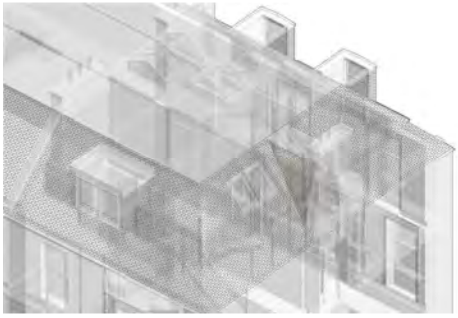
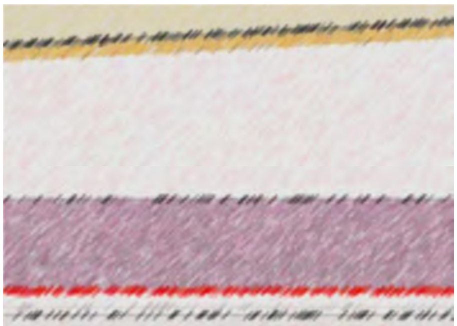
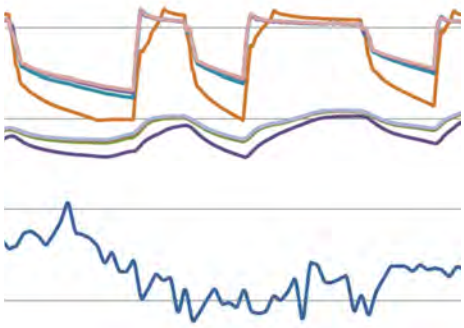
Developing Robust Solutions for Roof Upgrades

A Process for the development and implementation of robust, practical solutions for the thermal improvement and moisture control of existing roofs above habitable rooms







Grigor Mitchell, Pauline Ritchie (Grigor Mitchell Architect Limited). November 2012

Acknowledgements

The authors would like to thank the Energy Systems Research Unit of the University of Strathclyde for their help in this CIC Start Project. We are also grateful to CIC Start Online for providing the funding which allowed this research to be carried out.

A Late Victorian Edinburgh Tenement, showing the arrangement of pitched and flat roofs. Grigor Mitchell Architect Ltd.

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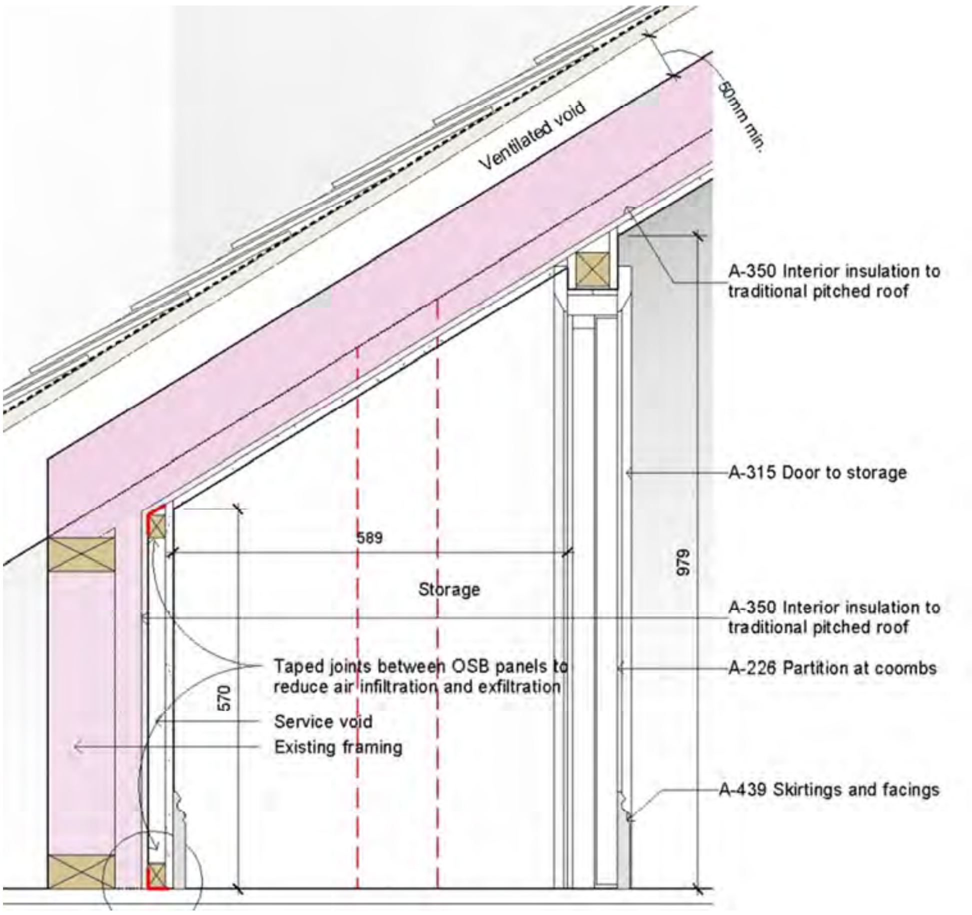
1. Aims

The aim of this feasibility study is to assist in the development of a process which produces robust, practical details and specifications for the thermal improvement to habitable roof spaces of traditional properties in respect to moisture control and the avoidance of interstitial condensation. At present in Scotland there has been limited research into this area.

The details and specifications are to be assessed with an advanced simulation software tool. The project will instigate a follow on project by the SME, involving the actual thermal upgrading a roof structure in order to trial the proposed specifications and to allow for in-situ testing. The SME will receive training in the use of the tool that will allow modification of template models representing specific roof structures, and analyses similar to those carried out during this project to be undertaken

The future benefits to the SME and Partner will include an increase in specialised knowledge of avoiding interstitial condensation when thermally upgrading the roofs of traditional properties. This will lead to consultancy opportunities and the development of bespoke services. The Partner will benefit by being able to test their software tools on real projects and to compare their models with real data supplied by the sensors. It is envisaged that the sensors will remain in place after the completion of this particular project to allow long term analysis of the moisture/thermal data.



