	61.2
Oil	21.1
Other	5.4

Table 2 : Main Fuel Source of RCBs, (Scottish-Govt, 2007)

A minority have renewable energy installations and less than half have energy conservation measures.

Energy conservation measure	Percentage
Double glazing installed	55
Draft proofing around windows and doors	41
Roof insulation	40
Low energy light fittings	31
Cavity wall insulation (recently built/upgraded)	20

Table 3 : Energy Conservation Measures in RCBs, (Scottish-Govt, 2007)

A high proportion of buildings had unsatisfactory or unsuitable physical fabric and high running costs associated with the energy forms used plus poor energy efficiency.

Ownership and location

Four-fifths of surveyed facilities are owned by the local community. Less than one fifth are owned by a local authority, which may have implications for how those buildings are managed (and perceived) by the local community. Committees running the RCFs need to understand local needs + be aware of the proximity of other service venues and providers that could compete with them and the implications this has for business planning and their longer-term sustainability.

Management committees and governance

The majority of committees meet at least quarterly but 25% only meet once or twice a year. The majority of committees have difficulty in recruiting and retaining volunteers for the management and running of the facility. Survey respondents expressed concern at the 'amount of red tape' experienced in relation to risk assessments, energy audits and health and safety audits, for example. Less than one fifth of respondent committees had prepared a business plan in the past five years and two-thirds had no budget preparation year-on-year. Almost one third of respondents reported that their facility has a budget deficit.

Financial balances

Balance	Percentage
Deficit	28.5
Surplus less than £1000	26.0
Surplus £1,000-£4,999	32.6
Surplus £5,000-£9,999	6.6
Surplus greater than £10,000	6.2

Table 4 : Financial Balance of RCBs, (Scottish-Govt, 2007)

Similar findings are reported by Action with Communities for Rural England (ACRE) in their latest 2009 report, which revisits their work in 1988 and 1998, where they found that 40% of buildings were not financially stable and required outside funding to breakeven. Significantly, the same proportion found it difficult to meet users' needs due to the age of the building. (ACRE, 2009)

Over three quarters had received funds from one to five funding sources in the last five years. The biggest funders were local authorities and the National Lottery; funding is also available through the Scotland Rural Development Programme (SRDP) and EU's LEADER.

Funding source	**Percentage who had received funding from this source in the past five years**
Central government	18.3
Local government	67.0
Donations from individual	64.8
Quangos, e.g. Scottish Arts Council	12.8
Local businesses	20.3
National business	7.1
EU funding, e.g. LEADER	7.4
National Lottery	37.8
Charitable Trust (national)	22.6
Charitable Trust (local)	19.6
Legacies	7.9
Other	18.9

Table 5 : RCB Funding received by Source (%), (Scottish-Govt, 2007)

The findings suggest that RCF committees might benefit from better and more readily available support and advice, of a consistent standard, particularly in relation to: energy conservation and renewables; legislation and regulatory responsibilities; business and budget planning; and the evaluation of their potential to be multiservice outlets where appropriate.

With the potential for RCFs to be 'Highly Valuable Assets' given the perceived social centrality of community buildings, their ability to potential to "house" combinations of rural service provision, and at the very least function as meeting places through which to overcome potential isolation and reinforce community cohesion; it is worrying to discover some of the Scottish Council for Voluntary Organisations (SCVO) 2001 survey findings. It provided some important insights as to key issues facing Scotland's RCFs. The main findings in 2001 were:

(i) that there were an estimated 3,000-plus community buildings in Scotland

(ii) less than half of respondents reported that the halls had good external structures and roof

(iii) over one third had at least one internal facility deemed 'inadequate for purpose'

(iii) nearly all used costly, inefficient and unreliable night storage heating

(iv) half had incomes of less than £5,000 a year

Six years later, the 2007 study found 59% of RCFs had no draft proofing around windows and doors and the majority of buildings appear to be poorly insulated. Obviously a large proportion of the existing RCF building stock remains deficient and still requires improvement despite the measures being little more than routine maintenance.

The 2007 study, (Scottish-Govt, 2007), reported that although there may be a justifiable interest in renewable energy options, it is important to consider them in the context of first ensuring energy conservation and efficiency, within RCFs.

Use of facilities

Surveyed facilities served a wide age-range of people: over three-quarters were used by young and elderly people; more than half provided a venue for parents and toddlers.

A principal purpose of the facilities surveyed was to provide a venue for community activities.

Number of activities taking place in RCF on a weekly basis	Percentage
None	20.6
1	24.8
2-5	49.3
6 or more	5.2

Table 6 : Usage Level of RCBs, (Scottish-Govt, 2007)

Less than one-fifth were used for public services such as a library, local authority services, a post office, a GP surgery or other health services despite the Scottish Government's 2008 report '*Delivering for Remote & Rural Health',* the 2007 report 'Action Plan: *Better Health, Better Care'* and findings from this research on current state and use. There may be scope for innovative ways of providing greater access to health services through these buildings. It may be worthwhile considering whether there could or should be greater partnership between public sector service providers and rural community facilities with benefit stemming from increased use levels.

Sharing of best practice for RCFs in Scotland

Despite the considerable challenges to their ongoing sustainability that many rural community facilities are facing, there are plentiful (and often unrecognised) examples of good practice and imaginative approaches to finding solutions. Further consideration should be given on how to successfully:

• share experiences and advice in relation to the facilities' physical condition and maintenance;

Uses of the RCB:

A number of respondents stated that their buildings were partly unsuitable for certain activities eg. Drama/Music shows or certain sports, due to the building layout, internal fabrics, danger from heating system components or damage to key features including windows in certain conservation areas.

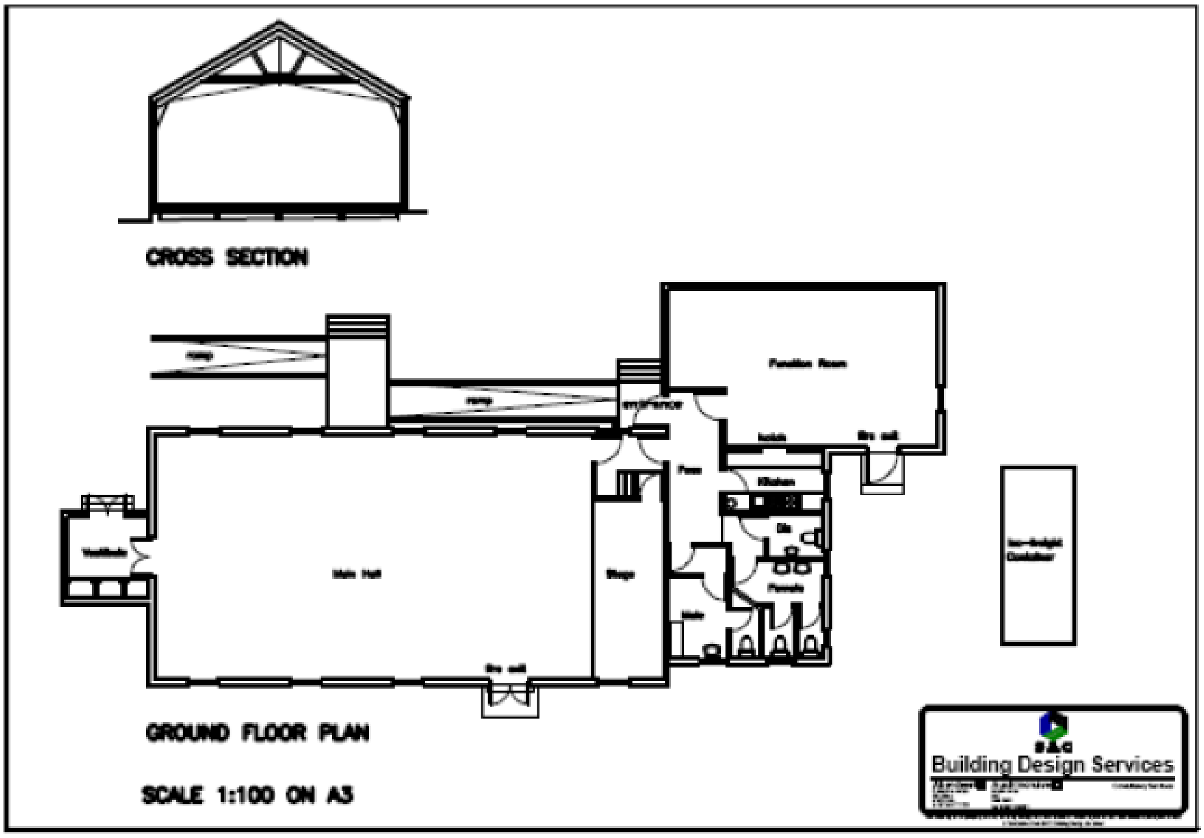


Table 7 : Typical RCB 'Public Hall' Layout, (Scottish-Govt, 2007)

It is the case of the Solid-Walled Base Case building that usage levels range from 7% of a week up to 15% of a week during infrequent busy periods. In this case it is the dilapidated building fabric's effect on comfort levels that are the issue rather that the layout. During winter there are periods when acceptable internal conditions are not able to be provided by the ill-suited and in-effective electric heating system.

The Wooden-Walled Base Case building is well maintained and has a better suited, if expensive to run, heating system that can provide adequate comfort conditions all-year round. The usage level is affected by the proximity of local buildings with layouts that are more suitable to user needs for more active pursuits like fitness and music or dramatic performances.

The surveyed RCBs in the Strathendrick area report similar issues to those above.

Perceived Future Needs and Options

The report grouped them under the following headings:

a. Improve the exterior of the building (no mention of renewable generation).
b. Improve the interior of the building: toilets, heating, insulation, storage etc.
c. Improved management: younger / more robust committees.
d. Increased usage levels and wider variety of users.
e. Eradicate:

    the feeling of fragility,
    the dependency upon certain users,
    the inadequate support from local authorities,
    the risk of failing to meet increasing running costs.

Ongoing funding needs of surveyed RCFs
Internal
Build new kitchen to comply with H&S and disabled access
Small kitchen extension
Refurbish kitchen and facilities (e.g. cooker, dishwasher)
Upgrade fire alarms
Painting of hall (internal)
Changing rooms (replace/refurbish)
Information Technology
Lighting
Disabled access toilets
Hot water in cloak room
New water heater
New heating system
Renewable energy heating and lighting
Insulation
Utilities bills (fuel, water, rates, electricity, fire safety equipment maintenance, electrical appliance testing): revenue finding required.
Replacement of stage
New public address system
Replacement of hall floor (sprung floor)
Storage facilities
External
Roof repair
Painting of hall (external)
Bike racks
Tarmac for car park/increase car park
Improved water supply
Structural repairs
Access ramps
All weather sports pitch
External masonry
Garden grounds

Table 8 : Ongoing Funding needs of RCBs, (Scottish-Govt, 2007)

Supporting Employment

ACRE's study quantifies some of the softer benefits stemming directly from the 10,000 RCBs in England.

They report community halls supporting employment opportunities in four distinct ways:

• Direct regular employment - by the management committee

• Indirect regular employment - provision of space for community activities at which people earn a living

• Irregular and occasional work - in building trades, catering and similar occupations

• Volunteering – building skills and adult education opportunities.

The halls responding to the survey each support, on average, seven jobs either directly or indirectly, excluding those in building trades. Although most are part time, these jobs are significant in the context of those rural areas where there are few job opportunities and household income is lower than average. Nationally, throughout England, the impact is substantial, indicating that at least 70,000 rural jobs are provided by community buildings. (ACRE, 2009)

No similar data was located for Scottish RCBs but with similar building uses and patterns across Scotland's 3,000 RCBs this would equate to approximately 20,000 rural jobs in Childcare, Fitness, Dance, Drama, Cleaning, Maintenance Trades and other casual entertainment vocations.

Key policy and practice issues

The recurrent or particularly salient themes from findings across the project that suggest areas for particular attention and action for those involved in the use, management, administration, funding and support for rural community facilities, from the level of individual committee members up to national organisations. The most relevant of the findings are:

Age and condition of the building :

At least two-thirds of surveyed RCFs are more than 50 years old; a high proportion of buildings had unsatisfactory or unsuitable physical fabric, and high running costs associated with the energy forms used and poor energy efficiency were common.

It is important for the structural implications to be understood and to explore strategic ways to address these.

Advice and support for RCFs :

Findings suggest that committees would welcome and benefit from improved, more readily available support and advice, to a consistent standard, particularly in relation to: energy conservation and renewables; legislation and regulatory responsibilities; business and budget planning; and the evaluation of their potential to be multi-service outlets where appropriate.

RCB Summary

There is clearly a need to improve the fabric of RCBs with the facility benefitting directly as well as wider social benefit in the local community. ACRE report, (ACRE, 2009), that the use of halls has trebled over the last 20 years, thanks to investment by local authorities, the lottery and other funders in addition to local fundraising. Further, increased use enables halls to fund maintenance and improvement work and build up small reserves, reducing the need for public funding for such work in the longer term.

Interestingly, investment in energy efficiency, renewable energy and other sustainability measures has multiple benefits, reducing running costs and carbon emissions as well as providing a practical demonstration of the benefits of such investment to local people who may be encouraged to engage in such measures at home.

By modelling and simulating typical Rural Community Buildings in this work via the Base-Case buildings, it is hoped to prove the study as worthy, required and valuable with subsequent benefit that can be derived by other RCBs who seek to understand more about the available options. The extent to which fabric improvements, energy efficiency measures and renewable energy systems can improve a RCB are identified in the following sections.

1.2. Buildings and Energy Use

Building construction has changed over time as knowledge, understanding, materials and human capability has evolved and improved. Prior to 1981 there was no regulation of the energy performance of buildings (Clarke et al., 2008). We now understand more about our buildings than we did in the past and we seek to build better 'new buildings' and improve our existing buildings wherever possible. Buildings emit more than 45% of CO2 emissions in the UK (Kelly, 2009) and through legislation, set out in the Climate Change Act (Scotland) 2009, we are required to reduce this as part of our meeting national targets of 42% by 2020 and 80% by 2050. (Scottish-Govt., 2009) (UK-Govt, 2008)

But 87% of all buildings that contribute this 45% of today's carbon emissions will still be functioning in 2050 thus to meet the reduction targets we will have to engage in a 'Deep Retrofit' of energy efficiency measures (Kelly, 2009). Clarke et al., 2007, in (Clarke et al., 2008) considered a 50% reduction in the heating demand for the entire Scottish housing stock could be achieved through the application of conventional fabric and system upgrades. Similarly, (Bell and Lowe, 2000) report the same based upon well-proven 1980s technology. The International Energy Agency adopt the same stance in their 'Transition to Sustainable Buildings' Report (IEA, 2013) stating that technologies and measures already exist that allow the buildings sector to be more energy efficient and sustainable, and thus to play its part in transforming the energy sector. Unlocking the potential of energy efficiency, particularly in the buildings sector should be a priority for all countries.

It is clear that there is a way forward but identifying exactly what way is best is problematic. Many argue that we are behind schedule and the Energy Efficiency Directive, stemming from the EU Energy Performance of Buildings Directive 2014 (EU, 2013), confirms this and details increased reporting of effort and the ramping up of energy efficiency deployments post-2016.

(Kelly, 2009) presents four ways by which the carbon emissions from existing buildings can be tackled:

- re-engineering the fabric of buildings
- improving the efficiency of appliances used in the home
- decarbonising the sources of energy to the home (as through a decarbonised grid or the use of local or distant renewable sources of energy)
- changes in personal behaviour.

Kelly immediately discounts the personal behaviour challenge as very difficult to manipulate and concentrates upon a triple-challenge that requires input from research, development, demonstration and early deployment of new measures and technologies with progress being assisted through research activities in the further and higher education sectors.

With Energy Conservation and Energy Efficiency Measures at the lower cost / large benefit end of the Carbon Management Hierarchy as drawn together by Historic Scotland (Historic-Scotland, 2011a) and they are rightly cited by many as the way forward for the are critically important to get right.

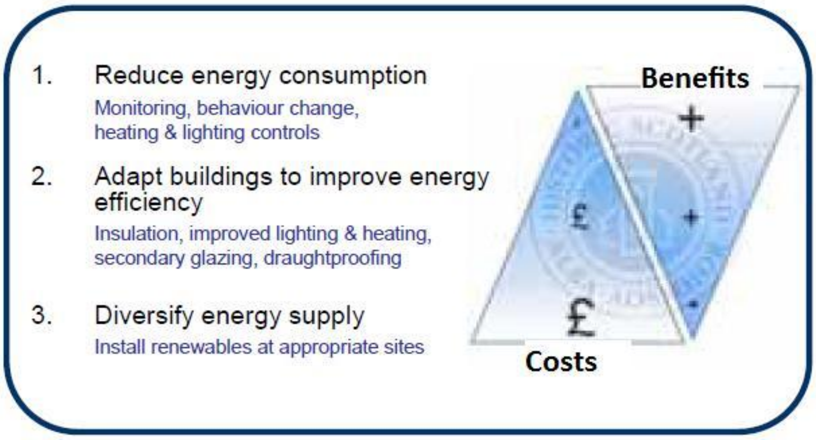


Figure 1 : Carbon Management Hierarchy, Historic Scotland

Suitable measures will be different for individual buildings and the main challenge remains identifying which measure to apply. To understand more the Heat Loss mechanisms from in property must be considered as in Figure 2 below.

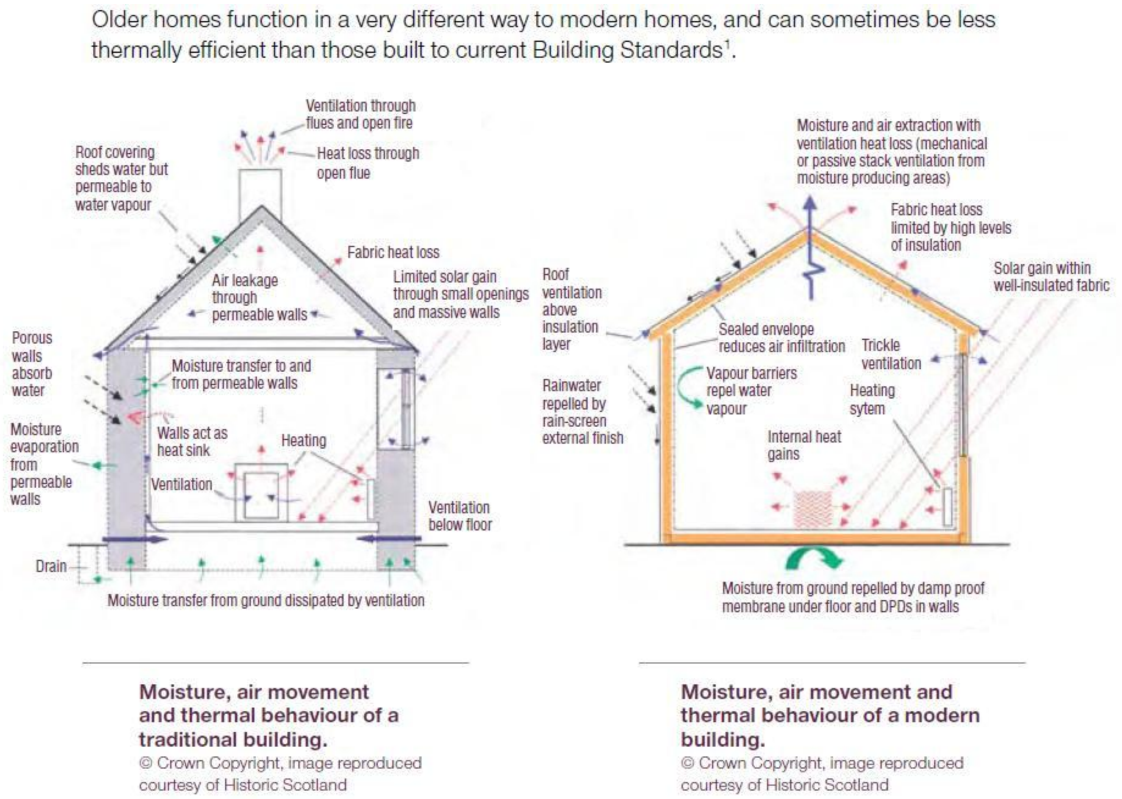


Figure 2 : Heat Loss Diagrams for Traditional and Modern Buildings (ChangeWorks, 2008)

1.3. Hard to Treat + Historic Buildings

Hard to Treat Buildings

Hard to Treat (HTT) buildings are generally defined as buildings that, for a variety of reasons, cannot accommodate 'normal' energy efficiency measures. They may take many forms but commonly they have one or more of the following attributes: solid walls, no loft space, are off grid and have no access or connection to a low cost fuel for heating and have technical or practical reasons that prevent simple-traditional energy efficiency measures from being fitted (EnergySavingTrust in (Changeworks, 2010)).

