Scottish Energy Centre
Institute for Sustainable Construction

CIC Start Online – Academic Feasibility Study
Scottish Energy Centre (HEI)
&
SA Estates (SME)

BENEFITS & OPTIONS FOR THE RETROFIT OF AN 18TH C TRADITIONAL SCOTTISH HOUSE USING PASSIVE HOUSE (Retrofit) STANDARD

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1.0 INTRODUCTION

In many ways dealing with older properties can be a complicated and laborious task which involves recognising and learning about the existing materials and continuously finding ways to implement new and modern materials. The aim is not only to re-create and to restore older properties which can be found in many of our cities in Scotland, but to also while doing so, integrate forms of energy efficiency and ecological design. There are also properties which are in need of repair but are not classified as having a heritage or historical significance or are listed, but nevertheless because of its use and significance as a dwelling or building need to be restored. This is the case of typical hard to treat properties particularly the tenemental buildings around Scotland.

There are various ways in which these buildings can be restored and made more efficient; from the more historic and environmentally conscious perspective, with ecological materials and reproduction of ancient traditions with some degree of upgrading and new material integration; to the more specific and technologically advanced methodology which integrates new and old products challenging all components and changing much of the original functionality of the building.

Both techniques are valid but both should respect and acknowledge the buildings historical and architectural significance as well as the way it will or is being occupied.

1.1 FEASIBILITY STUDY BRIEF

The study presented will explore the application of a German building standard which has been implemented in many new build properties in central Europe, particularly Germany and Austria and which has also explored the possibility of applying such standard to the retrofit and upgrading of buildings.

The feasibility study will explore these retrofit possibilities using the standard and how best it would integrate into a hard to treat property which has been selected as the case study. The dwelling is located in the village of Cellardyke in Fife, Scotland. It's a traditional typical coastal village home which has had some renovations and attachments to it which haven't been all to its favour and that haven't addressed the ecological and energy efficiency it deserves.

Retrofitting using the Passive House Standard has been applied to some dwellings in mainland Europe in recent years but more recently to some Victorian terraced homes in England.

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1.2 AIMS & OBJECTIVES

The aim of this study is to create an outline of the barriers and advantages which will produce the integration of the Passive House standard for the future retrofit of the dwelling in question. The study will look at the key areas which will need to be addressed and the ways in which it will be upgraded pointing out the constrains around it.

The main objectives are:

- To analyse the current state of the home and look at the main elements to retrofit
- To learn and consider all the targets that are set by the passive House standard
- To guide the owner and architect on the areas which will need to be upgraded and to what level of technicality
- To facilitate the architect on how to achieve the standard and the loopholes which surround it

This study will NOT develop a design of the new retrofitted dwelling; it will simply point out how well the standard will be implemented.

1.3 BACKGROUND

Given the pressure from energy demand and supply experienced in recent years, a great concern has been created over the performance of dwellings in Britain. According to the Energy Saving Trust it is estimated that 45% of energy is consumed by Buildings in Britain and 26 of that is being consumed directly by residential buildings. A big percentage of those dwellings are considered to be hard-to-treat properties or dwellings that are difficult to heat efficiently. It is also a concern that nearly 70% of current stock buildings will still be in operation and use by 2050, indicating that most of them are thermally inefficient. Tackling these buildings is a priority and one that brings many difficulties.

It is for this reason that many government bodies have opted for the inclusion of tough building regulations relating to new buildings and also new ways of upgrading and refurbishment of older properties which were constructed with low energy efficiency standards.

This has created, in line with building regulations, a series of building codes and standards which try and focus the design of buildings, towards an energy and thermal conscious approach.

One of these standards is the use of the Passive House Standard developed in Germany and Austria and which has been the preferred building standard in many countries across Europe. In Britain, the standard hasn't been so main stream as in other main land European countries but in the [past 10 to 5 years there have been a number of dwellings built this way but very few applying in the refurbishment sector.