Detailed design of thermal upgrade works to a traditional roof. Grigor Mitchell Architect Ltd.

2.0 Background

Currently there are many initiatives to increase the energy efficiency of Scottish homes including the 'Home Insulation Scheme' which is managed by the Energy Saving Trust and backed by the Scottish Government. One of the aims of this particular scheme is to improve the energy efficiency of homes by promoting and installing free or discounted loft insulation. However there is little precise guidance available on the best practice for insulating the pitched and flat roof structures of traditional properties especially in respect to the avoidance of interstitial condensation. The idea for this project was developed from experience of this issue. Grigor Mitchell Architect has built up a large body of experience of dealing with architectural projects where clients have requested that existing roofs of traditional properties be thermally upgraded.

In addition, over the last 3 years Grigor Mitchell Architect (GMA) has gained expertise in the Passivhaus building standard and in using advanced software tools such as THERM and WUFI. These experiences have highlighted the need for caution when specifying thermal upgrades in order to control moisture and avoid interstitial condensation. In addition, the experience of dealing with traditional properties has underlined the importance of conserving their key features where they are of high quality.

During this CIC Start Project, GMA worked in conjunction with the Energy Systems Research Unit (ESRU) of the University of Strathclyde. GMA produced details of 4 typical roof interfaces and modelled them using Revit BIM Software. The specification options aimed to ensure optimal thermal performance, decrement delay, air tightness and thermal bridge free construction. The need for building conservation was taken into consideration. These roof interface details were then passed on to the ESRU who created numerical models of them.

An attic space undergoing alterations, exposing the existing rafters. Grigor Mitchell Architect Ltd.

3.0 Relevance

3.1 Environmental

The main aim of this project is to look at the best way to reduce energy loss (and, hence, CO_2 emissions) through the roofs of 'hard to treat' traditional properties. The solutions will be cost effective and will best respect the existing building fabric. Natural insulation products will be considered for use in the project due to their excellent decrement delay properties.

3.2 Social

The upgraded roof structures will have improved thermal retention and comfort and will be cheaper to heat – very important in an age of rising fuel costs. As there is a particular emphasis on the avoidance of interstitial condensation (and hence mould) the internal environment of the refurbished space will be healthier for the occupants. There have, of course, been studies that have found a close correlation between asthma and allergies and the environments found in the home, office and school.

3.3 Economic

The thermal upgrading of properties is central to the Government strategy of substantially (and rapidly) reducing CO_2 emissions. Best practice solutions must be investigated using the powerful tools (and expertise) that are now available to us. Developing this process could help us avoid the damage that condensation can cause with the building fabric of properties and to the health of residents.

This project will allow the SME (and other Scottish professionals) to develop specialist skills in a key area which is applicable to a large number of property types, including tenements, in Scotland and further afield. Another potential spin off of this project could be the development and manufacture of suitable insulation products and membranes.

4.0 Scope

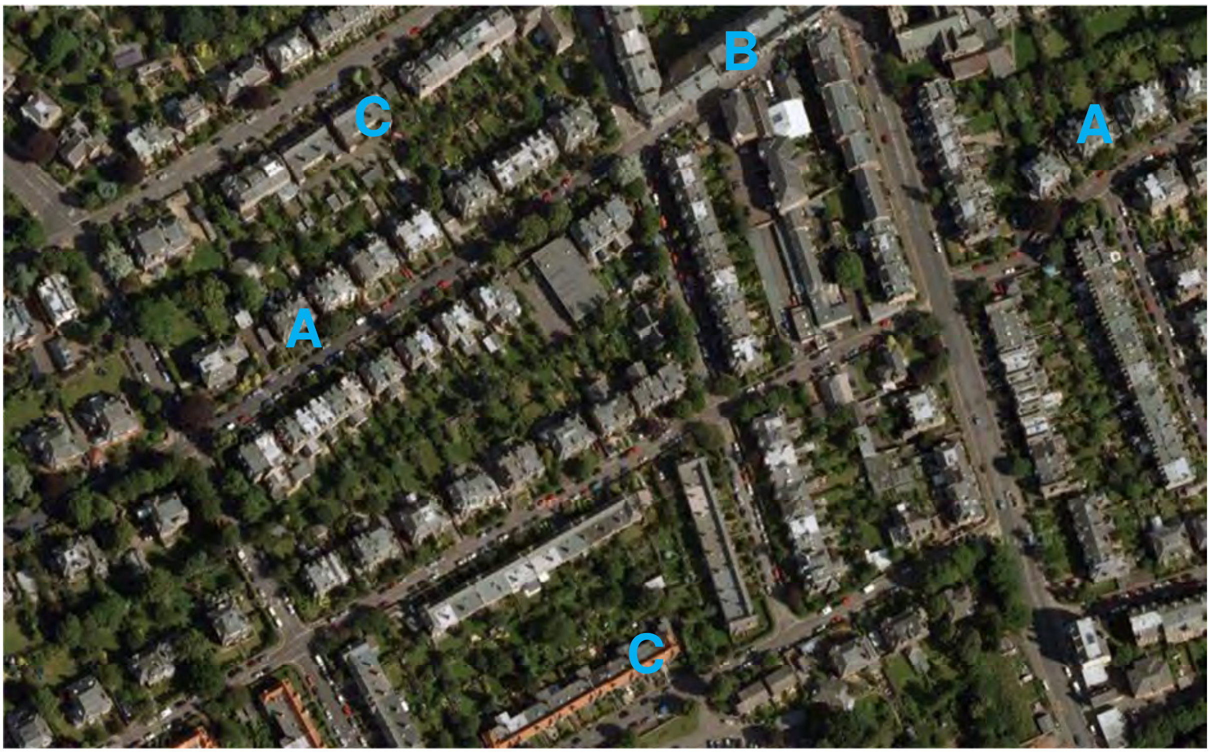
4.1 Traditional Roofs

The thermal upgrading of traditional roofs encompasses a large range of property types and building ages, each with their own particular construction methods and extent of ventilation. There are also a wide range of potential solutions for their thermal upgrade.