They draw a firm link to fuel poverty because of high heating bills associated with HTT buildings; where-as, in a more energy efficient building the heating bill would be less and occupiers could meet the cost. The situation of many HTT Rural Community Buildings can be likened to a household 'fuel poverty' situation.

The Energy Saving Trust see inadequate heating as harmful for both occupants and the fabric of the building; with older HTT buildings being more prone to moisture related problems such as condensation and rising damp - the main problems are:

- Damp conditions, made worse by inadequate heating, resulting in mould growth on cold surfaces and an increased risk of dry rot and attack from wood boring insects - leading to high long term maintenance costs.
- Furnishings and possessions can suffer damage from mould or insect attack - requiring more frequent replacement which increases financial pressures.
- Cold, damp internal conditions can have an adverse effect on occupants' health.

Studies of HTT buildings are well publicised and upheld as exemplars (positive and negative) for others to learn from. Positive work from Historic Scotland, seeking to address Scotland's Traditional Buildings, covers many of the possible solutions for HTT situations (Historic-Scotland, 2011b) with similar work being done by English Heritage (English-Heritage, 2010).

Figure 3 depicts the Heat Loss Split (%) from a building (Energy Saving Trust in (ChangeWorks, 2008)).

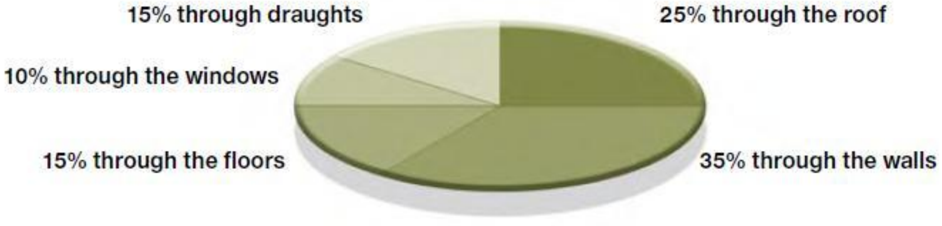


Figure 3 : Heat Loss from a building

Historic Buildings

Historic buildings have been used as the focus of studies into typical issues found in HTT buildings. The issues include (English-Heritage, 2012):

Moisture – Rain, Rising Damp, Internal Moisture Vapour, Damaged Services, Moisture Barriers.

Thermal Bridging – Insulated areas adjacent to un-insulated areas creating a condensation risk.

Material Compatibility – Adequate and proper for the circumstances.

Building regulations control much of this but dynamic modelling investigation can highlight any issues in advance while invasive monitoring studies of actual installations can clarify understanding, aid research and improve simulated output.

1.4. Building Modelling and Simulation

Building related models first appeared in the 1920's as scientists developed Response Factor Methods (RFM's) to calculate transient heat flows which were found useful when applied to simple wall structures. Their use developed through modelling of nuclear shelters and by the 1950-60's these where further extended by those involved in the Heating, Ventilation and Air Conditioning (HVAC) sectors as they sought to size equipment for use in simple stand-alone situations.

Computer technology in the 1960s saw the algorithms broadened and the first steps towards whole building modelling were taken with Tamami Kusuda developing a program based upon RFM's that "*combined algorithms for transient conduction in the building structure, solar heat gains and radiant transfer, and convection between building surfaces and the room air to allow the prediction of temperatures and heating and cooling loads under dynamic conditions"*.

By the 1970's the single room was modelled for the impacts of sunlight entering from outside and the weather with results output reflecting the internal conditions which eventually extended to other comfort metrics. Latterly, with the assistance of more powerful computing technology, it became possible to model and simulate larger portions of buildings and even whole buildings for many factors simultaneously.

The 1980's saw modelling beginning to support the development of Building Standards and compliance with regulations and proactive advancement of building energy modelling through the conception of the International Building Performance Simulation Association (IBPSA).

Complexity increased and specific focus on correctly modelling multi-faceted problems came to the fore despite divergence of effort caused by the existence of many, 'hundreds' (Crawley et al., 2008), competing packages (BEMBOOK, 2014). Verifying algorithms used within model based simulations remains key and much work is undertaken to check the computed outputs are representative of actual observed experiments and the outputs from other simulation tools (Strachan, 2006) .

The adoption of the Energy Performance of Buildings Directive (2002) in the UK through the new building regulations was the first step to ensuring that energy modelling became an integral part of the design process. The need for explicit modelling is becoming palpable, with the emergence of the myriad energy supply and demand reduction technologies mentioned above as the approach allows practitioners to match technologies to particular building types and contexts. In this way, it is possible to ensure supply matches demand over time, which is particularly problematic in designs incorporating stochastic renewable sources. Finally, strategic energy modelling can provide the data needed to develop more robust energy policies at the regional and national levels (Clarke, 2003; Clarke et al., 2004).

Improved standards, new materials, tighter legislation coupled with the requirement for more detail at the design stage have led to Modelling and Simulation adding more value during earlier stages of a buildings life. In new buildings, energy modelling should be carried out at an early stage of the design process in order to inform further development of the design and construction and in existing buildings, modelling can help to evaluate and prioritise the options for reducing carbon emissions cost effectively (BRE, 2014).

The Chartered Institute of Building Services Engineers (CIBSE) suggest that an examination of the energy aspects of a building require the information suites shown in Figure 4 below.

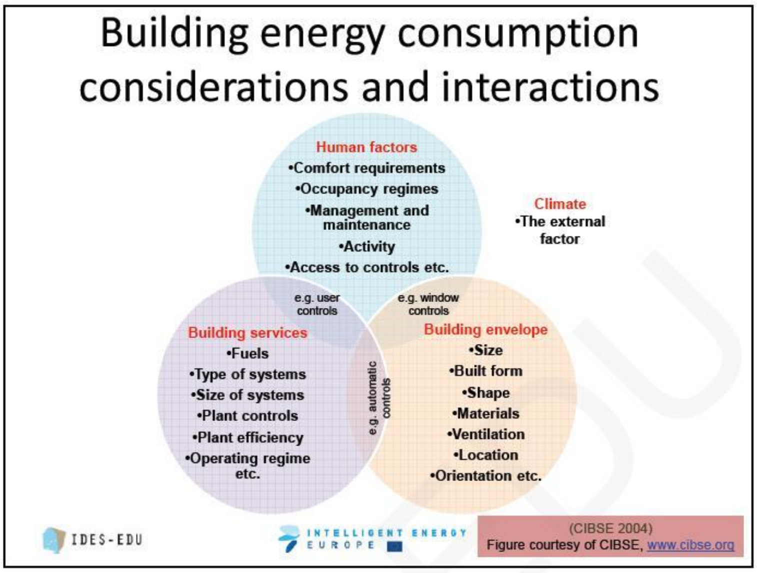


Figure 4 : Building Energy Consumption - Considerations + Interactions (CIBSE, 2004)

English Heritage in (English-Heritage, 2012) highlight that it is critical to understand a building before carrying out any works –"considering it as an 'Environmental System' with interlinked effects rather than free-standing situations". If a building is properly understood then works can be targeted to the most needed areas and flawed works avoided ensuring the best financial spend and best result for the building.

To fully understand the whole building - three levels of detail are required;

1. Large Scale – Performance of the whole building: Heating, Insulation, Ventilation and Energy Efficiency.
2. Medium Scale – How conditions vary between different locations in the building.
3. Small Scale – What happens at junctions between existing and new fabrics including potential insulation materials.

Understanding at the levels above will provide detail sufficient to overcome the main issues of Historic and HTT Buildings listed earlier in this section.

ESP-r Modelling + Simulation Tool

ESP-r as a modelling and simulation tool has the capability to provide detailed answer to the questions that need to be asked when designing fabric improvements to an existing building. The tool's modules are shown below in Figure 5.

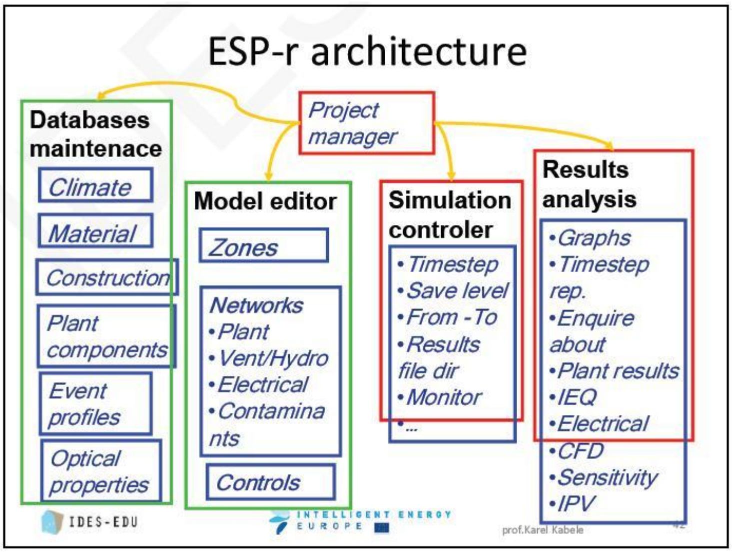


Figure 5 : ESP-r Architecture

ESP-r has been used in this study to manually generate simple building models and simulate their operation with a variation of inputs.

2. Approach + Methodology

2.1. Aim

This work aims to employ simple environment monitoring, model building and dynamic simulation to understand the impact of fabric improvements for energy efficiency on HTT buildings. It attempts to tie the output from monitoring with the modelling work to provide a truly representative model on which to base fabric upgrades and subsequent simulations.

Simulations will be used to investigate the effect of the staged improvements and allow reflection upon both heating system settings and occupation rates. Outputs from the simulation will drive the creation of a Heating System Suitability Matrix (SSM) for typical Rural Community Buildings with reference to industry guidelines and best practice.

2.2. Monitoring

Temperature loggers will capture internal temperatures within the zones of the building to provide actual detail on internal conditions. Met Office weather data will be obtained simultaneously to understand the ambient conditions the building has experienced during the temperature logging periods.

Two periods of logging are to be undertaken:

Initial period	- prior to improvement of the building to highlight the issues faced.
Second period	- post limited fabric improvements and replacement of heating system.

The output of this will highlight the effect of the changes to the building and allow correlation with the modelling and simulation.

2.3. Desktop and Field Survey

A desktop study and fieldwork relating to actual rural community buildings inputs into the occupancy regimes applied to the models during simulation while re-validating the issues facing RCBs, as raised by research findings and past studies. Information gathered will be directly reflected in the SSM.

2.4. Modelling

This work is primarily based upon the modelling of the monitored case study building, a HTT 19thC solid stone walled building.

Simple indicative modelling within ESP-r allows the construction to be representative of reality and easily altered to mimic fabric improvement. By using simple, close to the reality, models the need to engage in destructive internal investigation of the building actual make-up is removed.

A second building of wooden construction is modelled to broaden understanding of suitable fabric improvements, heating system settings and different occupancy levels.

2.5. Simulation

Simulations use a representative local climate file for the location of the solid walled building which may permit the monitoring outputs to be compared to the simulation outputs.

Typical energy efficiency measures are applied in stages and re-simulation undertaken.

The desktop study and fieldwork relating to local rural community buildings input into the occupancy regimes applied to the models during simulation.

Suitable heating system settings, namely: in-zone temperature, setback temperature, extent of pre-heat and magnitude of heat injection are investigated where appropriate.

The Base Load and Boost Load requirements are obtained through analysis of the suite of simulation results.

2.6. Heating System Suitability

A short desktop analysis outputs a Heating System Suitability Matrix based upon a typical Rural Community Building’s needs, restrictions, committee knowledge and occupancy regimes.

3. Local Survey

3.1. Rural Community Building Survey

The typically rural area centred 20 miles to the north of Glasgow, Scotland, has 11 villages and hamlets; each of which has their own Community Building(s). The National Gas Grid covers the southern section of the area only despite the proximity to Glasgow, Scotland's largest city. The area is easily accessed by road and many residents commute out of the area for work. There is a single school for secondary level education in the village of Balfron with most villages having a primary school for the resident and nearby children.

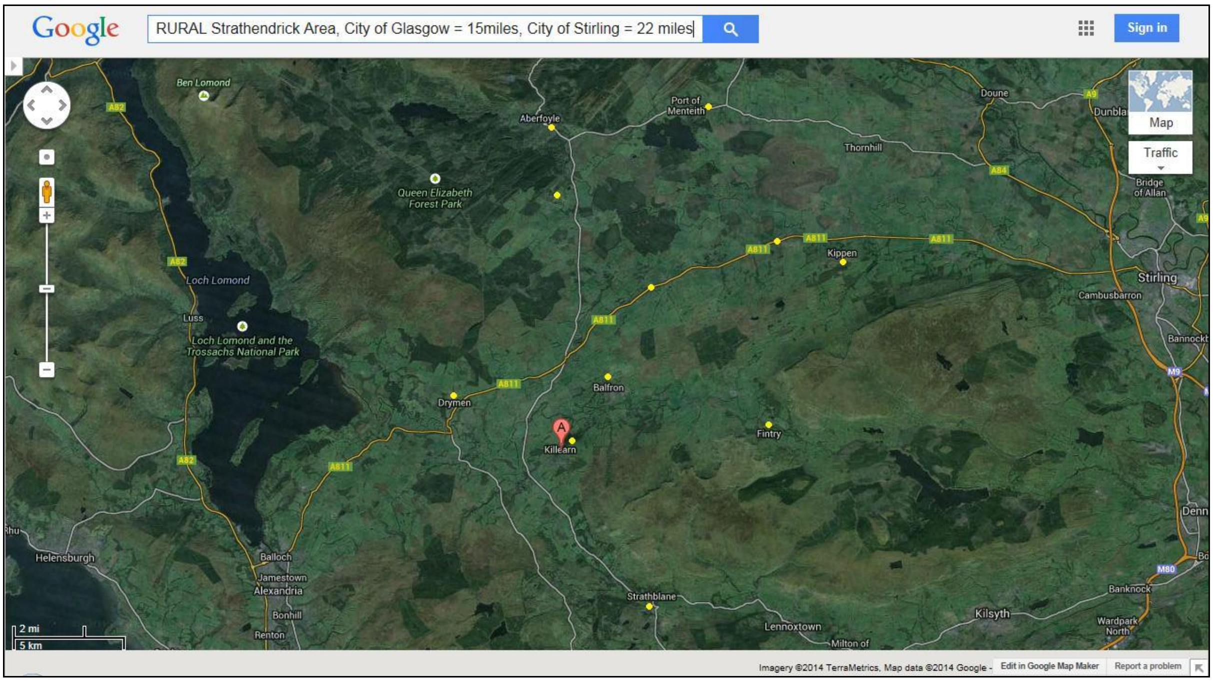


Figure 6 : Rural Strathendrick Map

Pictures of each village hall or building follow, Figure 6, and it is obvious that they are diverse in their size, style, construction and build material. A single improvement strategy is clearly unworkable hence this study and the larger national studies referenced in this work.

Highlights from the study include:

- Purchase of Halls for nominal sums (£1) from the Local Authority to help safeguard their future with investment through Local Development Trusts and Futures Groups.
- Buildings built by wealthy local businesses and landowners with the intention of them being run 'for the educational and social benefit of the local community.
- Gifting of buildings that were no longer required by Religious Organisations.

- Re-building after extensive fire damage and, in one case, the previous hall being 'Blown down by the wind'.
- Refurbishments costing between £1.2m and £1.7m that guarantee the future of buildings for their communities and include micro-generation and low carbon heating systems.

Lowlights also featured in the feedback:

- Halls closed for 6 months upon discovery of Asbestos within suspended ceiling tiles.
- Utility bills (Heat, Light and Electricity) in excess of £5000 where buildings are typically used less than 5% of any week.
- Buildings that see no use for weeks, sometimes months, at a time.
- Essential maintenance urgently required but no budget to find the work.
- Buildings losing users due to their inhospitably cold internal conditions during winter months.

3.2. Rural Community Buildings

To gauge their differences and similarities they are presented pictorially here with the detail of the survey held at Appendix A - Rural Community Building Survey.

Figure 7 : Strathendrick Village Hall Pictures

Drymen Village Hall, Pop: 820.

Arnprior Hall inc. Nursery, Pop: 200.

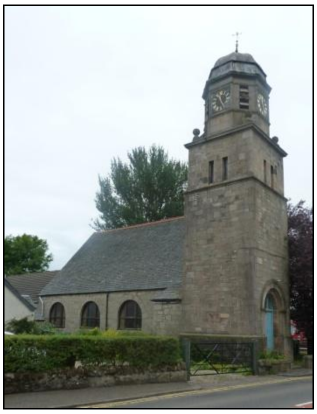
Strathblane Church Rooms, Pop: 1,964.

Gartmore Village Hall, Pop: 300.

Strathblane Village Club, Pop: 1,964.

Strathblane Village Hall, Pop: 1,964.

Killearn Village Hall, Pop: 1,701.



Buchlyvie Village Hall, Pop: 519.

Aberfoyle Memorial Hall, Pop: 769.

Fintry’s Menzies Hall, Pop: 691.

Balfron’s McLintock Hall inc. Retail units, Pop: 1,890.

Population Data: 2011 Census via http://www.citypopulation.de.

3.3. Survey findings

Based upon feedback from 11 of the 14 RCBs in the area; with one exception they all use mains gas for heating where it is available. Where no mains gas is available and the buildings have not been refurbished to modern 'low carbon' standards, they remain heated by electricity except one hall which uses oil fired central heating. Unimproved halls report their main issue being the cost of heating the building with many being unable to adequately control heating use by those hiring the venue resulting in a net financial loss after utility bills have been settled.

With one exception where the hall is primarily used by a local business during the working day; they report that there is scope for the building to be used more frequently and they would encourage that to happen. The main reason for losing a regular booking was 'moving to another local venue', mainly the local secondary school, but often bookings ceased during the winter months for certain activity types due to cold internal conditions.

The majority of halls reported the need for further maintenance. Half of the halls have taken steps to improve the building fabric and those who have not cite cost as the reason that nothing has been done. The only hall to not require maintenance was affiliated to the local Church who ensure that timely work is undertaken and the cost is met. All buildings have had draft reduction measures applied although some cite hall users as the cause of most heat-loss due to doors being left open. DIY loft insulation quilts have been installed in all buildings where it was feasible to do so.

Half of the halls have considered renewable energy systems but only 2 benefit from having had them installed; financing the installation was the main barrier to those who did not progress to an installation. Of the halls who have not considered renewable energy, the majority have other more pressing issues like maintenance and making the hall physically appealing to potential hirers.

Where buildings have been fully re-developed, Killearn and Gartmore, they now require to operate in a more aggressive 'commercial business' style to remain profitable as overheads have increased. The largest income now comes from private functions such as Weddings and other such celebrations with bookings being made more than 1 year in advance. Interestingly, the regular weekly hall users were unaware that the 'commercial' hiring of the hall was subsidising their lets.

Typical usage rates ranged between 5% and 20% with one hall peaking at 30% where weekend lets boosted hall use although this was mainly associated with the late-spring, summer and autumn seasons. Hall use levels have been steady but some report them as consistently dropping for a number of years.

4. Building Monitoring

4.1. Base Case Building – Temperature Logging

In order to attempt to validate the ESP-r model that would be built as part of this study it was deemed necessary to obtain an understanding of the performance of the Base Case building. By bringing together a suite of Temperature Data from the building with the output from the ESP-r model it would prove the model's composition and inputs as being accurate with respect to the real building.