1.4 LOCATION OF THE CASE STUDY

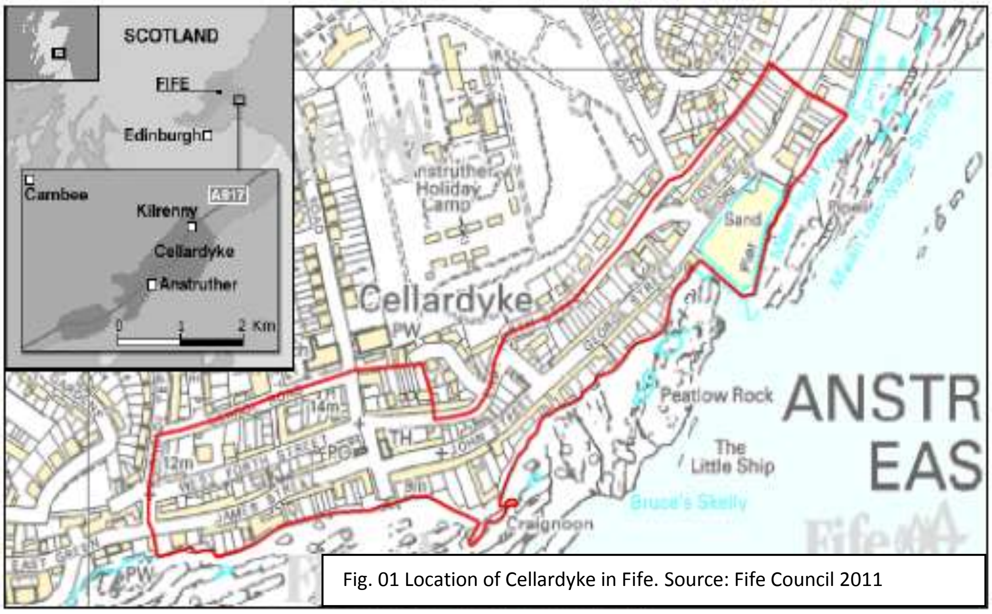

Fig. 01 Location of Cellardyke in Fife. Source: Fife Council 2011

The case study is in one of SA Estates properties; it is a stone walled, timber structure, 18th C town house located in Cellardyke, Anstruther in the East Neuk of Fife. The house is typical of many Scottish traditional coastal buildings and it sits in the conservation area of the town.

The site has two access points and it is on a slope. One access point is where the building is located, on George Street, and the other at the back on East Forth Street. The main entrance is at the lower end of the slope which opens directly onto the main street. The upper slope at the back, is used as a terraced garden, and borders with two neighbour gardens.

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1.5 EXISTING BUILDING

Fig. 02 Above - Front elevation. Source: JBW2011
Fig. 03 Below – back elevation. Source: JBW 2011

The dwelling is two storeys high with a converted attic space with limited head space between rafters and joists.
The main elevation is finished with rustic cement render applied onto a single core sand stone wall. All lintels and sills are flush with this render which gives the impression that it isn't original and was applied latterly. The front windows have been upgraded to recent PVC framed double glazed units. The roof has a double fall to the rear and to the front elevations. A dormer window dominated the front elevation belonging to the converted roof space.
The back elevation has partially preserved its original sand stone lime pointed finish, the right hand side of the external wall has a lime render. The distinctive feature of this elevation is that it has a semi circular stone extruded stair case from ground floor to first floor. The windows are also recent PVC double glazed units which stand out from the original features of the building. Two Skylights appear on the roof that open in to the converted loft space.
The roof is timber structured with higher than usual timber joist. Additional ceiling joist underneath are also present which support the voids floor. Externally it is covered by traditional terracotta clay pan-tile typical of the region.

The building has been previously used as a family home and has had numerous internal additions with stud partitions, plasterboard suspended ceilings and aged decor which has remained that way since its last upgrade in the early 1980's. Little of the interior decor can be rescued as it doesn't incur any historical significance.

The entrance level of the property appears to be lower than the back elevation level; there is at least 600mm difference. This is due to the slope going to the back of the site. There is at least 3000mm from the rear back elevation to a retaining wall which acts as the starting point of the slope. From this point there are steps along the side of the site towards the rear end of the site.

Thermally speaking, the existing building elements are poorly treated from air infiltration and thermal conductance through its fabric. There is no insulation on the existing walls, roof and floor.
The current heating system is linked to a gas fired boiler that distributes hot water to radiators throughout the dwelling and also provides hot water to bathrooms and kitchen.

1.6 METHODOLOGY

This report will develop awareness over elements that have to be contemplated when applying the passive house retrofit standard to the selected case study building.