In order to limit the scope of the study, through consultation with ESRU, the authors decided to focus on the upgrades to traditional flat roofs. This choice was also based on their recent experience of spatial and thermal upgrades of this form of construction in properties in South Edinburgh.

In addition, it was felt that as these constructions are deemed as ‘hard to treat’, they are often overlooked and therefore most subject to thermal ‘discomfort’ and heat loss. The solutions derived from these particular instances are also highly relevant to properties of all ages with flat roofs.

In the case of this project, ‘traditional’, defines late Victorian, when flat roof became more common, through to pre-second World War, when modern methods of roof construction became more typical.

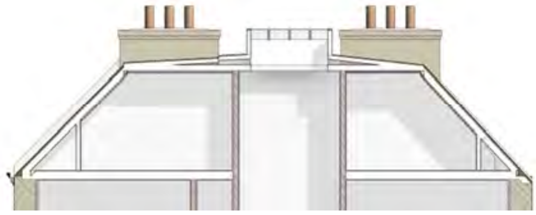


Satellite image of an area of South Edinburgh. Different property types are noted. Image courtesy of GoogleEarth

4.2 Property types with traditional flat roofs

A/ Habitable attics

The habitable accommodation in Victorian detached and semi-detached houses may have been formed at the time of building as servant accommodation or converted at a later date as additional bedroom space or as a self contained flat. In most cases ornate cornices and architraves are not evident. The floor plan may also be intersected by a large light well connected with the stair void



B/ Tenements

Top floor flats in late Victorian Tenement blocks in Edinburgh, as shown below, are often roofed to their rear with large areas of flat roof. Of note is the connection between the flat and pitched roof voids and the connection of private and communal spaces via the roof void

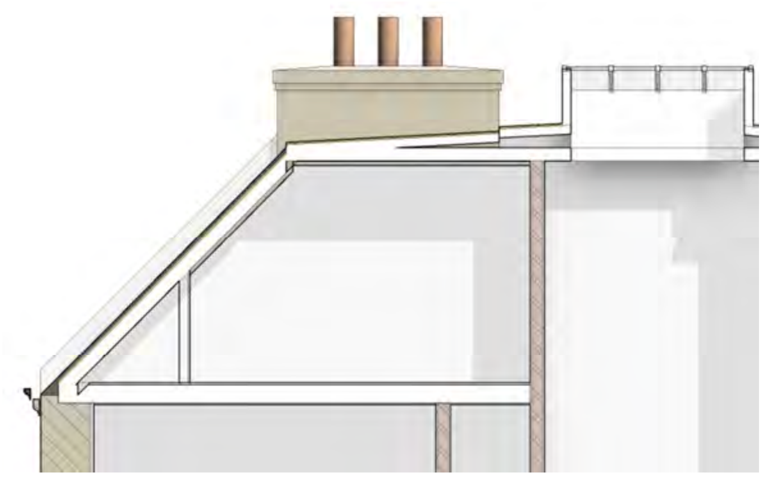
C/ Upper villas

The arrangement of pitched/ flat roof displayed below is also evident on upper villa flats built between the early years of the last century and the 1930's. Similar issues exist with the interconnection of roof voids and ventilation, although no clash exists between private and communal areas

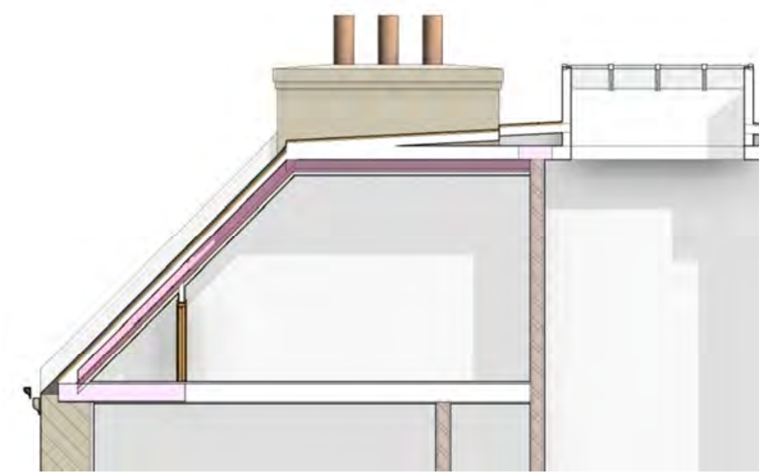
5.0 Specifications

5.1 Building Context

Property type A/ Habitable Attic Accommodation was selected as the basis for the analysis of the flat roof by ESRU. The justification for this is that a single room could be modelled in isolation, as opposed as a whole flat or series of rooms with a larger set of variables. Recent projects undertaken by the SME also include this type of accommodation, therefore their detailed knowledge of the roof construction could be utilised. To provide a context to the flat roof, it was assumed that the pitched roof would be insulated to a similar level and that an enclosed storage area would be formed at eaves level.