A set of 3 simple temperature loggers were employed to automatically record the Dry-bulb temperature at each of their locations within the building at a known frequency over a known period. In parallel to this, climatic data was manually retrieved from the on-line report issued by the nearest MET Office approved weather station.

Data Loggers

A set of 3 simple temperature loggers were employed to automatically record the Dry-bulb temperature at each of their locations within the building at a known frequency over a known time period.

The chosen loggers and software were: ThermaData® Data Logger Mk1 + ThermaData® Studio PC software. Marketed as "Simple Temperature Loggers/Blind Recording Thermometers, Self-Contained/Water Resistant with LED Status Indicators" with Windows based software for download, graphing and data export.

Specification	ThermaData® logger Mk1
Range	-40 to 85°C
Resolution	0.5°C
Accuracy	±1°C (±0.5°C with calibration utility)
Memory	2 048 readings
Sample rate	1 to 255 minutes
Battery	3.6 volt half AA lithium
Battery life	3 years minimum
Display	2 LEDs
Dimensions	55 x 25mm
Weight	45 grams

SOURCE: **http://thermometer.co.uk/data-loggers/590-mk1-thermadata-logger.html**

Table 9: Data Logger Specification Sheet.

4.2. Climatic Weather Retrieval

Weather data was retrieved from Government's weather forecasting website, www.metoffice.gov.uk/weather/uk, which details the latest actual observations at dedicated weather stations around the UK. The data may not be 100% accurate with respect to the Base Case Building's location due to the nearest Weather Station being around 10 miles distant. This was accepted as of lesser significance given the nature of how the weather data was used within the study.

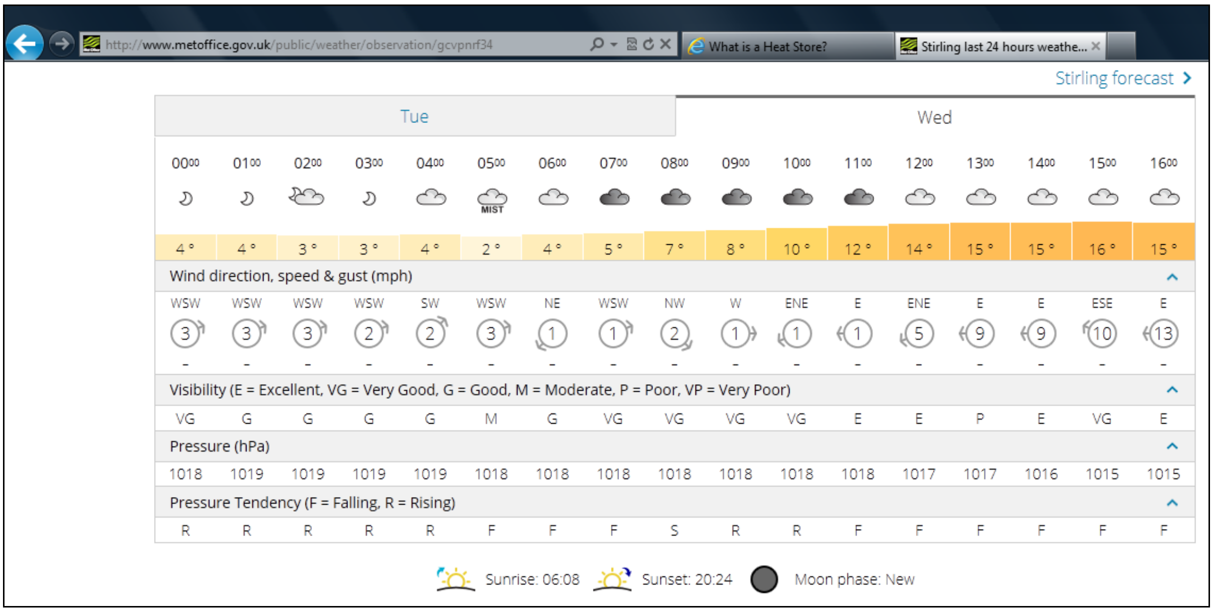


Figure 8: Met Office Weather Website Data.

4.3. Monitoring Difficulties.

Aligning Data Capture

With the building being used sporadically by a variety of groups often based around the local authority's school timetable; the booking diary features "School Term Only" bookings in addition to "Every Other Week" or "Last Thursday of the Month" which made it problematic to link usage-periods, manpower to download logger data and collect near-real-time weather downloads. Best efforts were made and the results presented here are caveated accordingly.

Hall Usage

Capturing the actual building use was unsuccessful despite best effort of all parties. Reliance upon 3rd party hall users to reliably log occupant numbers and activity types proved unworkable and no meaningful data was obtained.

Logging Periods

With the use pattern for the building being between 7% and 14% of any week it was not possible to capture both 'Busy' and 'Quiet' usage periods for the building. The timeframe available for the study restricted the ability to wait for 'better data' thus that captured had to suffice. After analysis, remembering the 7-14% usage rate, a representative hall-usage-period was captured by the Loggers and is presented and used within the study.

Climate Data

Actual ambient temperature was aligned to the Logger data. The following graphs represent the Ambient Temperature across the Data Monitoring Period.

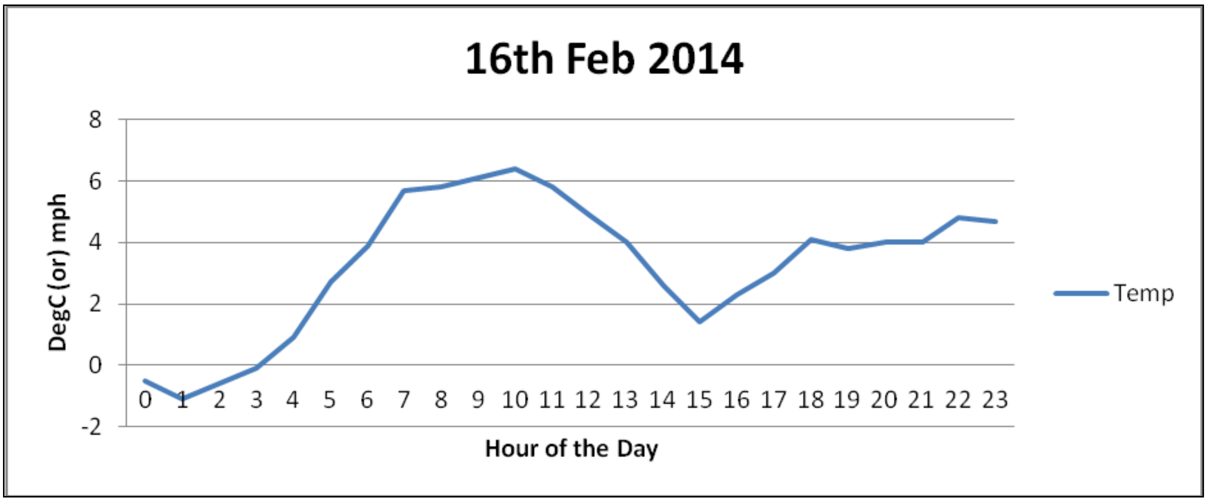


Figure 9 : February Ambient Temperature (1)

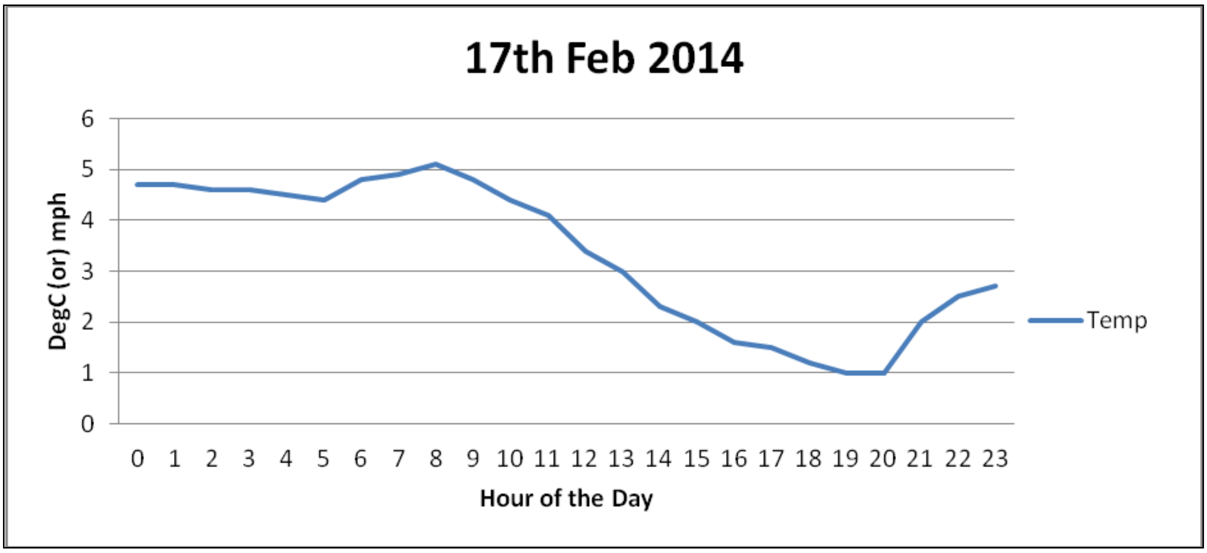


Figure 10 : February Ambient Temperature (2)

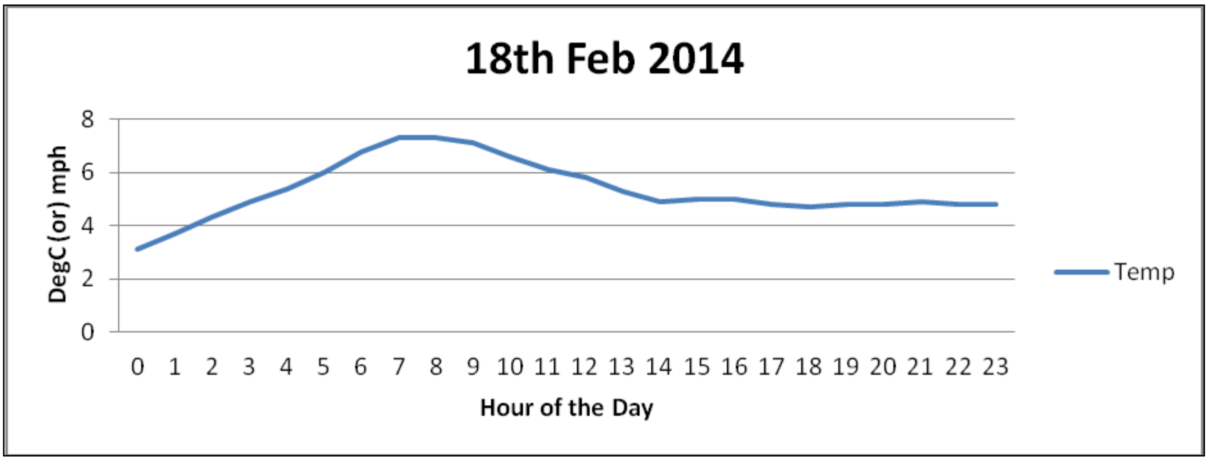


Figure 11 : February Ambient Temperature (3)

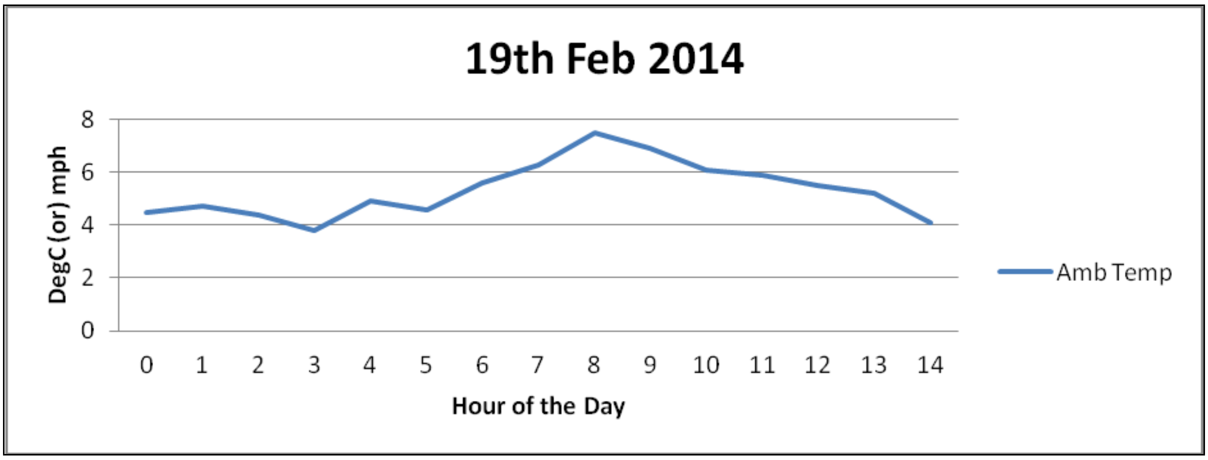


Figure 12 : February Ambient Temperature (4)

4.4. Outcome of Monitoring

Early Monitoring

An early period of data logging took place when the building;

- was unimproved with regard to energy efficiency
- had outstanding basic general maintenance tasks (draught exclusion, broken windows, leaking roofs)
- was heated by Electric Storage Heaters.

This proved the building to be Hard-To-Heat and often questionably fit-for-habitation. This was due to the Electric Storage Heaters being used as a panel heater would be used despite their being far less effective. With infrequent hall use their heat-charge/heat-discharge cycle neither being used appropriately and was unlikely to be effective given the building's state. While attempts to pre-heat the building for users were made, they were restricted due to the higher associated running costs.

The building was fitted with Radiative Wall Heaters which had been added historically but these were not fully functional due to breakage. Their use was actively discouraged due to the cost of their operating although the perceived improvement in internal comfort was acknowledged and their use not completely blocked.

Actual temperature profiles for the unimproved building are shown at Figure 13 below.

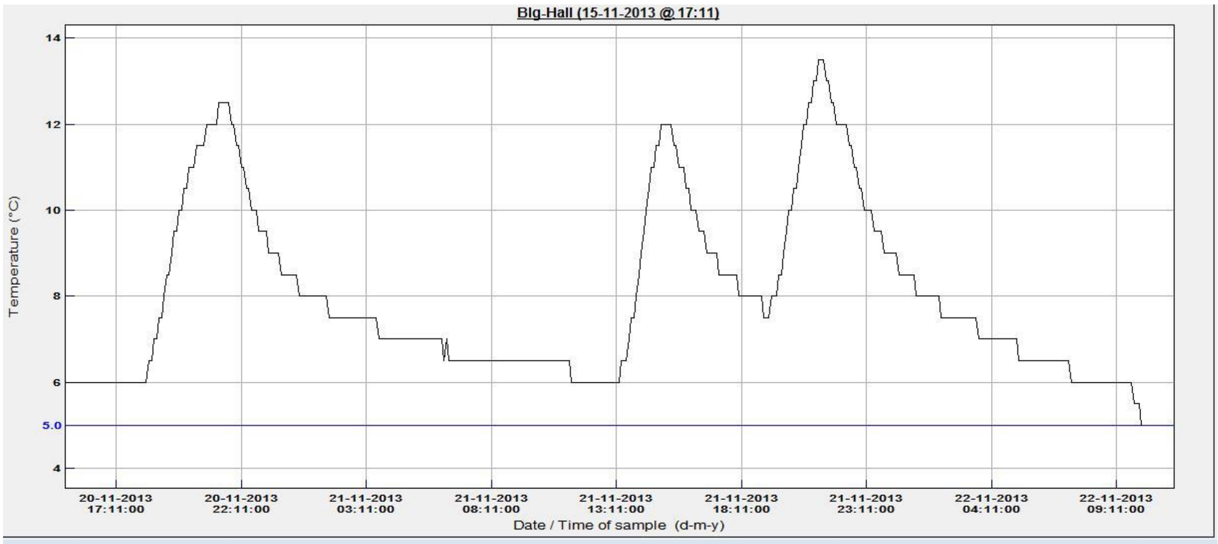


Figure 13 : Unimproved Solid Walled Building Internal Temperature

The in zone temperature rises slowly during the occupied periods rapid drop when the periods end. It is clear that the building has a high heat absorption capacity due to the thick solid walls and suffers from heat loss due to less well maintained building fabric.

Main Monitoring Period.

The main monitoring period took place after a Gas-Fired Wet Central Heating System was installed. A raft of Energy Efficiency measures and Basic Maintenance had also been undertaken:

- Broken windows replaced
- Draft Excluders fitted
- Roof edges sealed

Positioning of Temperature Loggers

Loggers were again located within the Main Hall, Small Hall and Facilities at convenient locations that were not easily accessible, without the use of a step-ladder, to avoid interference from hall users. Locations required minor revision due convective effects from the newly positioned radiators associated with the new heating system.

Floor/Ceiling Stratification

In order to gauge the extent of temperature stratification within the main hall – a suite of results was obtained to prove the cold-hot temperature gradient between the floor and the ceiling taking in the thermostat position as a convenient mid-point. This was backed up by a laser thermometer.

A gradient of 5 degC was observed between temperatures at the Ceiling and Floor, 4.8m height differential.

Graphical Results

Results of the logging for each zone are shown in Figures 14 and 15 below. They do show an improvement in achieving an acceptable in zone temperature that would be comfortable to hall users but it is noticeable that the pre-heat time remains extended. In part this is due to the circa 4degC overnight ambient temperature experienced during the monitoring phase but this also partly due to the building remaining unimproved in terms of potential energy efficiency measures.