Attic room, as existing

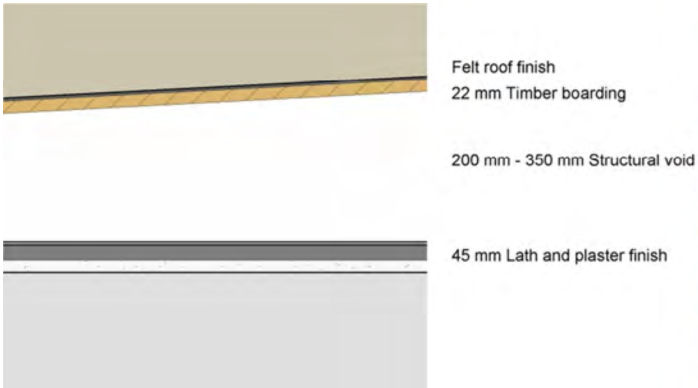


Attic room, after thermal improvement

5.2 Existing Case

Based on the SME's experience of this construction, the build-up of the flat roof was defined as follows:

- **Low pitch felt finish**
- **Structural ceiling void of varying heght with low rates of background ventilation**
- **Lathe and plaster ceiling**
- **High quality internal finishes not evident**



5.2 Specification Options

The four constructions proposed for analysis using the ESP-r simulation tool fall under the following main categories:

A/ External insulation or warm roof (Option 4)

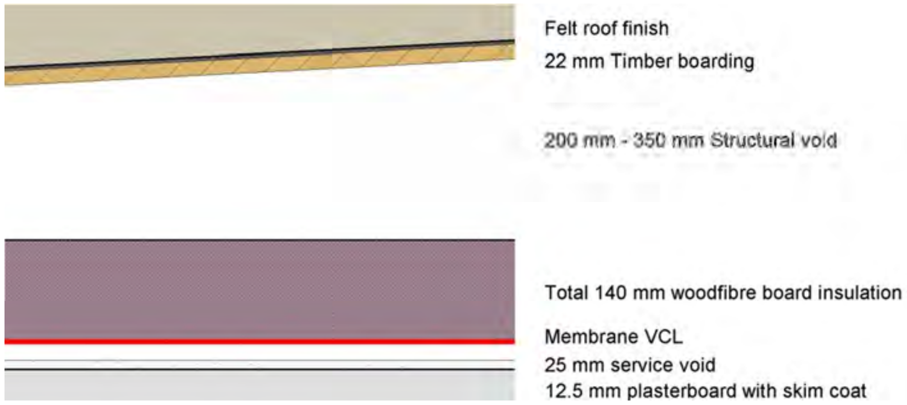
B/ Internal insulation or cold roof. (Options 1– 3)

The warm roof upgrade (Option 4) would generally be considered as the optimal solution in most cases, however issues of cost, access, ventilation mean that this is not always a viable route

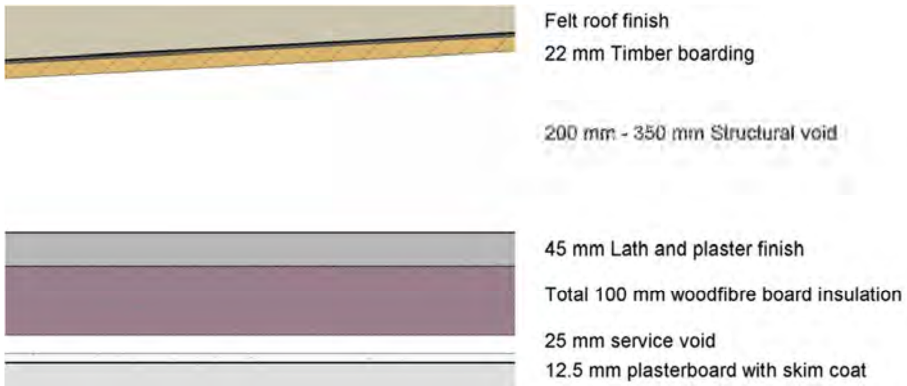
Internal insulation works are generally more disruptive and may pose the greatest risk of interstitial condensation in the existing roof void, once internal finishes are applied. As a method of limiting disruption, Option 2 was developed as a route to retain the existing ceiling finish. Options 1 & 3 present two possible routes of vapour control using a vapour open material such as OSB or a well sealed an impervious membrane.

In all 3 options dealing with the application of internal insulation, wood-fibre board insulation is proposed due to its environmental credentials, vapour permeability and density. The nominal thickness of 100 mm is deemed suitable for a thermal upgrade which is not regulated by the Technical Standards. In addition a service void is used in each case to avoid the puncturing of the vapour control layer by services.

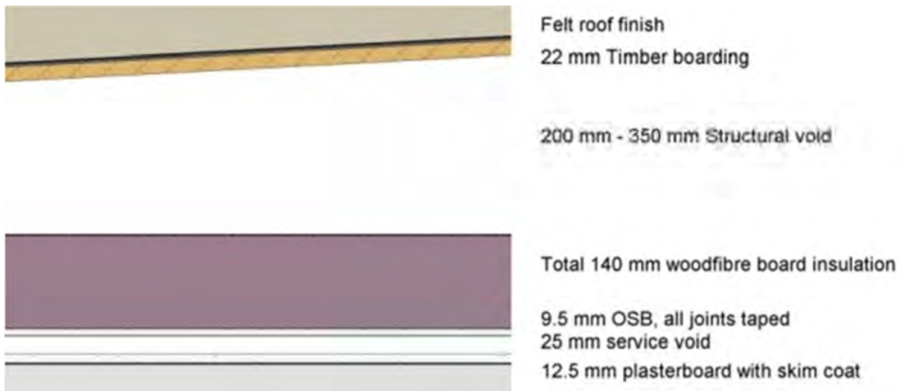
Option 1



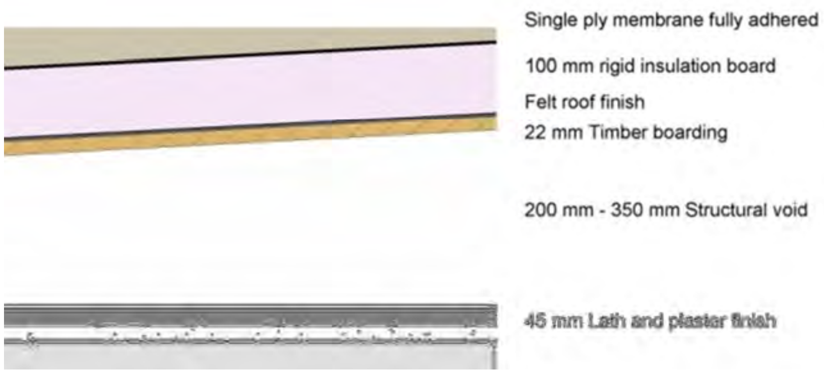
Option 2



Option 3



Option 4



6.0 Dynamic Modelling Assessment

Introduction

ESRU has a history of partnering with design groups to improve working practices and enhance deliverables. In this case the support involved creating a numerical representation of a typical roof conversion which would support the comparison of different choices of roof construction. The layout of the spaces was specified by GMA as were the constructions.

The constructions under consideration are as described in Section 5.

Options 1/2/3 are cold-roof implementations and option 4 is a warm-roof implementation. Only the original and option 4 preserve the original plasterwork.

The roof spaces were lightly populated (mostly evening and weekend occupancy) with one sequence of high humidity generation on Saturday morning. The storage spaces were assumed to have 0.2ach, rooms were assumed to be slightly leaky 0.4ach and the roof void 0.5ach infiltration.

Environmental controls were assumed to be a room radiator with a TRV. This type of heat delivery is 80% convective and TRVs are assumed to sense 35% air temperature and the balance radiant. Heating is to 20C during occupied periods with 15C otherwise.

A wireframe image of the model is shown in Figure 1.

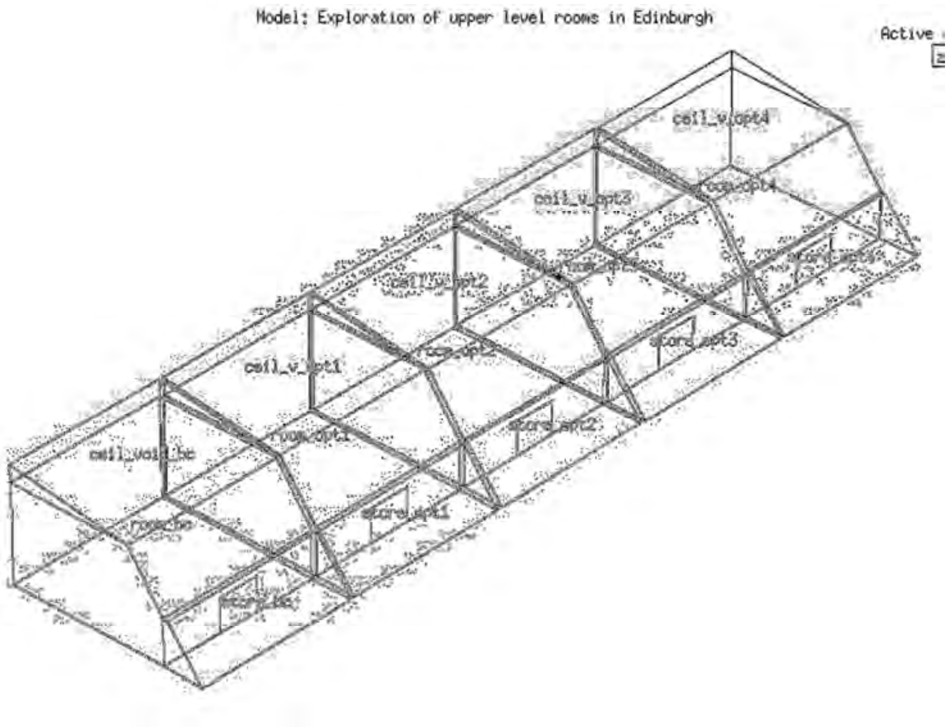


Figure 1: wireframe view of the ESP-r model

On the left is the base case (room/storage/ceiling space). Moving to the right are the variants 1/2/3/4. This approach allows the full performance characteristics of all of the variants to be available simultaneously.

Performance issues under consideration were:

- Comfort within the spaces
- Heating demands
- Frequency of surface condensation with and without cooking
- Storage space and roof void temperature patterns
- Movement of humidity between the spaces
- Patterns of temperatures within the roof constructions

Analysis Method

Numerical assessments were carried out via the ESP-r simulation tool making use of Glasgow airport weather data. ESP-r is a multi-domain simulation environment. It assesses not only the heat flows within the fabric of the building but the transport of moisture. In effect it is able to create a virtual experiment with hundreds of sensors. This allows design teams to explore a number of performance issues. The range of performance topics and reports available were discussed and the performance predictions were reviewed interactively prior to inclusion in this report.

Results

The energy impact of design decisions for these spaces follows a consistent pattern (Table 1). All of the options result in approximately the same level of demands for heating (approximately 50% reduction). The base case requires a small heating input for frost protection. The room air temperature tends to overshoot slightly at the start of an occupied period as the surfaces are warmed (see Figure 2). The cooking period on Saturday morning (day 11) is evident in Figure 3. This results in a high relative humidity in the store room which is ventilated to the room, but at a lower temperatures. The ceiling void humidity is more closely coupled to the external condition.

Option	Heating energy, kWh	Number of heating hours
Base case	57.39	100.5
Option 1	24.46	62.
Option 2	26.22	64.
Option 3	24.37	62.
Option 4	26.56	63.8