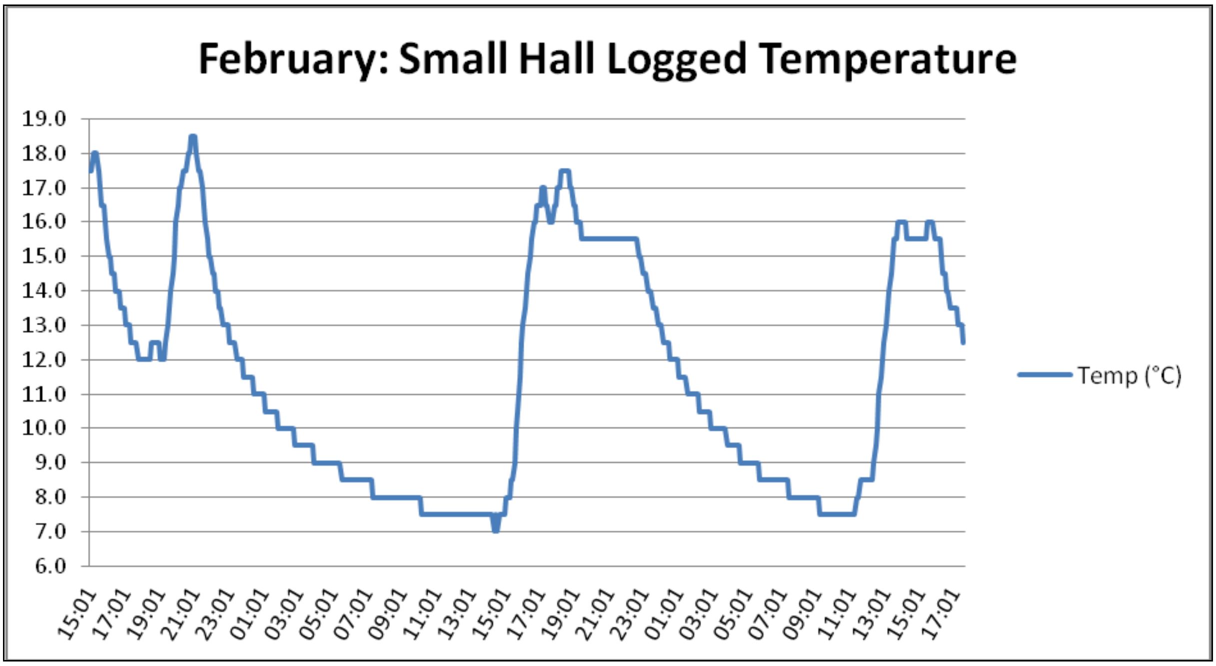


Figure 14 : Small Hall Logged Temperature

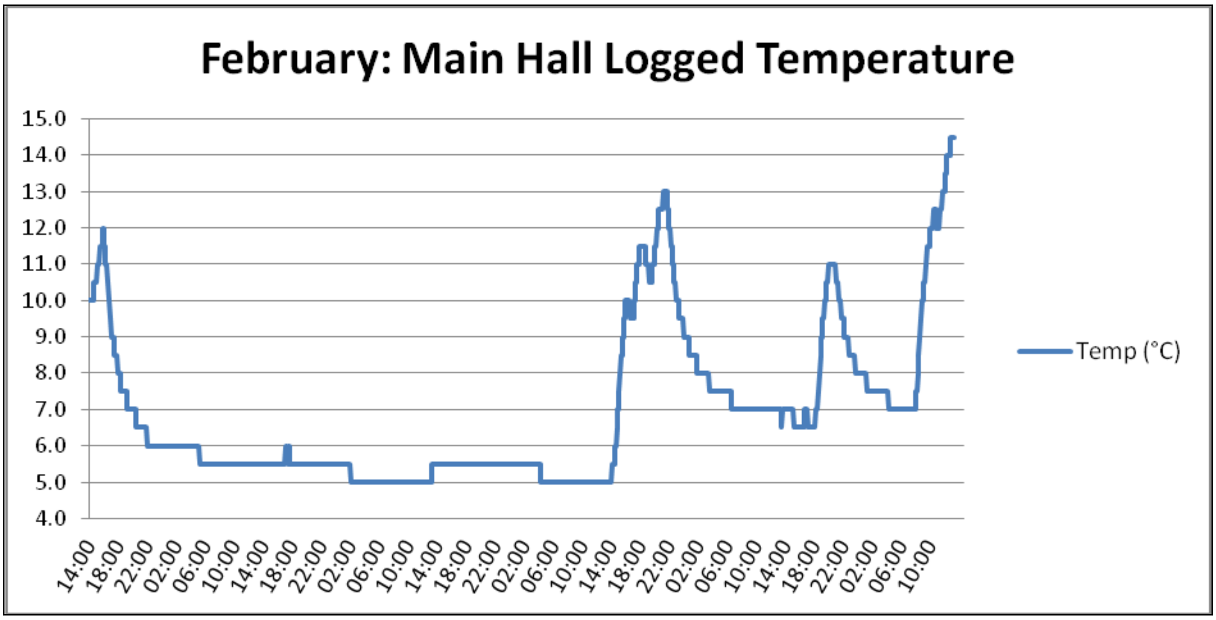


Figure 15 : Main Hall Logged Temperature

Without knowing the exact flow rates within the numerous legs of the new heating system it is impossible to say with certainty what the heat input to each of the three zones are thus closer analysis of the data is without merit.

Proving the ESP-r Model

The graphical output was used to help prove the ESP-r model that was developed in parallel with the monitoring work. This work would have been more robust had both the Hall Use Detail and the Actual Heat Inputs been available. Without such data only an indicative model could be produced for furtherance within this piece of work.

This highlights the difficulty and importance of rationalising a model and proving it as a correct representation of the building.

The start-point model within this study can only provide an 'indication' at best and attempts during modelling and simulation to match behaviours to reality cannot rectify the deficiency within the base model.

5. Building Modelling

5.1. Base Case 1 – Solid Stone Walled Building.

Figure 16 : Base Case 1 - Solid Walled Building

Building Description

A Solid walled church building built in 1868 in the buttressed box style with stugged (‘hammer and picked' to form a consistent pattern) stone surfaces as common from the mid 19th century. The building features a 1908 built extension of the same construction. (Gifford, 2007) (Historic-Scotland, 1)

The building is now a Community Centre run by a committee for the benefit of the local community. At the outset of this study the building was in need of routine maintenance and repairs to prevent further decline in the basic building fabric. It has a low usage rate as is typical of a RCB – it ranges between 7% and 15% during ‘busy’ school-term weeks.

The buildings electric heating system struggles to reach acceptable internal temperatures during the winter months and maintaining acceptable conditions is problematic and costly. It requires heating during the summer when hall occupants are not active ie: sitting down in a meeting.

Building Layout

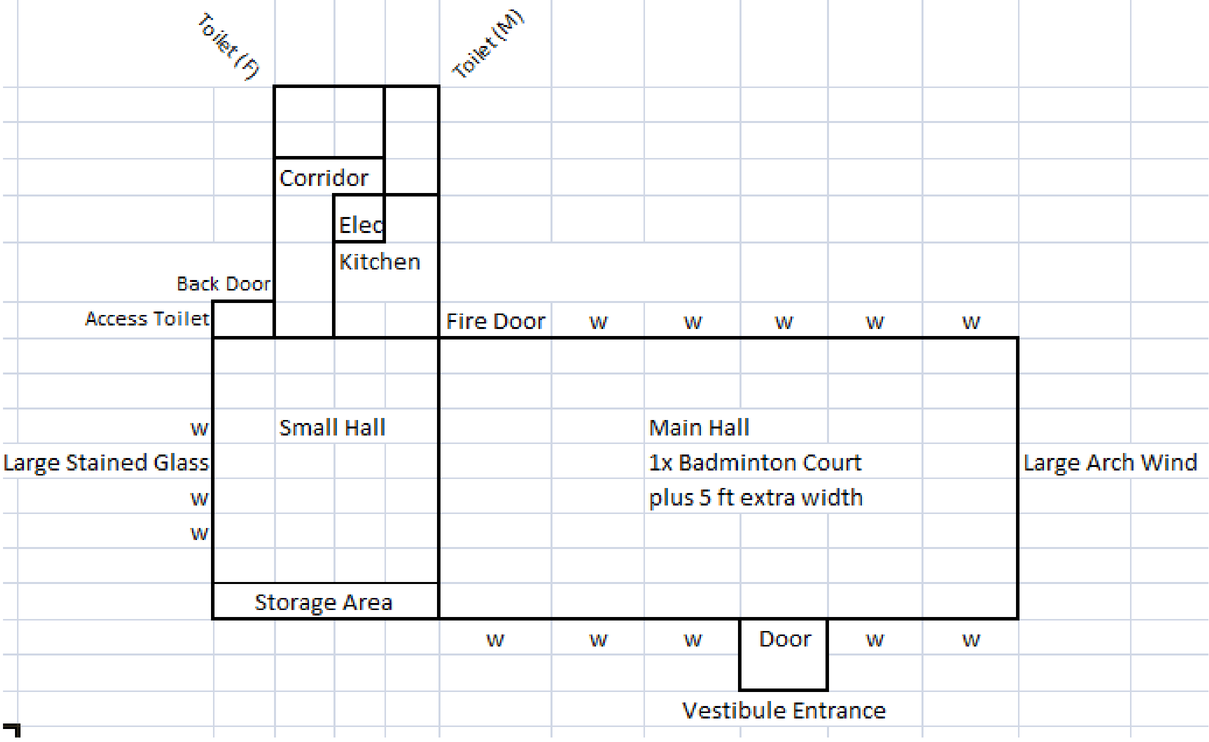


Figure 17 : Solid Walled Building Layout

All inhabited zones are on the same level: Main Hall, Small Hall and Facilities.

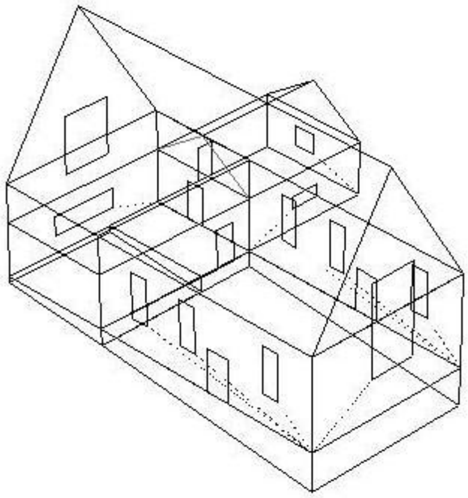


Figure 18 : Solid Walled Building ESP-r Model Wire Frame

Building Construction + Fabric Condition

Details of the construction of the Solid Stone Walled Building are available in Appendix – C.

The pictures in Figure 19 below highlight some of the maintenance issues reflected in the model.

Figure 19 : Base Case 1 - Outstanding Maintenance

Top-Left - Plywood shuttering sandwiching windows to prevent vandalism;

Top-Centre - Rotten wooden window with plastic sheet instead of glass;

Top-Right - Permanent air ingress/egress via broken extractor (one of two with same issue);

Bottom-Left - Stained-Glass-Window with no glass and crude boarding to interior;

Bottom-Right - Air ingress/egress through gap surrounding fire exit door (shown as sunlight entering darkened hall).

Not pictured issues include: Daylight visible between roof slates, insecure vent bricks, unsealed floor-to-wall junctions.

5.2. Base Case 2 – Wooden Building.

To broaden the study and reflect upon some of the more diverse building types found during the Local Community Building Survey; it was proposed to compose an additional model in ESP-r and run simulations that reflected the usage pattern of the second building type.

Figure 20 : Wooden Walled Building - Base Case 2

The building chosen was an ex-Military Wooden Hut as used post-WW2 in many military and national service situations in which they were used for many different purposes including both office and dormitory accommodation. Originally, the hut was used as an Air Force Training Corps building at a small airfield from where it was acquired, dismantled, transported and re-built on its present site by the local Church to act as a social space for their congregation and the wider village population. The initial re-build took place in 1974 and the hut was faithfully re-erected apart from a minor over-measurement when building the dwarf-wall foundation on which it sits – the mistake has been sensitively covered up with tastefully positioned sloped 'water shedding' timber which actually adds to the outward aesthetics and casts surface rain-water further from the brick foundation walls. In 1994 was extended in an outwardly similar style to the original two sections but additional insulation was added within the walls and double glazed windows have been added subsequently.

Building Construction + Fabric

The nature of the hut's construction is detailed in Appendix – C.

(Copyright: Google 2013)

Figure 21 : Aerial View - Base Case 2

Building Model in ESP-r

Detailed internal and external measurements of the building were taken and the model created with minimal deviation from the actual building so as to accurately reflect its energy performance. The actual bird's-eye view is shown in Figure 21 above along with the wire-frame model, below Figure 22, as built in ESP-r.

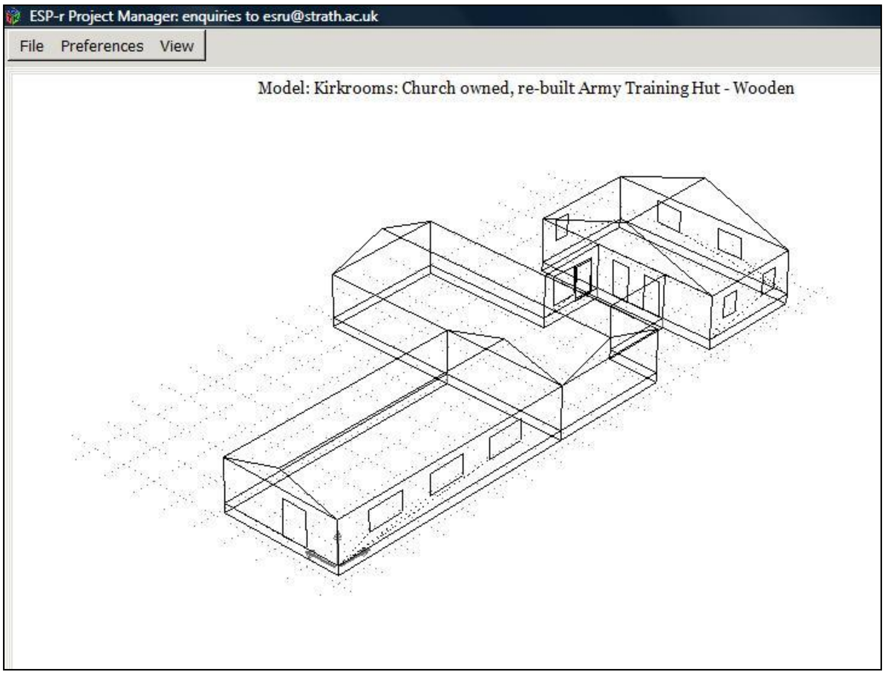


Figure 22 : ESP-r Model of Wooden Building

Having created the model with 3 zones to reflect the natural breaks in the building and the actual uses of the rooms the model stopped running within the ESP-r Simulator. With limited time available to debug the model it was decided to alter change the approach when no reason for the failure of the simulation could be identified swiftly.

Replacement Model

The second model was intended to act as a comparison to the Solid Stone Walled building used in the case-study. As the initial case study building's model was working within ESP-r Simulation Tool – a copy was made and altered with respect to construction and dimensions to be more closely representative of the Wooden Walled Hut in the second model.

This ultimately impacted the results analysis of the second building as:

(1) The model is not truly representative of the actual building, and

(2) Less time was available to run simulation scenarios.

The wire frame of the 'Replacement Model' is shown in Figure 23 below.

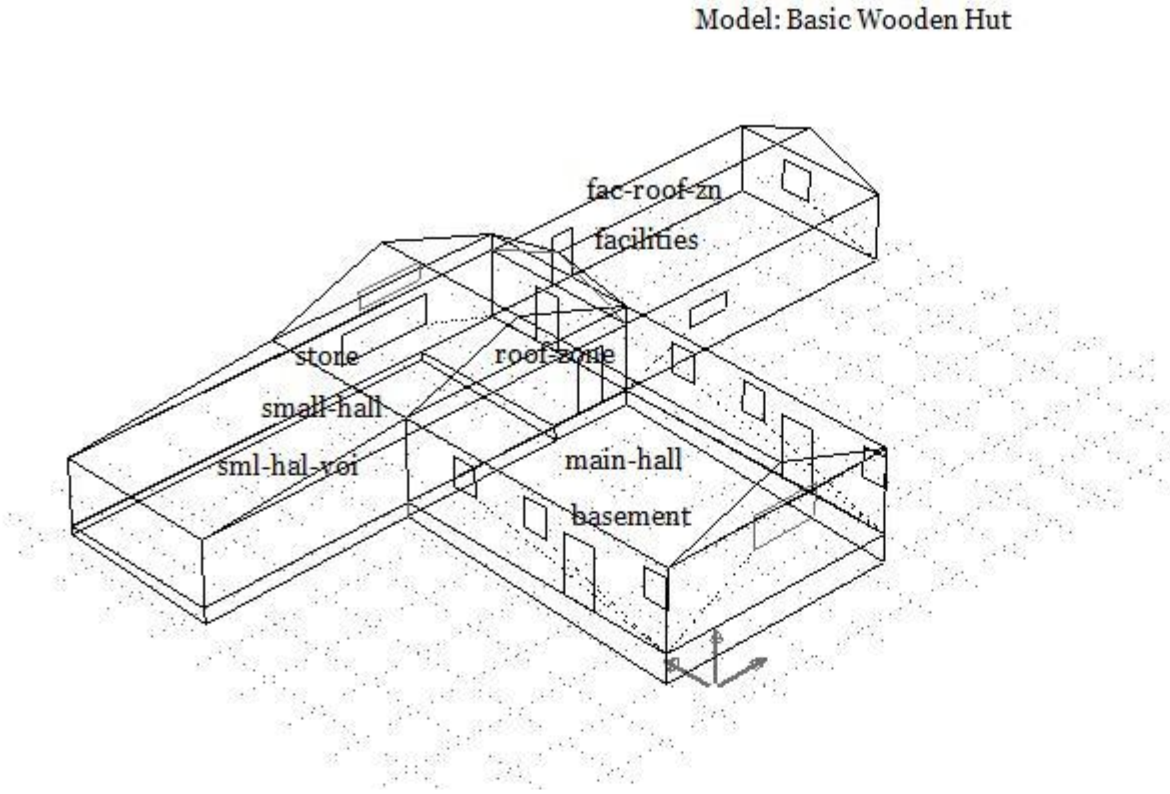


Figure 23 : ESP-r Wire Frame, Replacement Model.

Given the shortened timescale in which this model was created, the necessary simulations executed and required results gathered; several shortcomings had to be accepted:

- The solid floor was retained where a dwarf walled void exists in reality.
- The orientation of zones is not accurate with respect to one-another in reality.
- One apex roof is modelled as 'sloped-flat' although in reality as the slope is <20 degrees it would have been attributed as flat in ESP-r regardless of it being an apex.

- Some windows are visible in the wire frame but they defined with the same construction as the wall they are in as removing them threatened the stability of the model.
- There are fewer windows in the model than in reality.

The model features no material or construction shortcomings as all intended Constructions that had been added to the ESP-r Database were utilised.

Building Maintenance / Air-Tightness

The Wooden Hut has been maintained rigorously and there are no noticeable outstanding items requiring attention. Windows are all draft free and extraction vents are sealed properly when not in use. The roof spaces do not suffer from gaps allowing daylight to be seen unlike the Solid-Walled-Building. From these observations the initial Air-Tightness as been set as equal to the Upgraded Air-Tightness of the Solid Walled Case Study and no improvement will be made upon this during the modelling work and simulations.

Air Changes/Hour	
Facilities Roof Space	2
Facilities	1
Main Hall	1
Main Roof Space	2
Small Hall	1
Store above SH	2
Basement	5
Void below Small Hall	5

Table 10 : Air Changes applied to the Wooden Hut Model

Model Heating Regime

The model utilises the same Continuous Heating approach, 22degC with 14degC setback, as the Solid Walled Model. No data was available from the building as it is controlled manually by the caretaker according to weather predictions and expected building use with no concern for the cost of the utility bill due to the safe financial position of the building owners.
Thus; the mirrored approach provides the option of comparison between the modelled building types.

With the halls providing a venue for a wide variety of user groups from Mother and Toddler Crèches or Yoga which require room higher temperatures than exercise classes or sports such as badminton; it was prudent to model a higher temperature so as to be more representative of possible heating need and potential system capability levels. In reality, any minor over specification of heating at this stage would provide additional contingency for real-life scenarios and would be taken forward as a ‘working assumption’.

The simulation function within ESP-r allows for repetitive iterations to investigate the effect of changes to any one (or more) system settings or values. It is entirely typical for a ‘best initial guess’ to be used at the outset and for it then to be refined as the simulation section shows.

6. Simulation

6.1. <u>Base Case 1 – Solid Stone Walled Building</u>

The building is unoccupied throughout the **'Fabric Improvement'** stages.

STAGE 1:

A) Daytime Heating: Heated to 22degC between 0600 -2200
B) 24Hour Heating: Kept Heated to 22degC permanently
C) Daytime Heating with 14degC Setback between 2200-0600
D) As (C) with Loft Insulation
E) As (D) with Under Floor Insulation
F) As(E) with Improved Air-Tightness
G) As (F) with Internal Wall Insulation
H) As (G) with Double Glazing to Inhabited Zone Windows
I) As (H) with Secondary Internal Double Glazing to the Stained Glass Windows

STAGE 2:

Heating Setting Investigation

Reduced Temperature of 20degC with 10degC Setback when unoccupied. A 30% occupancy regime is assumed as per Appendix – C.

Gradual increased in Capacity of Heat Inputs to zones:

J) Main Hall: 10kW, Small Hall: 6kW, Facilities: 8kW
K) Main Hall: 12kW, Small Hall: 8kW, Facilities: 10kW
L) Main Hall: 14kW, Small Hall: 8W, Facilities: 10kW

6.2. <u>Base Case 2 – Wooden Building</u>

The building is unoccupied throughout the '**Fabric Improvement**' stages.

STAGE 1:

Continuous 22/14 Heating

The heating is set operate between 0800 and 2200 in order to maintain in-zone temperatures of 22degC Dry-Bulb temperatures between 0900 and 2200 with a 14degC Dry-Bulb Set-Back Temperature overnight between 2200 and 0800.

Continuous Heating with Loft Insulation

As above with an additional 300mm layer of Rockwool Loft insulation laid on top of the existing 100mm installed between the rafters throughout the entire building.

Continuous Heating with Loft + EPS under ALL Floors

As above with a layer 100mm layer of EPS installed beneath the plywood the floors of where the model has a below zone void rather than a solid floor.

Continuous Heating with Loft, EPS Floor + IWI

As above with additional sandwich of 50mm EPS and 13mm Plasterboard applied to the internal side of all external walls within inhabited zones.