Table 1: Heating demand during a winter week

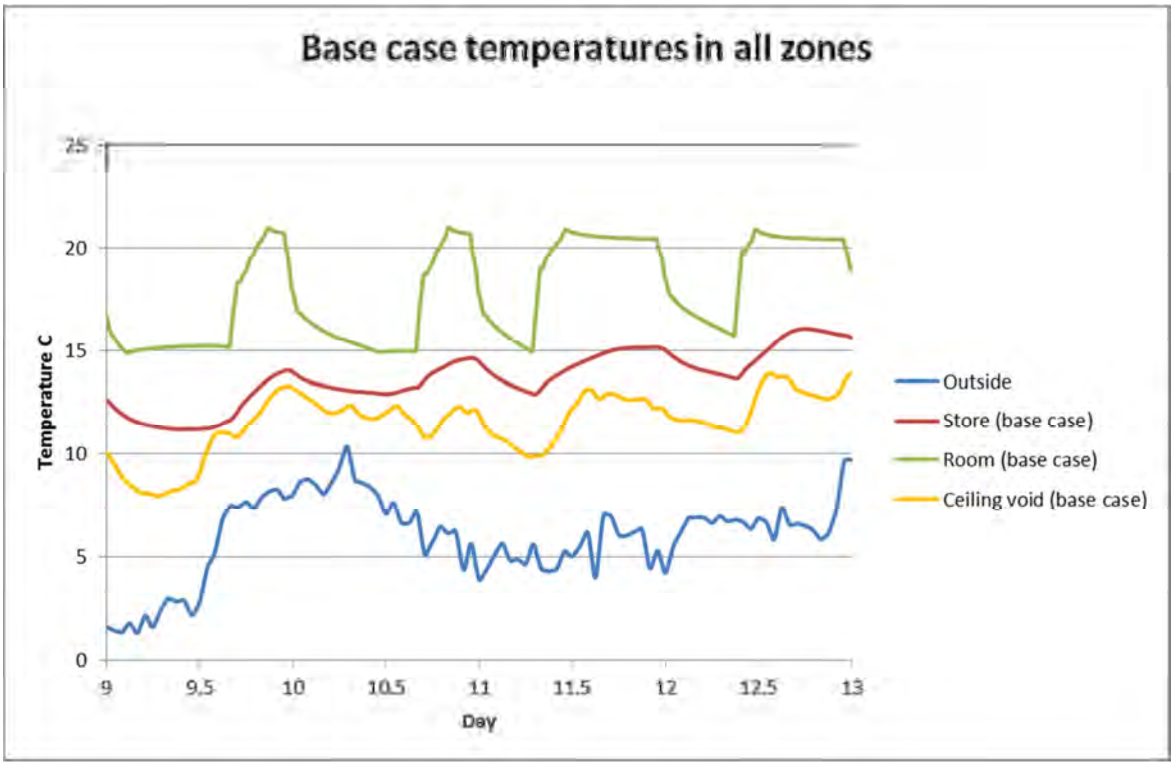


Figure 2: Winter temperatures for base case.

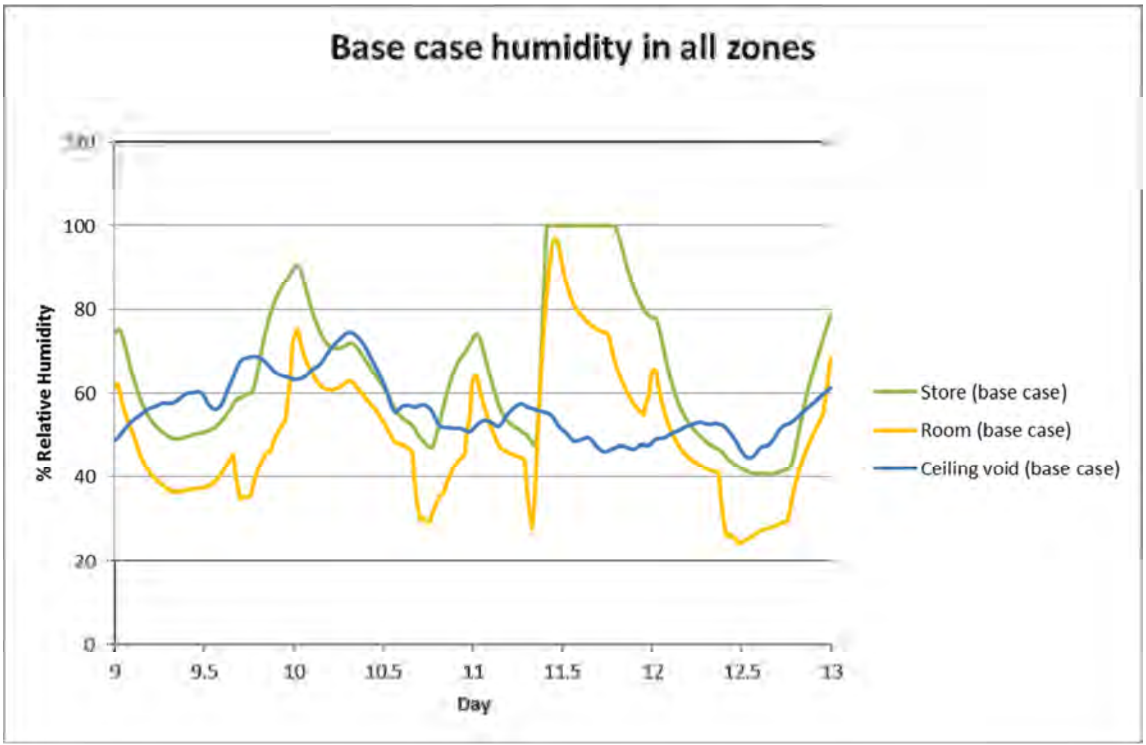


Figure 3: Humidities for base case

Initial assessments identified the storage spaces as being a likely point of failure in refurbishment work. For instance, the doors to storage spaces tend to be ill fitting and the significant exposure in such rooms to the roof and façade are greater than in the occupied spaces. This results in cold spaces which nevertheless also get a portion of the moisture generated within the occupied space in addition to the moisture which might accrue from wet clothing tossed into the spaces. Figure 4 shows the difference between the temperatures in the storage space and adjacent room. The temperature patterns for all options were very similar, being in all cases slightly higher than for the base case.