STAGE 2:

Occupancy Investigation

The same occupancy regimes of 10%, 15%, 20% and 30% were applied as per Appendix – C.

6.3. Results Discussion

Benefit from Fabric Improvements

Solid Walled Building

Figure 24 below demonstrates the effect of the gradual implementation of the Fabric Improvements to the Solid Stone Walled Base Case Building. To highlight the impact of the improvements the Heat Load associated with the unimproved building is included. The challenges facing the building are clear when consideration is given to the building requiring around 4 times the heat of an Average Scottish 4 Bedroom Detached House (Sutherland, 2014).

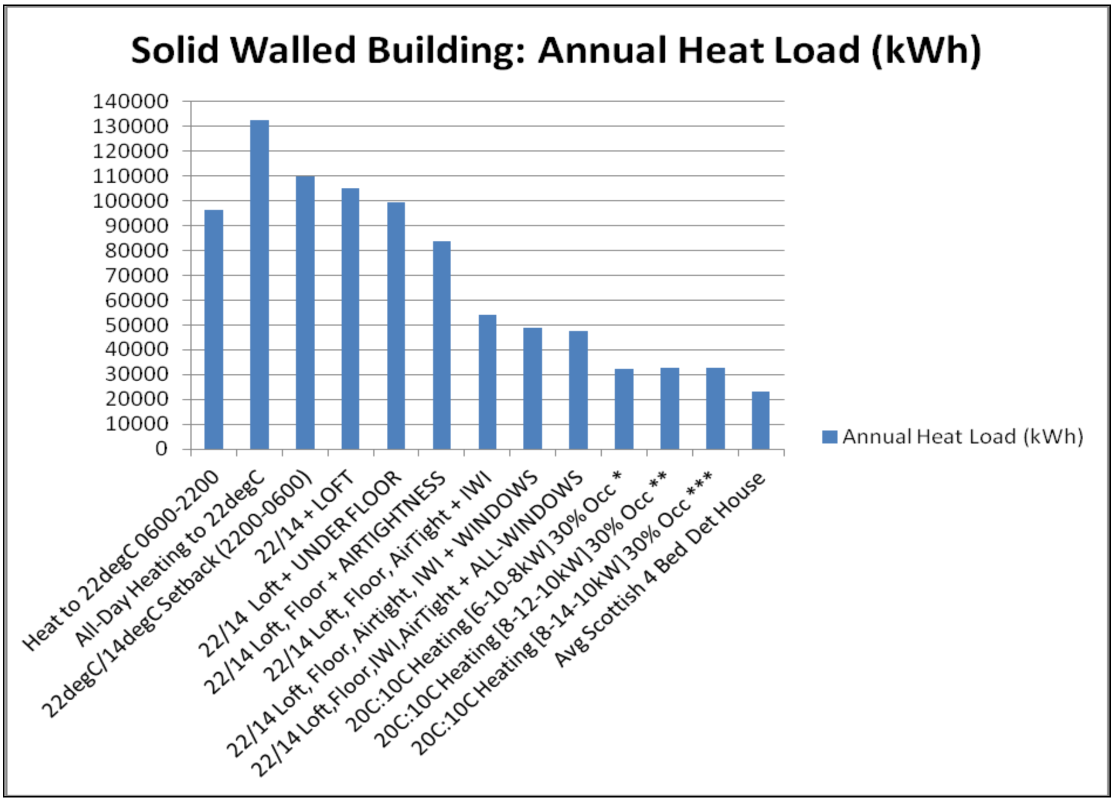


Figure 24 : Annual Heat Load reduction due to Fabric Improvements to Solid Walled Building.

Figure 24 summarises the Heat Load required by the building post-improvements and also reflects the investigation into the system settings that are required to allow the building's internal comfort conditions to be generally acceptable to the occupants.

Having iteratively increased the Maximum Heat Input to the Main Hall from 10kW through 12kW to 14kW - an improvement in the system's ability to achieve 20degC Db Temperature was observed as shown in Figures 25, 26 and 27 below.

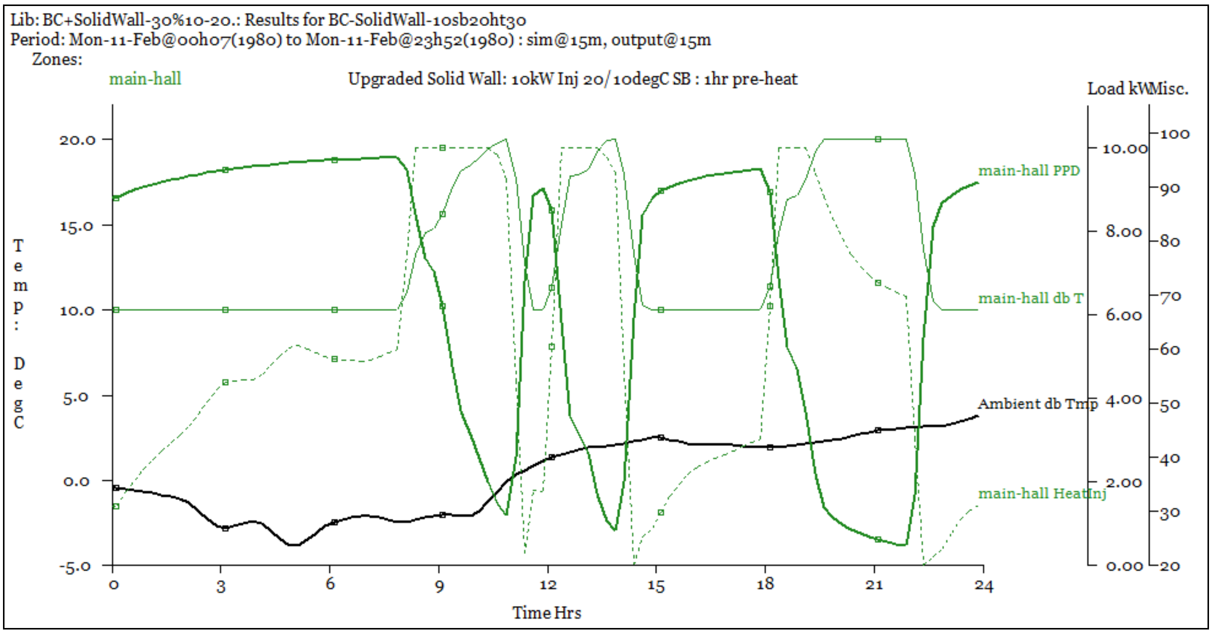


Figure 25 : Solid Walled Building- Main Hall: Heating 10kW to 20degC/10degC Setback

The prescribed 20degC is not attained until the end of the Occupied Period at 11am. Clearly this is unacceptable to occupants as the Percentage-of-People-Dissatisfied (PPD) indicates. Similar issues occur for the lunch period and, although less so, during the 7pm- 10pm period which has a greater Sensible Heat Load due to the occupants.

Simulating with 12kW Heating System Input shows a marginal improvement as shown below in Figure 26.

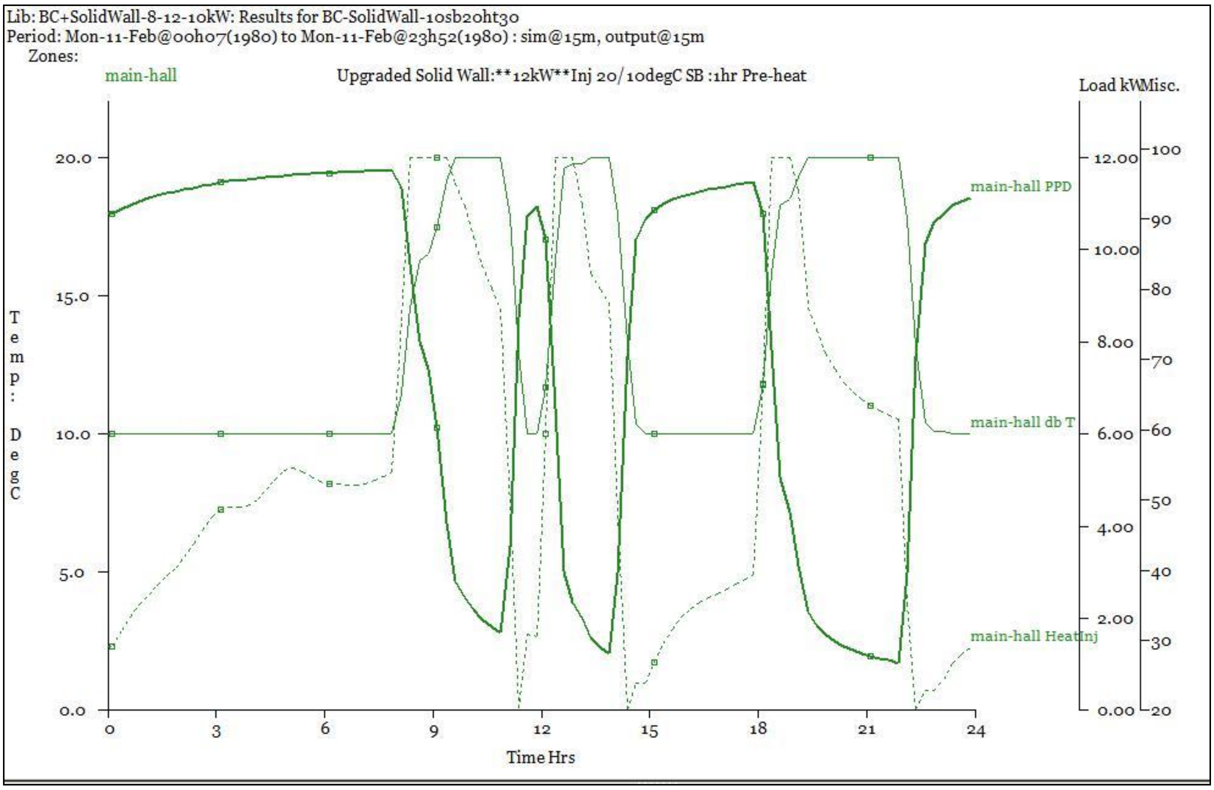


Figure 26 : Solid Walled Building: Main Hall: Heating 12kW to20degC/10degC Setback

A further increase to 14kW Heating System Input does not alleviate the problem as shown in Figure 27.

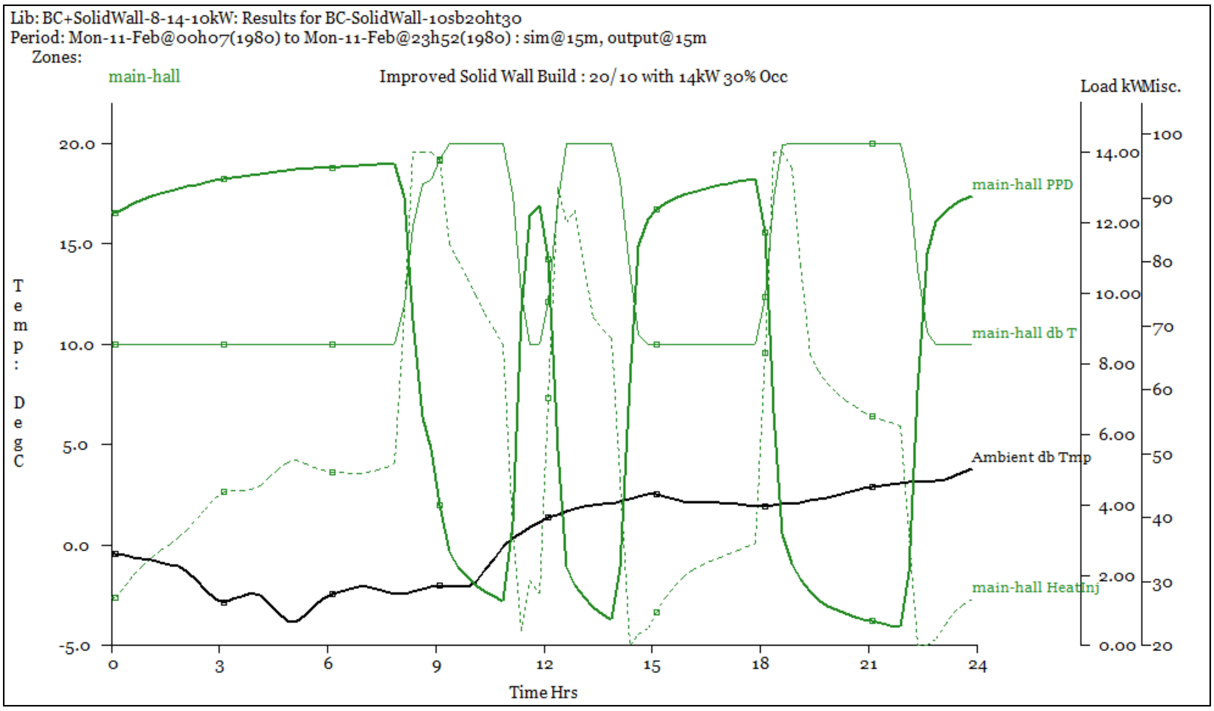


Figure 27 : Solid Walled Building: Main Hall: Heating14kW to 20degC/10degC Setback

Clearly the building's Thermal Mass requires either:

a) greater-still level of Heat Input

b) longer period of Heat Input, or

c) higher overnight set-back temperature.

Output from simulating a 14degC Setback Temperature proves the impact this has on comfort during occupied hours (0900-1100, 1300-1400 and 1900-2200) with Figure 28 showing the Main Hall Db Temperature being 20degC at the start of these occupation periods as hall users desire.

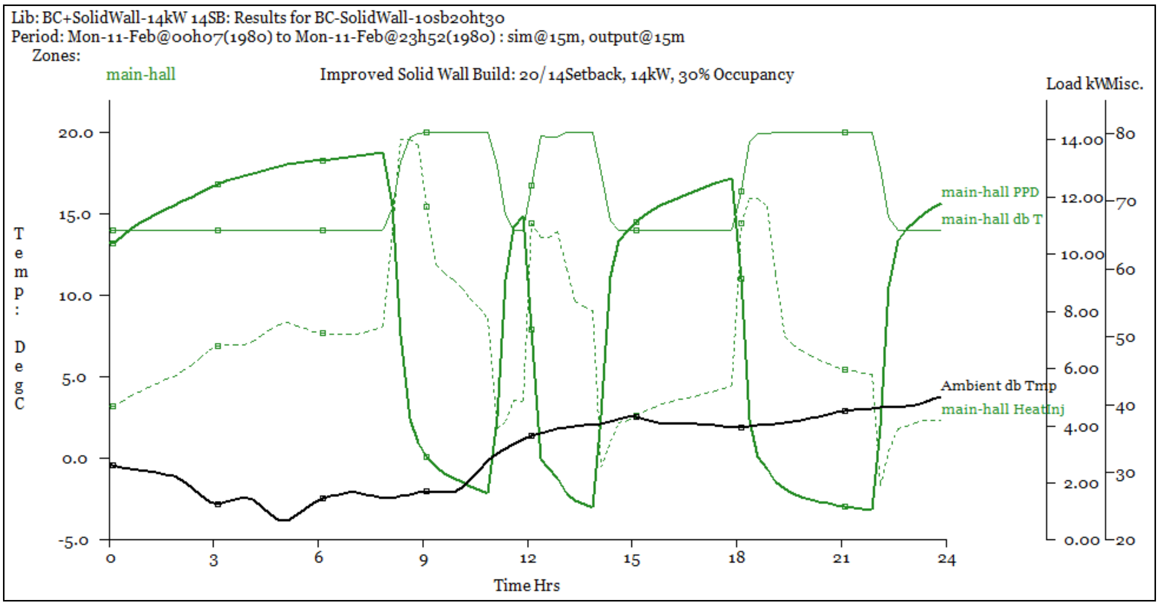


Figure 28 : Solid Walled Building: Main Hall: Heating 14kW to 20degC/14degC Setback

Such iterations highlight the value of simple building modelling and the ability to iteratively simulate performance under different conditions. The outputs of building efficiency and necessary building system capabilities are useful in the early design stages of buildings and building system design (BRE, 2014).

Wooden Walled Building.

The output from the Modelling of the Wooden Hut presents a similar picture. The benefit from the gradual application of the Fabric Improvements is depicted in Figure 29 below.

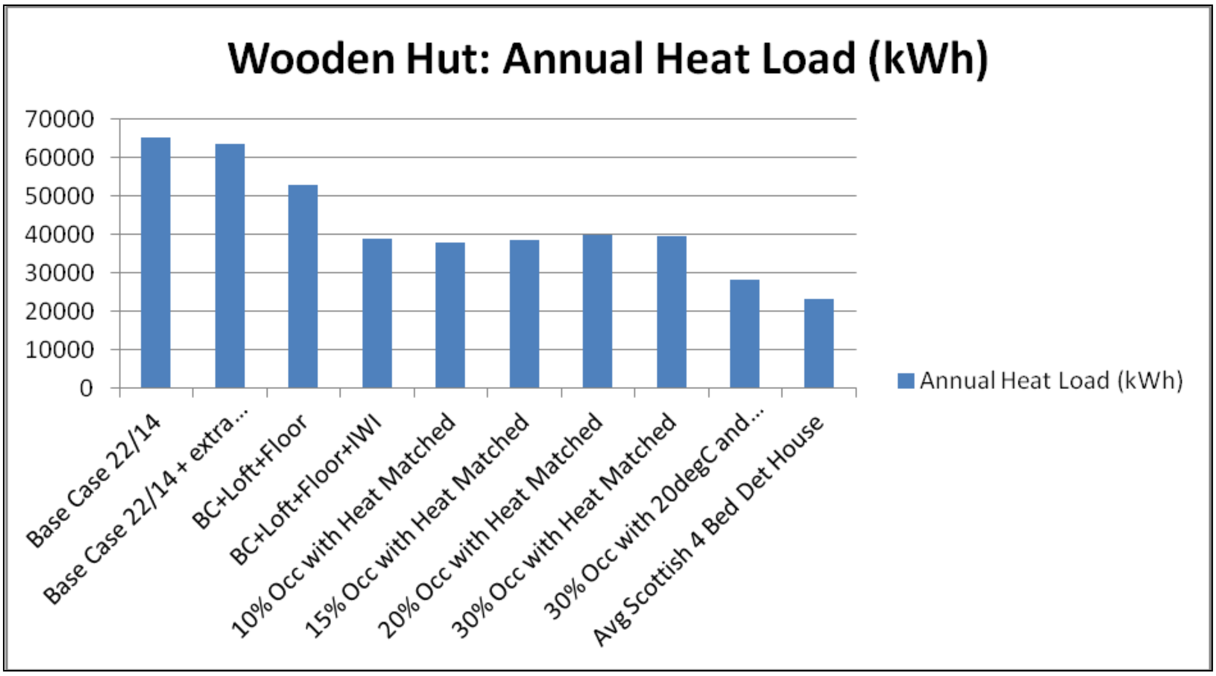


Figure 29 : Wooden Building: Annual Heat Load reductions due to Fabric Improvements

Seasonal Differences

Pursuing the same iterative approach to suitable system heating capacities and settings within the control system such as Zone Temperature it can be seen that the improved wooded building performs better during winter as depicted in Figure 30 below.