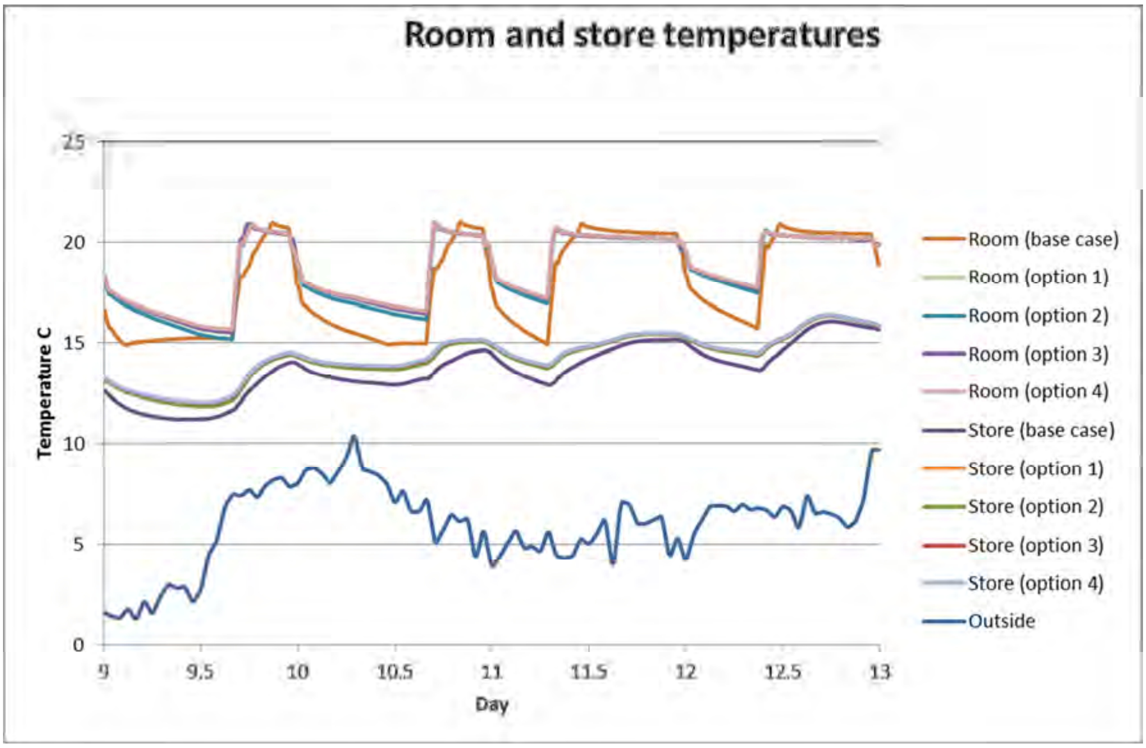


Figure 4:Room and store temperatures base case and all options

The ceiling voids fall into three broad patterns: the initial un-insulated roof structure, the cold roof condition in options 1/2/3 and the warm roof condition with option 4 which is essentially the same as the ambient outside temperature. These are shown in Figure 5.

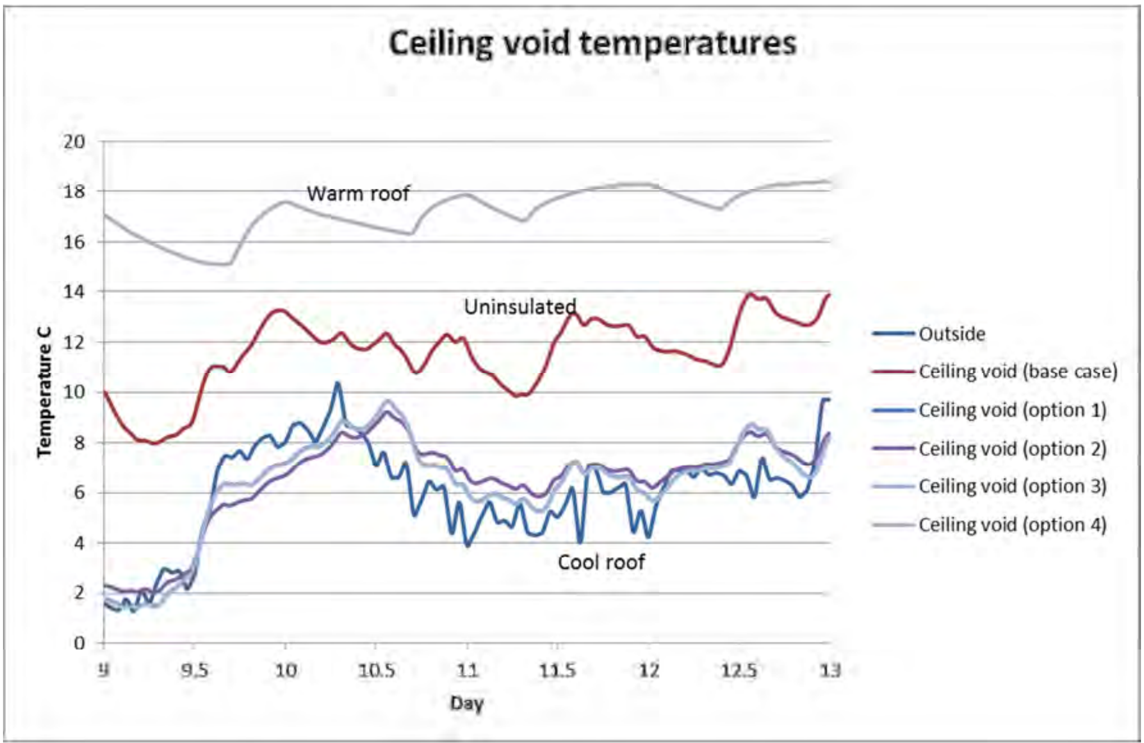


Figure 5: Ceiling void temperatures for base case and all options.

Condensation patterns were also assessed. A pulse of 200W of latent gains was added for two hours on the Saturday morning gradually trailing off to normal humidity from occupants. This resulted in high Relative Humidity for a number of hours until the ventilation air dilutes the humidity. The storage spaces have essentially the same condensation risk for all options, with 10.5 hours of condensation during the week. The original room has 9 hours of instances whereas all the other options have about 5 hours of instances of condensation during the week. The roof space for the original roof space and the option 4 roof space have no reported condensation. The other options have some condensation on the end-walls within the very cold space (Figure 6).