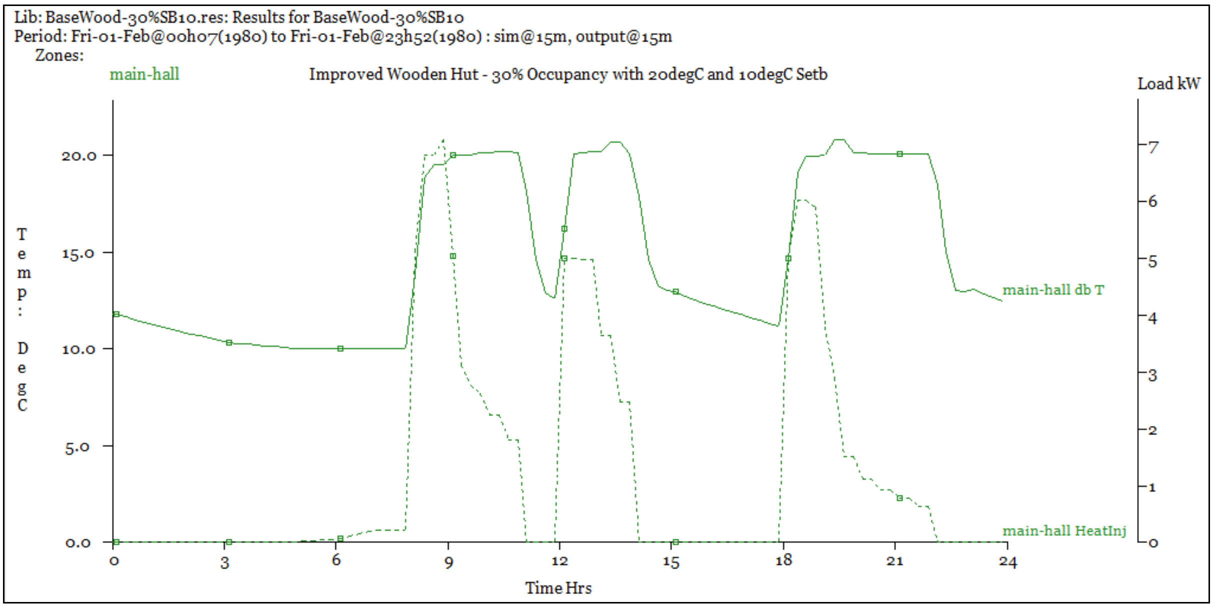


Figure 30 : Improved Wooden Building: Main Hall Heating 7kW to 20degC/10degC Setback

Compared with the Solid Walled Building there is no requirement to increase the SetBack Temperature or increase the capacity of the heating system to deliver a greater heat input to the zone, zones or building.

6.4. Base Load / Boost Load

For the Solid Walled Building the heat load across a simulated year is shown in Figure 31 below.

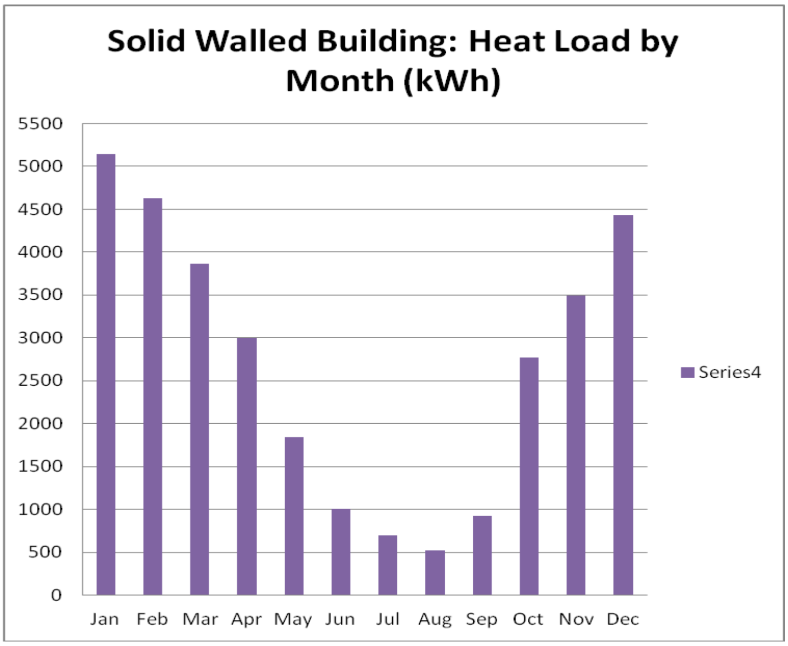


Figure 31 : Solid Walled Building: Heat Load by Month (kWh)

For the Wooden Walled Building the heat load across a simulated year is shown in Figure 32 below.

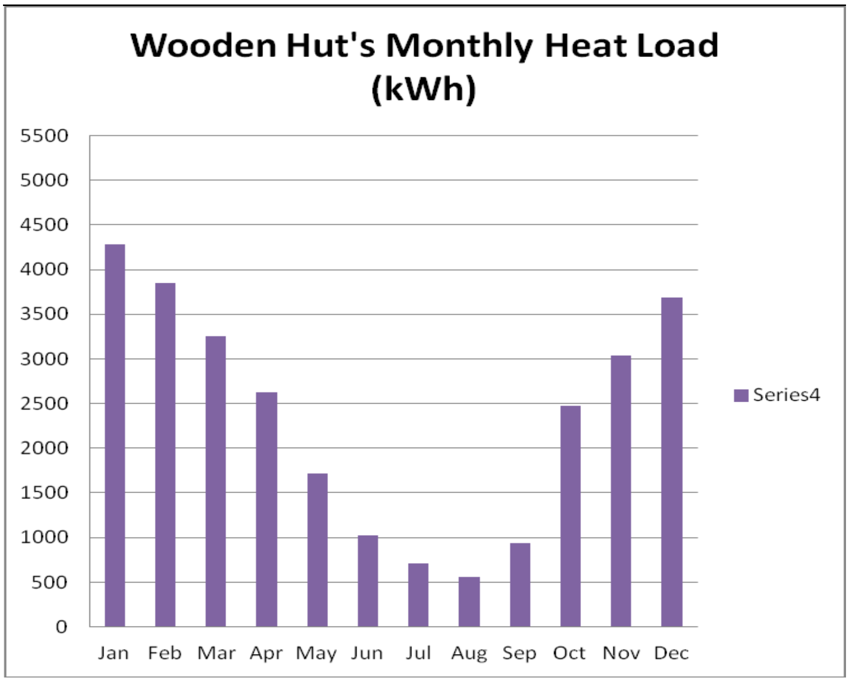


Figure 32 : Wooden Building: Heat Load by Month (kWh)

Figures 31 and 32 show the large seasonal difference and begin to highlight the opportunity for well-designed heating system solutions. Normally Base Load would reflect the demand exhibited in the summer months with 'Peak' demand met by a 'Boost' System. It is felt that is could be improved upon as the summer load is considerably lower than the winter load.

Using the Results Analysis Tool within ESP-r to closely interrogate the simulation data output it was possible to observe the frequency with which the Building's Heat Load was within known bands between 0 (zero) and the maximum for the building type. Graphically this is presented at Figures 33, 34 and 35 for the Wooden Building.

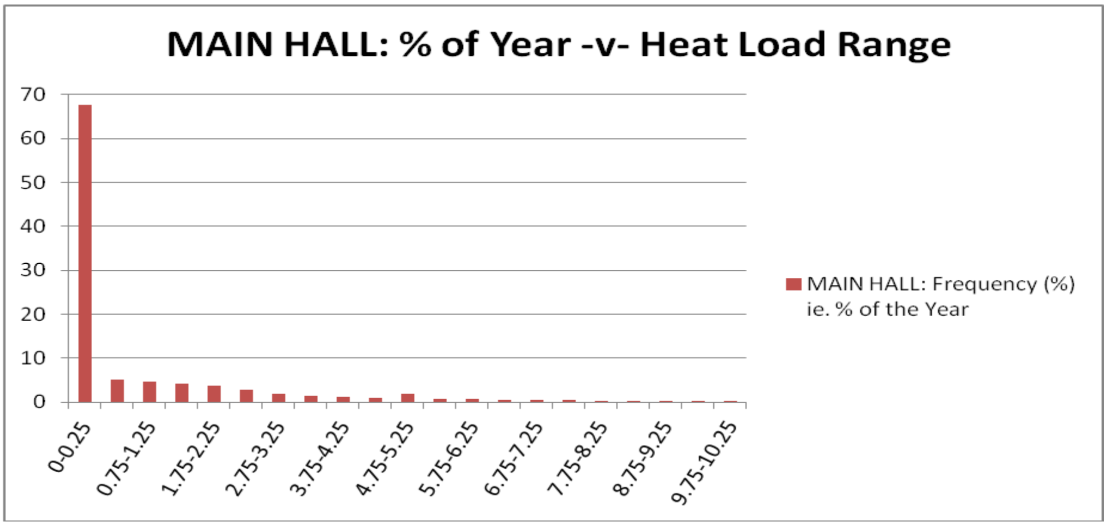


Figure 33 : Improved Wooden Building, Main Hall: (kW) Heat Load Range Frequency

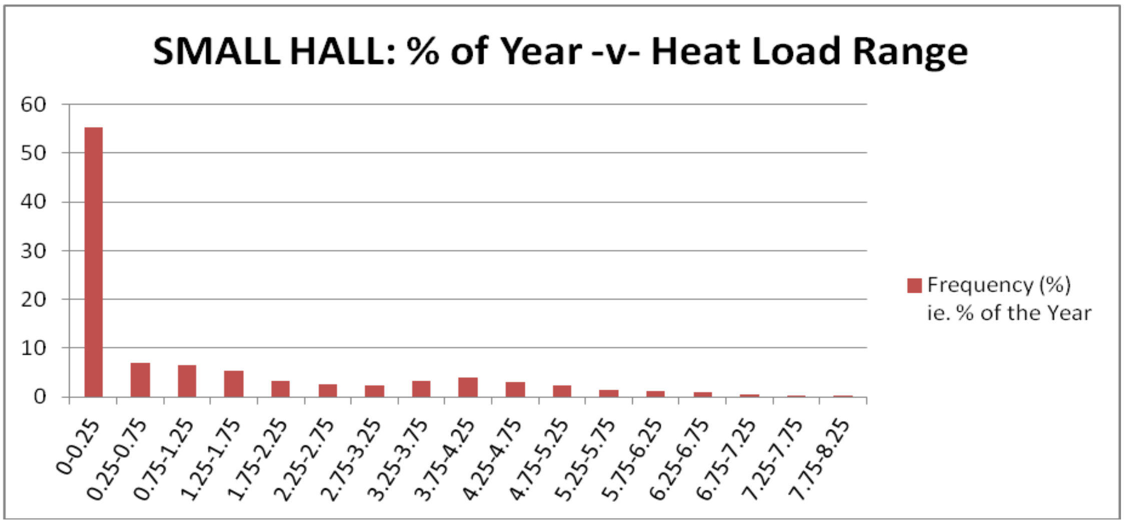


Figure 34 : Improved Wooden Building, Small Hall: (kW) Heat Load Range Frequency

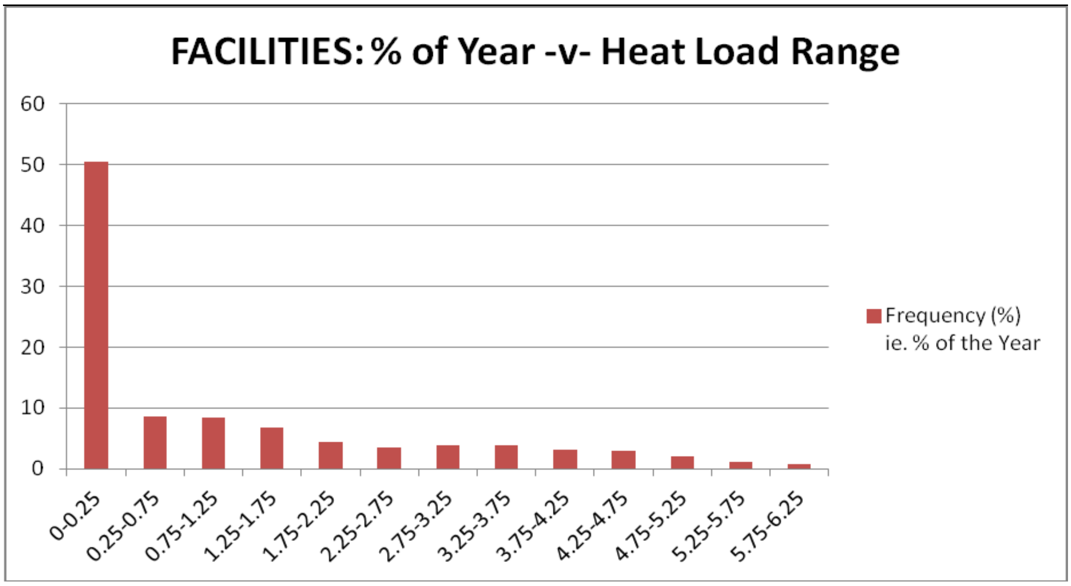


Figure 35 : Improved Wooden Building, Facilities: (kW) Heat Load Range Frequency

Using MS Excel identify the "%-of-the-Year" values that certain Heat Input are required – this was to related to possible Base Load and Boost Load capabilities that buildings required. Full detail is available at APPENDIX – C.

	TOTAL	TOTAL "WORST CASE"	
% of Yr	**BASE LOAD CAPACITY**	**BOOST CAPACITY**	% of Yr
70%	**2.75** kW	**22.0** kW	30%
80%	**6.25** kW	**18.5** kW	20%
90%	**10.75** kW	**14.0** kW	10%

Table 11 : Wooden Building Base and Boost Load Capacities for 30% Occupancy

The Worst Case Boost Capacities are based upon the Maximum Heat Inputs required for each zone ALL being required Simultaneously and is shown as the Sum of the 100% values for each zone in Table 13 (below) for the Wooden Building.

BASE LOAD CALCULATIONS (kW)

% of Yr	FAC	MAIN	SMALL			
Up to 70%	1.25	0.25	1.25	kW		
Up to 80%	2.25	1.25	2.75	kW		
Up to 90%	3.75	2.75	4.25	kW		
100%	6.25	10.25	8.25	kW	TOTAL CAPACITY	24.75 kW

Table 12 : Wooden Building, Total Heating Capacity (kW)

Ultimately, the Base Load is deducted from the 100% 'TOTAL CAPACITY' Heat Load to give the "Worst Case" Boost Capacity required to meet the Building's Heat Demand. Applying the same methodology to the Solid Stone Walled Building yielded the data in Table 14 below.

% of Yr	TOTAL BASE LOAD CAPACITY	TOTAL "WORST CASE" BOOST CAPACITY	% of Yr
50%	**3.13** kW	**22.0** kW	50%
70%	**6.63** kW	**18.5** kW	30%
90%	**11.63** kW	**13.5** kW	10%

Table 13 : Solid Walled Building: Base and Boost Load Capacities for 30% Occupancy

At this point a design team could move forward and select or design systems to meet both the Base Load and Boost Capacity. Assumptions and deficiencies highlighted within the work would have to be borne in mind as they may not be commercially acceptable risks.

This approach has driven out the % time within a year that each system (base or boost) would be required which is used as a key factor in the System Suitability Matrix to identify systems that are able to cope with short running spells, long periods on stand-by, give instant or near-instant heat injections to a building's zones and are reliable with minimal requirement for intervention.

7. Heating System Suitability Matrix

Having analysed the effect of Energy Efficiency measures and observed the ability to simulate the alteration of relevant system parameters to fine-tune the achievement of acceptable in-zone comfort levels within the improved building types the next natural step is to look at the suitability of different Heating System Technologies. With Conventional Gas and Electric Systems being used currently their continued use is relevant and included here alongside Renewable Heating Systems which are now readily available from mainstream suppliers and encouraged by the governments incentive schemes at the present time.

By analysing with respect to the provision of Base Load and Boost Load separately is key as a tandem approach is common when implementing a Renewable Technology due to it being prudent to design a system that incorporates a Conventional technology as a back-up. For carbon cost reasons, stated at the outset, it is prudent that buildings seek to utilise more Renewable or ‘Greener’ systems and it is at this point that RCBs have some data to assist them.

There are many possible solutions that would provide acceptable comfort levels in RCBs but some may be more suitable than others. This section aims to highlight the key factors, positive and negative, of Renewable Energy Systems that could be considered as options for the two RCB types investigated here.
This matrix remains generalised and without reference to particular manufacturers so as to encourage full and fair future investigations without bias at their outset.

7.1. System Suitability Matrix (SSM) Approach

Reflecting specifically upon the needs of RCBs and remaining mindful of the outputs from, and analysis of, the modelling and simulation work presented here including the required level of Base and Boost Loads that the Base Case Buildings exhibited in their post-Improvement states; each of the System Types has been rated against critical factors to gauge their ability to perform the required function.

The grading has been carried out in conjunction with widely available documentation provided by:
Carbon Trust, Energy Saving Trust, Ofgem, The Combined Heat and Power Association, The UK Government, The Scottish Government, The Biomass Energy Centre, Changeworks, Historic Scotland
Upon summation of the individual ratings the systems wider suitability is reconciled along with any issues, concerns or points worthy of note. The matrix focuses upon the challenges facing RCBs specifically and features key decision points and affecting factors important, arguably critical, to RCB decision makers.

The colour scheme, explained below, provides a simple effective comparable visual indication of potential suitability or unsuitability.

7.2. SSM Key

The Ratings given to each system type follow the scale below.

The summation of the ratings has been given a Traffic-Light colour grade to reflect upon the STOP-GO nature of the decision making process that a Suitability Matrix would feed into. The colours are explained below.

Rating Scale:	Y = Strong Yes	y = Yes	n = Partial No	N = Definite No
Colour Code:	Not Suitable	Less Suitable	Possibly Suitable	Suitable

Table 14: System Suitability Matrix Key.

7.3. RCB Heating SSM

SYSTEM TYPE:	Biomass: Log	Biomass: Woodchip	Biomass: Pellet		ASHP	GSHP		ELEC Storage (o/n charge)	ELEC Panel		Mains Gas	LP Gas	mCHP (Gas)	Oil Fired CH
Use:														
BASE LOAD (including any concern)	Manpower							Control	Cost			Cost		Cost
BOOST LOAD + BASE LOAD	Manpower							Control	Cost			Cost		Cost
BOOST LOAD Stand-Alone	Manpower							Control	Cost			Cost		Cost
RCB Decision Making:														
Rural Community Building Specific - Top Issue (Financial as Fuel Cost is RCB's no.1 Issue)	Lower Run Cost	Med Run Cost	Med Run Cost		Lower Run Cost	Lower Run Cost		High Run Cost	High Run Cost		Med Run Cost	High Run Cost	Med Run Cost	High Run Cost
Rural Community Building Specific - Other Factors	Manpower	Space	Space		Knowl-edge + Space	Knowl-edge + Space		Occupancy v Operating Regime	Install		Install	Install	Occupancy v Operating Regime	Install

Table 15 : Rural Community Buildings Heating System Suitability Matrix (Summary)

Refer to Appendix D for the complete SSM with the low level ratings that combine to give the Summary above.

7.4. SSM Discussion

It is clear from the numerous caveats included within the individual ratings sections that there are many unique points that must be borne in mind when analysing the capability of a system to meet the requirements being placed upon it. Best practice during all stages of a systems life must be followed: research, requirement gathering, actual need definition, natural resource availability investigation, physical system design, control system design, system integration, install, commissioning, operator training, maintenance and monitoring with the ability feedback and revisit stages, such as control and operation, which can affect future performance.

Having summed the individual ratings and independently graded the systems it is clear that some are more suitable than others. Fuel Cost or Utility Bill Cost are the negative (or partial negative) aspect of Conventional Electric and Oil Fired systems but the financial outlay associated with changing to an alternative system(s) may prove prohibitive for a RCB who may find that the Energy Efficiency measures have considerably reduced their Fuel spend therefore alleviating the financial pressure. Obviously with any increase in conventional energy prices the RCB may have to re-visit the decision in the future and embrace an alternative heating system.

One typical issue with RCBs is the proximity to the Natural Gas Grid and a connection to it in instances where it is near-by. Typically, off-gas-grid buildings are heated by LP Gas, Oil or Electricity which are all more costly than Mains Gas (ChangeWorks, 2009). The SSM rates alternative systems in such situations and highlights the potential issues with typical implementations of each technology. There are negative aspects to most systems eg: Biomass systems require fuel stores that a building may be unable to accommodate or GSHP that requires a collection loop that cannot be accommodated in the available surrounding landscape; but in most cases a more suitable alternative will be available.

Looking specifically at systems to provide the necessary Boost Load capability it is observed that there is a trend for them being either:

a) Conventional Fuelled; or
b) An alternative system sized to provide both Base and Boost.