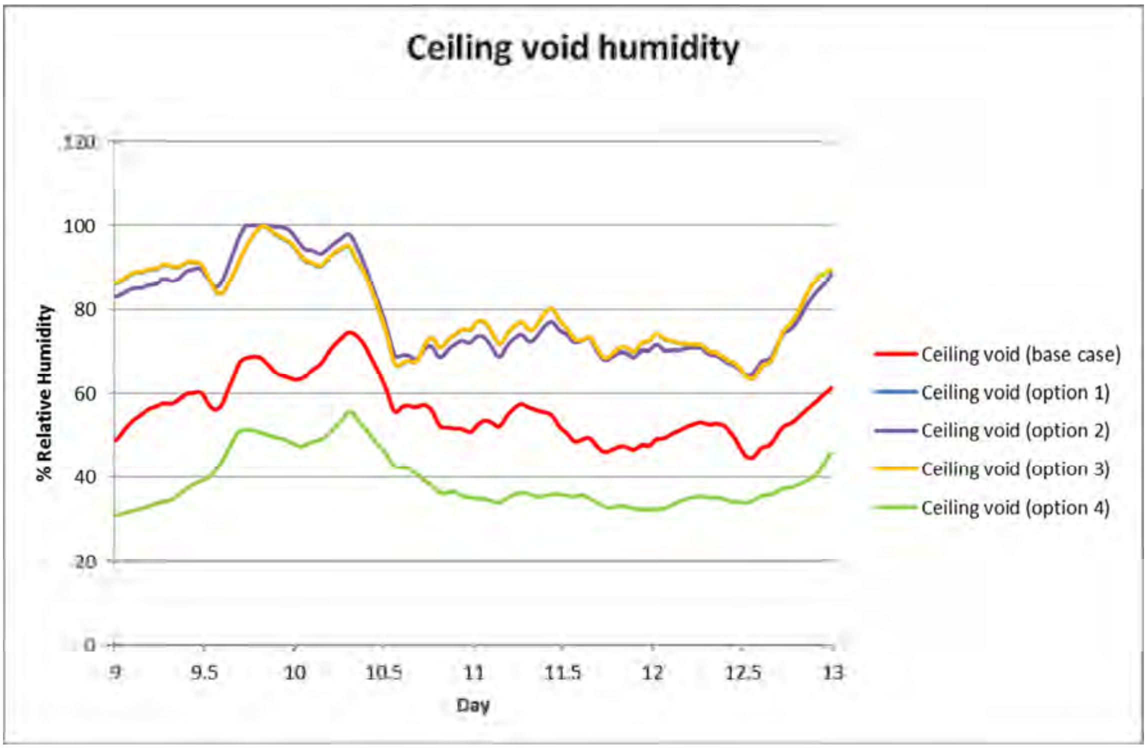


Figure 6: Ceiling void humidities for base case and all options.

Conclusions

- Non-upgraded roof structures are more sensitive to internal moisture sources than any of the alternative constructions. Condensation risk in the roof spaces is relatively low, being greater for the cold roof options.
- For a two hour moisture generation scenario e.g. cooking or showering, condensation was detected in all models, however it was considerably reduced with upgraded constructions.
- The area of greatest condensation risk appears to be in storage spaces adjacent to the occupied space which tend to be colder and which are poorly sealed from moisture laden air within the occupied spaces.
- The alternative constructions reduce energy consumption for the room by about 50%.

Grigor Mitchell Architects have been provided with the models, and received training that will allow them to carry out further analyses of the cases considered in this project for themselves, or to modify the thermal models to represent specific cases that they may work on in future.

7.0 Conclusions

7.1 Learning Outcomes

At the outset the formation of a warm flat roof construction was anticipated as the preferred route in terms of moisture control and avoidance of interstitial condensation. Due to access limitations and/or ventilation issues, this method is not always viable.

It was anticipated that the 3 'cold roof' options presented for analysis using ESP-r would display a more marked difference in relation to condensation risk due to the differing vapour permeability and position of the vapour control layer. The three 'cold roof' options do indicate a greater level of condensation risk, albeit small, than the 'warm roof' thermal upgrade. The removal of the existing lathe and plaster and use of either OSB or a membrane however, does indicate a slightly reduced ceiling void humidity. It is however beyond the capacity of the ESP-r software to analyse whether this would lead to a seasonal fluctuation of moisture levels in the roof void, ultimately resulting in a progressive build-up of interstitial condensation over a number of years.

The most interesting and potentially influential outcome of the assessment, and initially out-with the anticipated scope, is the high risk posed to perimeter storage spaces adjacent to an occupied space. Although these spaces are within the thermal envelope the restricted air exchange with the occupied space can lead to lower surface temperatures, higher humidity and surface condensation. Potential improvements to the design of these spaces, could involve an increased level of insulation either improved ventilation between the storage and main spaces (louvred doors). Sealing these spaces from the main room does not seem practical.

7.2 Future Aims

At present there is limited research in Scotland investigating how best to detail and specify thermal upgrades to habitable flat roof spaces of traditional properties in respect to moisture control and avoidance of interstitial condensation.

As the SME is already involved with in the refurbishment and conversion of traditional properties, the acquired knowledge/process can be applied immediately as part of architectural services or as a consultancy service to other design professionals, marketed via the company website, professional networking meetings, student lectures and community group talks.

The ultimate aspiration of the SME is to create a sustainable building consultancy with a comprehensive knowledge base of best practice solutions to improve the thermal efficiency of traditional properties. This knowledge base would encompass design, installation and testing. To this end it is hoped that further training with the Academic Partner using ESP-r, so that the simulation tool can be imbedded in the SME's process for developing and analysing project specific solutions.

The SME also proposes to undertake further work with advanced software tools such as WUFI, to establish the impact of different types of vapour control layer on the control of moisture over a longer period.