The former carries the advantage of being a Back-up system in the event of the alternative being unavailable where-as the latter places more reliance upon the alternative system being resilient, correctly sized, well-managed, monitored, controlled and/or operated in order that it performs to designed specification and is able to meet all the demands placed upon it. Failure at any stage will risk the ability to deliver the required heat load and with no alternative system as back-up it will render he building unfit for occupancy due to the lower than acceptable temperature.

Heat Pumps present an interesting dilemma for RCBs. Part of this study has attempted to leverage some detail surrounding the Occupancy Regimes of a RCB that typically present the heating need as near random . With the lower occupancy rates and non-continuous hire patterns it is difficult to justify a continual heating input to a building. Typically a Base Load reflects the background heating (Carbon-Trust, GSHP) need that is required across all seasons but in this study it has been thought of as the level of heat load that is required up to a defined percentage of the year with the Boost Load being the remainder up to the theoretical maximum that the building could ever need. This skews the size of the Base Load to be larger than that typical of the Seasonal approach but it challenges systems to be able to run at lower heat levels and store (or accumulate) heat for use in meeting spikes in demand while the system increases its output to replenish the store and output more in the immediate future. Heat pumps have this capability and through careful user control (based on knowledge of forthcoming occupancy) plus integration with heat stores, collection loops and in-zone monitoring it is possible to achieve the higher Base Load level before relying upon a Conventional Boost Load system.

From the Solid Walled and Wooden Walled Case Studies it was observed that the necessary Base Load for 70-80% of the year was approximately 7kWthermal – this value is within the capability of both GSHPs as well as ASHPs in the modelled climate as proven via the Merit Tool thus a well designed and executed system should be more than capable of delivering this heat load.

The ability to correctly operate and control the running of a system is vital and with many RCBs having no access to knowledgeable persons this can present a formidable challenge to RCB Committees and Trustees which may sway suitability decisions away from alternative systems with them retaining allegiance with the conventional systems or fuels that they have experience of. Education and awareness (broadening) site visits could be employed to help increase their exposure to alternative technology. Seeing it working in a similar environment/role may reduce any fear or doubt about it being suitable and capable of meeting their needs. Once selected, installed and commissioned there will be a requirement for Operator Training, set up of a system monitoring routine plus an initial and on-going support package similar to that provided routinely for Conventional Boilers. (Carbon-Trust, 2011)

The SSM considers, in broad simple terms, the financial aspects of changing heating systems. There are many environmental regulations such as the Clean Air Act (1993) (Govt, 1993) rules and eligibility criteria that make a detailed study unsuitable at this junction. Indeed, with regulations changing over time it is impossible to compile a definitive picture of available incentives, funding, grants, tariffs, loans or government sourced cash-back offers. Instead it is felt best to advise interested parties to consult the Ofgem website for the latest information. Presently the FIT and RHI schemes offer financial reward where qualifying systems are installed and operated within the scheme rules which may make such systems viable and a worthwhile option for the RCB to consider.

The take-up of alternative technology systems is being actively encouraged with Historic Scotland indicating that a buildings Traditional nature or Listed Status should not be a barrier to the adoption of modern renewable or alternative systems (ChangeWorks, 2009) (Historic-Scotland, 2011b) . The SSN developed here aims to highlight the available options and show the potential issues that may be encountered.

8. Conclusion

8.1. Modelling and Simulation

Being able to create a model and gradually introduce heat conserving materials or fabric improvements allows a comparison to be made between a selection of measures as has been seen here. Separate work could accompany this and give greater insight through cost-benefit analysis of each of the measures. Ultimately it is possible to generate a model that reflects the 'ideal' suite of improvements and use that to simulate the likely heating requirements.

Having the ability to repeatedly run simulations with different heating strategies gives the ability to research what capacity a system in such a building would need to have – this highlights a typical function that modelling can have at an early design stage where building fabric is being decided upon.

The heating regime that would most benefit the building could come from either:

(a) higher capacity for heat injection (Boost Load Capacity); or

(b) higher SetBack temperature delivered by Base Load System.

The former would provide a degree of contingency in normal situations as well as future proofing subsequent developments such as opening up additional space within the building or adding a small extension which would have to meet modern building regulation standards.

The latter, if not used sensibly, ie. different levels across different seasons or actively linked to the Ambient Outside temperature, has the potential to increase running costs if not managed correctly. Given the findings of the (Scottish-Govt, 2007) where inexperienced persons are running local RCBs; there is a chance that complacency will result in manual alterations to the setback level NOT being made.

The thermal response of the building to a heat-injection will input into the nature the potentially suitable heating systems (single or twin element, ie. solely mains gas boilers or a combination of heat pump + gas fired boiler).

Close scrutiny of the results sets will identify occasions where over-heating occurs. From this it is possible to detail the level of need for air extraction or air conditioning. Depending upon the nature of the building's design it may be possible for the users to self-regulate through opening windows but this is not always possible as observed in Solid Walled Base Case where windows are boarded over or in locally surveyed buildings where large secondary glazing units are in place making it difficult for building users to access open-able windows.

8.2. Base and Boost Load Analysis

The work here presented a different viewpoint compared to the traditional approach of Base Load being the 'Minimum Load Required at All Times of the Year'. Where occupancy rates are low due to the building being unoccupied for days, possibly weeks, at a time there is no practical need for heating. It aimed to investigate the time extent, or '% of year', which the Boost Load is required in these buildings as the low occupancy rate would suggest that constant base-load may be unworkable and that a larger Boost Load capability would be required to quickly lift the internal temperature.

The SSM analysis links to this as system characteristics make them more or less suitable for providing as Base or Boost loads.

Fuller analysis of the building's situation would be required and access to the following was available:

i. More certain Occupation Regime for a building – if that is possible for a RCB
ii. Correct Climatic Data for model verification
iii. Detailed Building Construction Information
iv. The need for Cooling – so to control systems and prevent this

8.3. Heating System Suitability

The SSM presented focuses upon the needs of RCB making it non-generic. The traditionally accepted route of Reduce, Conserve, Understand, Apply measures *before* considering replacing a Heating System should be followed. The modelling seen here assists in that journey although it does require an element of specialist knowledge that places it outside of the RCB committee members themselves hence professional advice will be required in a real life situation.

9. Future Work

Two main directions exist for future work.

1. Revisit the Fabric Improvement and Energy Efficiency Measures to study their effect in more detail with emphasis on the health of the building fabric eg: avoiding Interstitial Condensation, Cold Bridges and other typical problems associated with retro-fitting energy conservation measures in buildings.

2. Focus on studying the performance of Alternative Heating Systems based upon Heat Pumps and Biomass technology to assist building knowledge of their operating regimes in Low Occupancy buildings.

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APPENDICES

11. APPENDIX A - Rural Community Building Survey

SURVEY QUESTIONS:	BUCHLYVIE	KILLEARN	BALFRON	KIPPEN
Building Construction/Materials	Solid Stone Wall, Slate roof	Solid Stone Wall, Slate roof	Steel Frame + Blocks	Solid Brick
Has it been extended?	Y, old	Y, new	N	N
If Yes, Extension Construction/Materials	As above	Modern Efficient		
What fuel is used for heating?	Electric - Storage Heaters	GSHP, Gas Back-up+Boost	Gas	Oil
When was the heating system last changed?	Additional Radiant heaters	2010's	Mid 1990s	Unsure, was Coal
Why was it changed?	Additional Radiants, to heat hall quickly	Redeveloped Building	Mains Gas Available	Automatic System
Are you concerned by cost the Heating the building?	Yes, it is a large % of the running cost.	Y	N, can pay bills	Y
Have you investigated any alternative type of heating?	N	Y	N	Y
Have you taken steps to:				
upgrade the building fabric	N	Y, Secondary Glazing	Y, EWI+Render	N
Reduce Drafts	Y	Y	Y, Double Glazing	Y, curtains + Paint
Install Insulation	N	Y, Loft, Floor, IWI	Y, Loft Insul	Y, Part Under Floor
Would the hall benefit from more/regular maintenance?	Y	N	Y	Y
Would this be difficult to fund?	Y	N	N	Y
Hall Maintenance is done by Who?	Council + Volunteers	All except Council	All except Council	All except Council
Have you considered Renewable Energy system?	N	Y	N	Y
If yes, did they go ahead?		Y		N
If yes but did not proceed - what was the largest issue?	Finance			Grants unavailable
Hall Use Rate	7%	7-30%	20%	10%
Online Booking Diary	N	Y	N	N
Could the hall be utilised more?	Y	Y	Y	Y
What stops it being used more?	?	Local Alternatives	Local Alternatives	?
Have you lost a group to another local building?	Yes	Y	Y	N
If yes, why did they move?	Business	Business	Space	
(Business Decision/Hall Condition/Space)				

SURVEY QUESTIONS:	FINTRY	STRATHBLANE (Case-Study)	VILLAGE CLUB	ARNPRIOR (*)
Building Construction/Materials	Stone+ Slate	Wood + Metal Sheet	Stone, Brick, Tile	Parts Wooden+ Flat Roof, Parts Stone + Slate Roof
Has it been extended?	N	Y	N	N
If Yes, Extension Construction/Materials		As above		
What fuel is used for heating?	Electric	Electric	Gas	Elec
When was the heating system last changed?	2012	Never	Unknown	Never
Why was it changed?	Old system ineffective		Modernise	
Are you concerned by cost the Heating the building?	Y	Y	Y	Y
Have you investigated any alternative type of heating?	Y	Not yet	N	N
Have you taken steps to:				
upgrade the building fabric	N	Y	Y	N
Reduce Drafts	Y	Y	Y	Y
Install Insulation	N	Y, Loft + Floor	Y, Floor + Loft	N
Would the hall benefit from more/regular maintenance?	Y	N	Y	Y
Would this be difficult to fund?	Y	N	Y	Y
Hall Maintenance is done by Who?	All	Committee, Volunteers, Trades	All except Council	Trades
Have you considered Renewable Energy system?	Y	Y	N	N
If yes, did they go ahead?		On-going		
If yes but did not proceed - what was the largest issue?				
Hall Use Rate	< 5%	11%	10%	50%
Online Booking Diary	N	N	N	N
Could the hall be utilised more?	Y	Y	Y	N
What stops it being used more?	Local Alternatives	Local Alternatives	Local Alternatives	
Have you lost a group to another local building?	Y	N	Y	N
If yes, why did they move?	Heating		Space	
(Business Decision/Hall Condition/Space)				(COMMERCIAL BUSINESS SHARES BUILDING)

SURVEY QUESTIONS:	GARTMORE	PORT OF M
Building Construction/Materials	Stone + Slate	Block + Render
Has it been extended?	2014	1990s
If Yes, Extension Construction/Materials	Modern	As above
What fuel is used for heating?	Heat Pump	Elec
When was the heating system last changed?	2014	Never
Why was it changed?	Modernise	
Are you concerned by cost the Heating the building?	N	Y
Have you investigated any alternative type of heating?	Y	N
Have you taken steps to:		
upgrade the building fabric	Y	N, except windows
Reduce Drafts	Y	Y
Install Insulation	Y	N
Would the hall benefit from more/regular maintenance?	Y	Y
Would this be difficult to fund?	N	Y
Hall Maintenance is done by Who?	Trades	All except Council
Have you considered Renewable Energy system?	Y	N
If yes, did they go ahead?	Y	
If yes but did not proceed - what was the largest issue?		
Hall Use Rate	7%	< 5%
Online Booking Diary	Y	Y
Could the hall be utilised more?	Y	Y
What stops it being used more?	Functions	Parking
Have you lost a group to another local building?	N	Y
If yes, why did they move?		Parking
(Business Decision/Hall Condition/Space)		

12. APPENDIX B - Simulation Data

12.1. Hall Use - 30% Occupation.

TIME	MON	TUE	WED	THU	FRI	SAT	SUN
0800							
0830							
0900	Under-5s Group 10 Ad + 10 Ch	Tennis	Under-5s Group 10 Ad + 10 Ch	KeepFit	Under-5s Group 10 Ad + 10 Ch	Plant Sale	
0930	Under-5s	Tennis	Under-5s	KeepFit	Under-5s	Plant Sale	
1000	Under-5s	Tennis	Under-5s	KeepFit	Under-5s	Plant Sale	
1030	Under-5s	Tennis	Under-5s	KeepFit	Under-5s	Plant Sale	
1100							
1130							
1200							Wedding
1230							Wedding
1300	Lunch Club	Lunch Club	Lunch Club	Lunch Club	Lunch Club		Wedding
1330	Lunch Club	Lunch	Lunch Club	Lunch Club	Lunch Club		Wedding

		Club					
1400						Fitness	Wedding
1430						Fitness	Wedding
1500						Fitness	Wedding
1530						Fitness	Wedding
1600						Birthday	Wedding
1630						Birthday	Wedding
1700						Birthday	Wedding
1730						Birthday	Wedding
1800						Wed Prep	Wedding
1830						Wed Prep	Wedding
1900	Wk1+2 = Cubs (Term only) -OR- Wk 3 = WRI	Aerobics	M.Lodge	Scouts (Term Only)	Occ. Event	Wed Prep	Wedding
1930	Cubs / WRI	Aerobics	M.Lodge	Scouts	Occ. Event	Wed Prep	Wedding
2000	Cubs / WRI	Zumba	M.Lodge	Scouts	Occ. Event		Wedding
2030	Cubs / WRI	Zumba	M.Lodge	Scouts	Occ. Event		Wedding

2100	Cubs / WRI	Circuits	M.Lodge	Scouts	Occ. Event		Wedding			
2130	Cubs / WRI	Circuits	M.Lodge	Scouts	Occ. Event		Wedding			
2200										
Summary								USAGE		
Periods								TOTAL		
Used	12	12	12	12	12	16	20	96	1/2hour periods	
Hours	6	6	6	6	6	8	10	48	Hours	Max=168
								29	% of Week Used	

Notes:

Usage rates as low as 7% during non-school terms were reported during the study.

The weekend occupation detailed above is NOT TYPLICAL of an unimproved building.

The simulations within this work used 10%, 15%, 20% and 30% occupation rates. The rates <30% did not reflect the hall being unused for several consecutive days due to limitations within the model set-up.

12.2. Hall Use - 10% Occupation.

TIME	MON	TUE	WED	THU	FRI	SAT	SUN
0800							
0830							
0900	Under-5s Group 10 Ad + 10 Ch	Tennis	Under-5s Group 10 Ad + 10 Ch	KeepFit	Under-5s Group 10 Ad + 10 Ch		
0930	Under-5s	Tennis	Under-5s	KeepFit	Under-5s		
1000							
1030							
1100							
1130							
1200							
1230							
1300							
1330							
1400							
1430							
1500						Fitness	
1530						Fitness	

1600						Birthday Party					
1630						Birthday Party					
1700											
1730											
1800											
1830											
1900	Wk1+2 = Cubs -OR- Wk 3 = WRI	Tennis	M.Lodge	Scouts (Term Only)	Occ. Event						
1930	Cubs / WRI	Tennis	M.Lodge	Scouts	Occ. Event						
2000	Cubs / WRI	Tennis	M.Lodge	Scouts	Occ. Event						
2030	Cubs / WRI	Tennis	M.Lodge	Scouts	Occ. Event						
Summary								USAGE			
Periods								TOTAL			
Used	6	6	6	6	6	4	0	34	1/2hour periods		
Hours	3	3	3	3	3	2	0	17	Hours	Max=168	
								10	Percentage of Week Used.		

12.3. Occupant Heat Inputs.

Simulations ran with Occupant related Heat inputs based upon the data displayed below. The Convective:Radiative ratio was 9:1.

Existing Activities

Group	Scouts	WRI	Cubs	Under-5s	Tennis	Dance	Badminton	M-Lodge
People	25	20	20	20	15	20	10	20
Exercise	35%	0%	35%	50%	4	15	4	0
Walking	35%	10%	35%	20%	2	4	1	0
Sitting	30%	90%	30%	30%	9	1	5	20
Exercise o/p	3500	0	2800	4000	1600	6000	1600	0
Walking o/p	1750	400	1400	800	400	800	200	0
Sitting o/p	750	1800	600	600	900	100	500	2000
TOTAL Output (Watts)	6000	2200	4800	5400	2900	6900	2300	2000

HEAT OUTPUT KEY		
Sleep	70	Watts
Sitting	100	Watts
Waking	200	Watts
Exercise	400	Watts

(ASHRAE, 1997)

Extra Activities										
	Fitness Class	Small Keep Fit	Disco	Beer Fest	Film Night	Breakfast	Lunch	Plant Sale	Meeting	Birthday Party
People	25	5	100	120	100	15	20	30	10	40
Exercise	25	5	50	5	0	0	0	0	0	10
Walking	0	0	20	40	2	1	2	20	1	15
Sitting	0	0	30	75	98	14	18	10	9	15
Exercise o/p	10000	2000	20000	2000	0	0	0	0	0	4000
Walking o/p	0	0	4000	8000	400	200	400	4000	200	3000
Sitting o/p	0	0	3000	7500	9800	1400	1800	1000	900	1500
TOTAL Output (Watts)	10000	2000	27000	17500	10200	1600	2200	5000	1100	8500

12.4. Construction Materials – Base Case 1

The Base-Case 1 Solid Stone Walled building is constructed from the following materials**: U values are in W/m^2**

STONE EXTERIOR WALL U=1.647

Surface layer	Mat db	Thick (mm)	Conduc- tivity	Density	Specif heat	IR emis	Solr abs	Description
1	81	300.0	1.830	2200.0	712.0	0.90	0.60	sandstone
2	81	200.0	1.830	2200.0	712.0			sandstone
3	81	300.0	1.830	2200.0	712.0	0.90	0.60	sandstone

ISO 6946 U values (hor/up/dn heat flow) for methvenwall is 1.647 1.733 1.545 (partn) 1.434

PARTITION WALL U = 1.852

1	76	12.0	0.120	540.0	1210.0	0.90	0.90	plywood sheathing
2	0	50.0	0.000			0.0	0.0	air gap (R= 0.170)
3	76	12.0	0.120	540.0	1210.0	0.90	0.90	plywood sheathing

ISO 6946 U values (hor/up/dn heat flow) for mvn-partn-wl is 1.852 1.961 1.724 (partn) 1.587

CEILING U=0.36

1	211	100.0	0.040	250.0	840.0	0.90	0.30	glasswool
2	76	12.0	0.120	540.0	1210.0	0.90	0.90	plywood sheathing

ISO 6946 U values (hor/up/dn heat flow) for mven-ceiling is 0.361 0.365 0.356 (partn) 0.350

WOODEN FLOOR U=3 up , 2.5 down

1	75	30.0	0.160	950.0	2093.0	0.91	0.65	floorboards

ISO 6946 U values (hor/up/dn heat flow) for mven-wod-flr is 2.797 3.053 2.516 (partn) 2.235

DOORs U=3.3

1	69	25.0	0.190	700.0	2390.0	0.90	0.65	oak

ISO 6946 U values (hor/up/dn heat flow) for door is 3.316 3.682 2.928 (partn) 2.554

PLYWOOD WINDOWs U= 2.3

1	72	18.0	0.150	700.0	1420.0	0.90	0.65	plywood 700d
2	0	50.0	0.000			0.0	0.0	air gap (R= 0.010)
3	72	18.0	0.150	700.0	1420.0	0.90	0.65	plywood 700d

ISO 6946 U values (hor/up/dn heat flow) for mvn-ply-wndo is 2.381 2.564 2.174 (partn) 1.961

STAINED GLASS WINDOW U= 5.3

1	243	4.0	1.050	2500.0	750.0	0.83	0.05	clear float

ISO 6946 U values (hor/up/dn heat flow) for mvn-glaswind is 5.753 6.954 4.677 (partn) 3.791

SLATE ROOF U = 6.8 up, 4.6 down

Ext	143	10.0	2.000	2700.	753.	0.95	0.85	48.	0.00	Slate tile : Slate tile
Int	161	1.0	0.500	1700.	1000.	0.90	0.90	1000.	0.00	bitumen felt : Bitumen felt

ISO 6946 U values (horiz/upward/downward heat flow)= 5.650 6.803 4.608 (partition) 3.745

FACILITIES WINDOWs U = 5.75

1	243	4.0	1.050	2500.0	750.0	0.83	0.05	clear float

ISO 6946 U values (hor/up/dn heat flow) for mvn-glaswind is 5.753 6.954 4.677 (partn) 3.791

12.5. Upgrade Strategy – Base Case 1

1) Loft Insulation

This added 300mm of Rockwool insulation to the Ceilings above:

Main Hall

Small Hall

Store Area

Plus 400mm of Rockwool to the Ceiling above:

Facilities

Note: There was NO insulation above the Facilities area in the Base Case Model.

Upgraded Ceiling U= 0.098 Previous Ceiling U = 0.36 (100mm Insul)

2) Under Floor Insulation.

This added 100mm of Expanded Polystyrene (EPS) insulation under the existing 25mm Wooden Floor below:

Main Hall

Part of Small Hall

Upgraded Floor U= 0.27 Previously U= 3 up , 2.5 down

3) Internal Wall Insulation

This added 100mm of Expanded Polystyrene (EPS) insulation to the inner surface of the Exterior walls in inhabited zones which was then finished with 0.095m of Plasterboard:

This was applied in:

Main Hall

Small Hall

Facilities

Upgraded Solid Walls U = 0.25 previously U = 1.647

4) <u>AirTightness</u>

By way of simulating improvements to the Air Tightness of the building the following Scheduled Air-Flows were manipulated. This was modelled independently of changes to windows although in practice the measures, especially in an old building, often are in parallel.

	Initial Air Changes/Hr	**New Air Changes/Hr**	Comment
Facilities Roof	3	**2**	Visibly Leaky Roof
Facilities	3	**1**	Poorly Maintained Windows Initially
Main Hall	2	**1**	
Main Hall Roof	4	**2**	Roof better, verges sealed
Small Hall	2	**1**	
Store	4	**2**	Open to Main Roof
Basement	9	**5**	
Small Hall Void	9	**5**	

5) <u>Windows</u>

The Base Case building has suffered with lack of maintenance and repair with rotten wooden window frames, missing pieces of glazing. During the study the worst affected windows were upgraded to double glazing. The Main Hall windows have been boarded over in the past to prevent vandalism, a measure which was been successful in that respect, but this was at the sacrifice of natural light and building aesthetics. In reality these windows were simply lined with an insulated plasterboard to help stop heat-loss. In the model and simulation these boarded windows were now replaced by double glazed units as this is more progressive to opening up a building.

The Stained Glass windows have been modelled as augmented with an internally fitted double glazed unit so as to preserve the outward aesthetic feature of the historical/religious picture. In reality, no change has been made by to the sensitive nature of the windows although with missing panels in sections of one window this position is accepted as short-term.

DOUBLE GLAZED WINDOWs U = 2.8 Prev: Single Glazed, U = 5.7 and Plywood Window, U = 2.3 but not transparent!

STAINED GLASS WINDOW + INTERNAL DOUBLE GLAZED SECONDARY UNITs U = 1.9 Prev U= 5.3

12.6. Construction Materials – Base Case 2

Original Building

Walls -

20mm Fir Clad with 8mm Slatted Profile,

Hollow wall with 75mm Timber Stud Work,

12mm Plasterboard with painted internal finish.

Ceiling –

100mm Rockwool Insulation,

12mm Plasterboard with painted internal finish.

Floor -

25mm Pine floor boards,

2mm Linoleum -or- occasional Carpet/Floor Mat.

Roof -

1mm Formed Metal Roofing Sheet with Grit surface for aesthetics,

Wooden roofing trusses forming an open roof void.

Foundation Wall –

Double width Brick with no cavity.

Newer Extension (as above but with the following differences)

Walls -

As previously but...

Hollow wall contains 75mm Rockwool insulation.

Roof -

Beneath Formed Metal Sheet there is 100mm of Rockwool sandwiched between thin polythene sheeting and 25mm Ply Sheet.

Floor -

100mm Rockwool insulation hanging in mesh net between Floor Joists,

25mm Pine floor boards,

2mm Linoleum -or- occasional Carpet/Floor Mat.

13. APPENDIX C - Base Load + Boost Load: Data Investigation.

13.1. Solid Walled Building

Base Case Solid Walled Building: 30% Occupancy Rate, 14kW Main Hall,

8kW Small Hall, 10kW Facilities, 20degC Temp with 14degC SetBack Temperature

Period: 01-Jan to 31-Dec

Hourly Heat Load

FACILITIES:

kW Range	Distribution No of 15 min Periods	Frequency (%) ie. % of the Year	Cumulative Distribution	Cumulative Frequency (%)
0-0.25	7608	21.71	7608	21.71
0.25-0.75	4795	13.68	12403	35.39
0.75-1.25	6024	17.19	18427	52.58
1.25-1.75	5858	16.72	24285	69.3
1.75-2.25	3981	11.36	28266	80.66
2.25-2.75	1921	5.48	30187	86.14
2.75-3.25	1926	5.5	32113	91.64
3.25-3.75	1726	4.93	33839	96.57
3.75-4.25	934	2.67	34773	99.24
4.25-4.75	245	0.7	35018	99.94

MAIN HALL:

kW Range	Distribution No of 15 min Periods	Frequency (%) ie. % of the Year	Cumulative Distribution	Cumulative Frequency (%)
0-0.25	12764	36.43	12764	36.43
0.25-0.75	1482	4.23	14246	40.66
0.75-1.25	1531	4.37	15777	45.03
1.25-1.75	1529	4.36	17306	49.39
1.75-2.25	1445	4.12	18751	53.51
2.25-2.75	1669	4.76	20420	58.27
2.75-3.25	1586	4.53	22006	62.8
3.25-3.75	1776	5.07	23782	67.87
3.75-4.25	1609	4.59	25391	72.46
4.25-4.75	1444	4.12	26835	76.58

4.75-5.25	21	0.06	35039	100
5.25-5.75	1	0	35040	100

SMALL HALL:

kW Range	Distribution No of 15 min Periods	Frequency (%) ie. % of the Year	Cumulative Distribution	Cumulative Frequency (%)
0-0.13	11542	32.94	11542	32.94
0.13-0.38	2621	7.48	14163	40.42
0.38-0.63	2864	8.17	17027	48.59
0.63-0.88	3167	9.04	20194	57.63
0.88-1.13	3055	8.72	23249	66.35
1.13-1.38	2267	6.47	25516	72.82
1.38-1.63	2189	6.25	27705	79.07
1.63-1.88	1640	4.68	29345	83.75
1.88-2.13	1111	3.17	30456	86.92
2.13-2.38	1158	3.3	31614	90.22
2.38-2.63	995	2.73	32609	92.95
2.63-2.88	866	2.47	33475	95.42
2.88-3.13	551	1.57	34026	96.99
3.13-3.38	421	1.2	34447	98.19
3.38-3.63	255	0.73	34702	98.92
3.63-3.88	193	0.55	34895	99.47
3.88-4.13	119	0.34	35014	99.81
4.13-4.38	51	0.15	35065	99.96
4.38-4.63	11	0.03	35076	99.99
4.63-4.88	3	0.006	35079	99.996
4.88-5.13	1	0.004	35080	100

4.75-5.25	1389	3.96	28224	80.54
5.25-5.75	1217	3.47	29441	84.01
5.75-6.25	1056	3.01	30497	87.02
6.25-6.75	897	2.56	31394	89.58
6.75-7.25	966	2.76	32360	92.34
7.25-7.75	505	1.44	32865	93.78
7.75-8.25	373	1.06	33238	94.84
8.25-8.75	322	0.92	33560	95.76
8.75-9.25	275	0.78	33835	96.54
9.25-9.75	255	0.73	34090	97.27
9.75-10.25	219	0.63	34309	97.9
10.25-10.75	170	0.49	34479	98.39
10.75-11.25	140	0.4	34619	98.79
11.25-11.75	142	0.41	34761	99.2
11.75-12.25	80	0.23	34841	99.43
12.25-12.75	65	0.19	34906	99.62
12.75-13.25	52	0.15	34958	99.77
13.25-13.75	42	0.12	35000	99.89
13.75-14.25	40	0.11	35040	100

Where the Base Load falls short of the Total Load Required this would have to be made up by the Boost Capacity. Contingency has been introduced through the assumption that the MAX Heat Loads for each Zone would be required simultaneously which may not be the case in reality. By making this assumption it is ensured that the BASE + BOOST will be AT LEAST EQUAL IF NOT GREATER THAN the buildings zones highest collective heat load.

Continuation of:

Base Case Solid Walled Building: 30% Occupancy Rate, 14kW Main Hall,
8kW Small Hall, 10kW Facilities, 20degC Temp with 14degC SetBack Temperature

BASE LOAD CALCULATIONS (kW)

Cum. Freq.	FAC	MAIN	SMALL		
50%	0.75	1.75	0.63		
70%	1.75	3.75	1.13		
90%	2.75	6.75	2.13		
100%	5.75	14.25	5.13	TOTAL CAPACITY	25.13 kW

SUMMARY

by % Freq

% Freq	TOTAL **BASE LOAD CAPACITY**
50%	**3.13** kW
70%	**6.63** kW
90%	**11.63** kW

TOTAL **BOOST LOAD CAPACITY**	% Freq
22 kW	50%
18.5 kW	30%
13.5 kW	10%

13.2. Wooden Walled Building

Base Case Wood Hut Building: 30% Occupancy Rate,

20degC Temperature with 10degC SetBack Temperature

Hourly Heat Load

Period: 01-Jan to 31-Dec

FACILITIES:

kW Range	Distribution No of 15 min Periods	Frequency (%) ie. % of the Year	Cumulative Distribution	Cumulative Frequency (%)
0-0.25	17658	50.39	17658	50.39
0.25-0.75	3008	8.58	20666	58.97
0.75-1.25	2962	8.45	23628	67.42
1.25-1.75	2384	6.8	26012	74.22
1.75-2.25	1521	4.34	27533	78.56
2.25-2.75	1205	3.44	28738	82
2.75-3.25	1359	3.88	30097	85.88
3.25-3.75	1394	3.92	31491	89.8
3.75-4.25	1092	3.12	32583	92.92
4.25-4.75	1062	3.03	33645	95.95
4.75-5.25	718	2.05	34363	98
5.25-5.75	423	1.21	34786	99.21
5.75-6.25	254	0.72		

SMALL HALL:

MAIN HALL:

kW Range	Distribution No of 15 min Periods	Frequency (%) ie. % of the Year	Cumulative Distribution	Cumulative Frequency (%)
0-0.25	23694	67.62	23694	67.62
0.25-0.75	1816	5.18	25510	72.8
0.75-1.25	1615	4.61	27125	77.41
1.25-1.75	1493	4.26	28618	81.67
1.75-2.25	1315	3.75	29933	85.42
2.25-2.75	956	2.73	30889	88.15
2.75-3.25	679	1.93	31568	90.08
3.25-3.75	538	1.54	32106	91.62
3.75-4.25	430	1.23	32536	92.85
4.25-4.75	357	1.02	32893	93.87
4.75-5.25	706	2.01	33599	95.88
5.25-5.75	293	0.84	33892	96.72
5.75-6.25	265	0.76	34157	97.48
6.25-6.75	174	0.5	34066	97.22
6.75-7.25	215	0.61	34281	97.83

kW Range	Distribution No of 15 min Periods	Frequency (%) ie. % of the Year	Cumulative Distribution	Cumulative Frequency (%)
0-0.25	19347	55.21	19347	55.21
0.25-0.75	2432	6.94	21779	62.15
0.75-1.25	2296	6.55	24075	68.7
1.25-1.75	1894	5.41	25969	74.11
1.75-2.25	1175	3.35	27144	77.46
2.25-2.75	922	2.63	28066	80.09
2.75-3.25	869	2.48	28935	82.57
3.25-3.75	1188	3.39	30123	85.96
3.75-4.25	1399	3.99	31522	89.95
4.25-4.75	1086	3.1	32608	93.05
4.75-5.25	821	2.34	33429	95.39
5.25-5.75	524	1.5	33953	96.89
5.75-6.25	419	1.2	34372	98.09
6.25-6.75	307	0.88	34679	98.97
6.75-7.25	197	0.56	34876	99.53
7.25-7.75	109	0.31	34985	99.84
7.75-8.25	55	0.16	35040	100

7.25-7.75	178	0.51	34459	98.34
7.75-8.25	128	0.37	34587	98.71
8.25-8.75	81	0.23	34668	98.94
8.75-9.25	54	0.15	34722	99.09
9.25-9.75	41	0.12	34763	99.21
9.75-10.25	12	0.03	34775	99.24
% of the Year that Heating above 90%		**11.85**		

Continuation of:

Continuation of:

Base Case Wood Hut Building: 30% Occupancy Rate,

20degC Temperature with 10degC SetBack Temperature

BASE LOAD CALCULATIONS (kW)

% of Yr	FAC	MAIN	SMALL			
Up to 70%	1.25	0.25	1.25			
Up to 80%	2.25	1.25	2.75			
Up to 90%	3.75	2.75	4.25			
100%	6.25	10.25	8.25	TOTAL CAPACITY	24.75	kW

SUMMARY

by % Freq

% of Yr	TOTAL BASE LOAD CAPACITY		TOTAL BOOST LOAD CAPACITY		% of Yr
70%	**2.75**	kW	**22.0**	kW	30%
80%	**6.25**	kW	**18.5**	kW	20%
90%	**10.75**	kW	**14.0**	kW	10%

14. APPENDIX D - System Suitability Matrix

14.1. Matrix Summary

SYSTEM TYPE:	Biomass: Log	Biomass: Woodchip	Biomass: Pellet	ASHP	GSHP	ELEC Storage (o/n charge)	ELEC Panel	Mains Gas CH	LP Gas CH	mCHP Gas	Oil Fired CH
Use:											
BASE LOAD (including any concern)	Manpower					Control	Cost		Cost		Cost
BOOST LOAD + BASE LOAD	Manpower					Control	Cost		Cost		Cost
BOOST LOAD Stand-Alone	Manpower					Control	Cost		Cost		Cost
RCB Decision Making:											
Rural Community Building Specific - Top Issue (Financial as Fuel Cost is LARGEST ISSUE for RCBs)	Lower Run Cost	Med Run Cost	Med Run Cost	Lower Run Cost	Lower Run Cost	High Run Cost	High Run Cost	Med Run Cost	High Run Cost	Med Run Cost	High Run Cost
Rural Community Building Specific - Other Factors	Manpower	Space	Space	Knowl-edge + Space	Knowl-edge + Space	Occupancy v Operating Regime	Install	Install	Install	Occupancy v Operating Regime	Install

14.2. Key.

Rating:	Y = Strong Yes	y = Yes	n = Partial No	N = Definite No
Colour Code:	Not Suitable	Less Suitable	Possibly Suitable	Suitable

14.3. Matrix Detail

SYSTEM TYPE:	Biomass: Log	Biomass: Woodchip	Biomass: Pellet		ASHP	GSHP		ELEC Storage (o/n charge)	ELEC Panel		Mains Gas CH	LP Gas CH	mCHP Gas	Oil Fired CH
Base Load Analysis:														
Required frequently	y	Y	Y		Y	**Y**		N	Y		Y	Y	Y	Y
Available All Year round	y	Y	Y		Y*	Y		Y	Y		Y	Y	Y	Y
Lower level heat input	*n*	y	y		Y	**Y**		Y	Y		Y	Y	Y	Y
Instant / near-instantly	n	y	y		y	y		N	y		y	y	y	y
Long Input Periods	y/n	Y	Y		y	y		N	Y		Y	Y	Y	Y
Reliable provision	y	Y	Y		y	y		N	Y		Y	Y	Y	Y
Weather independent	Y	Y	Y		y#	y		Y	Y		Y	Y	Y	Y
BOOST LOAD Analysis:														
Long Stand-by periods	n	y	y		n	n		N	Y		Y	Y	n	Y
Accept Seasonal Use	3	3	3		y	y		Y	Y		Y	Y	n	Y
High Level heat input	Y	Y	Y		y^	y^		Y	Y		Y	Y	Y	Y
Instant / near-instantly	n	$Y^{\$}$	$Y^{\$}$		$n^{\$}$	$n^{\$}$		$n^{\$}$	y		y	y	y	y
Short duration inputs	N	N	N		y	y		N	y		Y	Y	n	Y
Reliable provision	y	y	y		y	y		N	Y		Y	Y	y	Y

Weather independent		y	y	y		y#	y#		N	Y		Y	Y	y	Y
RCB Analysis:															
Specialist Knowledge to Operate		y	y	y		Y	Y		n	N		n	n	y	N
Specialist Knowledge to Monitor		n	n	n		y	y		N	N		N	N	n	N
Space Requirements															
- Boiler Room		Y	Y	Y		y	y		N	N		y	y	y	Y
- Fuel Storage		Y	Y	Y		N	N		N	N		N	Y	N	Y
- Collection Loop		N	N	N		N	Y		N	N		N	N	N	N
- Buffer Tank		Y	Y	Y		Y	Y		N	N		pos	pos	Y	Pos
Underfloor System (Base Load Only)		y	y	y		y	y		N	N		pos	pos	pos	Pos
Radiators/Pipes(Base and/or Boost Load)		y	y	y		y	y		Y	Y		Y	Y	Y	Y
Internal Upheaval (esp. if no Radiators at present)		Y	Y	Y		Y	Y		N	N		Y	Y	Y	Y
Re-Design of existing Wet CH for Low Op Temp?		N	N	N		Y	y/n		N	N		N	N	N	N
Visual/Physical effect on		n	n	n		y	y		n	n		N	N	N	N

Historic/Listed Building beyond flue/chimney/fuel store/Boiler Room															

Costs Analysis:															
Running Cost Comparative to other systems		Lower	Lower	Med		Low~	Low~		High	High		Med	High	Med	High
Incentivised or Assistance		y	y	y		y	y		N	N		N	N	y	N
Level of Financial Investment required		MED	HIGH	HIGH		MED	MED		MED	MED		LOW	MED	HIGH	MED
GreenDeal Finance Available? "		y	Y	Y		Y	Y		N	N		Y	Y	y	Y
Feed-In Tariff Available? "		N	N	N		N	N		N	N		N	N	Y	N
Renewable Heat Incentive Payments Available? "		N	Y	Y		Y%	Y%		N	N		N	N	N	N
SYSTEM TYPE:		**Biomass: Log**	**Biomass: Woodchip**	**Biomass: Pellet**		**ASHP**	**GSHP**		**ELEC Storage (o/n charge)**	**ELEC Panel**		**Mains Gas CH**	**LP Gas CH**	**mCHP Gas**	**Oil Fired CH**

Notes:

- If correctly sited, sized, installed and operated.

3 - Unsuitable as a stand-alone Boost System

$ - May need

control

^ - If sized

correctly

& - Different Heating Method - Heats Contents + Fabric not Air.

H - Running costs are due to the Electricity to run the Compressor, pumps and fans. This could be lessened IF part of the electricity is from self-generated building PV system.

% - ASHP equipment must not be capable of providing Cooling, GSHP can be reversible but must be metered for only the Heating provided.

~ - Knowledgeable Operation of system will reduce operating cost through careful use and control

" - Assuming selected system is eligible + Building Fabric Improvements have been made.

Compiled with

Reference to:

Carbon Trust CHP Guide - (Carbon-Trust, 2010)

Carbon Trust Biomass Heating Guide - (Carbon-Trust, 2009)

Carbon Trust Ground Source Heat Pump Implementation Guide - (Carbon-Trust, GSHP)

Carbon Trust – How to implement ASHPs - (Carbon-Trust, ASHP)

Carbon Trust ‘Down to Earth’ Lessons Learned from Installing GSHPs - (Carbon-Trust, 2011)

Scottish Government Ground and Water Source Heat Pump Guide - (Scottish-Govt., 2010)

Biomass Energy Centre – Tech. Best Practice for Biomass - (Palmer and Rolls, 2011)

UK Govt. – What Measures does the Green Deal cover - (UK-Govt, 2011)

Ofgem Renewable Heat Incentive Guidelines - (Ofgem, 2014)

Combined Heat and Power Association ‘Knowledge Centre’ - (CHPA, 2014)

Changeworks – Renewable Heritage Guide – Microgen in Trad .+Historic Homes - (ChangeWorks, 2009)