The building in question has the potential to be refurbished using any approach or standard as long as this is performed using a conscious environmental and energy efficient method. The use of the Passive House standard was explored in such a way that it can be replicated in similar building types and equally be cost effective.

The report has explored all the standards requirements and has matched them with the needs and potential constrains attached to this building. Indication on what is to be done and what approach to take will also be commented on.

In order to conduct some of the alternatives measured U values were produced using the BRE U-value calculator and a dynamic thermal simulation software called CYMAP which is used to evaluate buildings and their components.

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2.0 PASSIVE HOUSE RETROFIT – EXPECTATIONS & REQUIREMENTS

The passive house standard has been applied to many residential and commercial buildings throughout Europe over the last 20. A passive house or "Quality Approved Passive House" is a house that is regarded as energy-efficient and benefiting from an all year-round comfort and good indoor climate without the use of active space heating or cooling systems. The space heating requirement is reduced considerably by using passive measures integrated to the building fabric or as building methods that can use natural means of heating and cooling. The objective is that with adequate use of passive solar and ventilation methods in combination with internal gains, that an all year round comfort level is reached with minimal energy use.

During design stage and specification, the use of various criterions is applied. The standard relies on the use of its Passive House Planning Package (PHPP) which helps the designer to verify and properly specify the passive house. According to the Scottish Passive House centre "It has proven itself over many years as a reliable and accurate instrument for energy balance calculations and for the implementation of design changes in order to improve energy balances on domestic and commercial buildings"

Most of the designs incorporated into passive houses benefit from natural light from big openings that let solar radiation into the building and natural ventilation mechanisms to inject the homes with fresh air while also taking advantage of heated air already in the home.

The homes are regarded as being highly insulated with minimal thermal bridging around the fabric and with small space heating requirements and overall low energy use. As a result of this the homes are thermally comfortable and economical to run and often can subsist from internal and external solar gains that are constantly being re-used – this is referred to as a Mechanical Ventilation with Heat Recovery (MVHR) Unit. The owners of passive homes often have no conventional space heating devices (boilers/radiators) in their rooms as a result of the use of MVHR units which can be daunting and psychologically difficult to understand they are not present, making it important for the residents to be briefed for them to understand their new highly efficient home both in its operation and its sensitivity.

The implementation of passive house standards can be at times strict and complicated, especially because there are certain guidelines and levels of targets that have to be met in order to obtain certification and recognition on the new building or in this case the retrofit.

Many passive homes have been built as new buildings where the site restrains and design stage planning can be meticulously calculated and detailed. In the case of a refurbished building the standard can become complicated and not as straight forward as in a new build. There are many barriers to applying the standard to an existing home where the designer is not completely sure on the components performance. Although it is recommended to make a detailed survey of the buildings fabric and services, there are many elements that are impossible to determine their performance. The same new build criteria are applied to a passive house retrofit but some limitations are permitted as a result of certain embedded uncertainties in the existing building.

The following list can be identified as the basic criterion that should be contemplated when planning to build and restore a building using the passive house system.

a) Site Planning

This aspect of the list is more directed to a new build being developed and it focuses on the importance of site suitability, infrastructure and services, planning permission from planning officials of the region, shape of the building (terraced or as a large block) and the availability of elevations facing south for solar harnessing or the amount of shading it may have minimising solar gains.
All of these factors are very important and should be considered in all passive homes. Ideally these requirements should be looked at in the retrofit but at times there are many constrains already influencing on the buildings which will make the application of the standard not worthwhile.

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b) Pre-planning

The pre-planning stage relates more to the shape and configuration of the building in question. Once again in a new build this can be easier as this can be subject to the requirements of the building user. In a retrofit an evaluation of the building looking at all its positive and negative aspects should be performed. At this stage it is important to do a pre-PHPP calculation and contact local passive house certifiers to discuss the project.

This stage includes the following:

- The buildings morphology and density – the amount of wall exposure
- South facing elevations and their dimensions to receive solar gains and light
- Solar shading factor influenced by: adjoining walls, trees and other plants, balconies, overhangs and adjacent buildings
- The envelope shape – its complexity avoiding projecting shapes lowering the junctions between them thus lowering thermal bridging
- The buildings floor plans focusing on service zones that are centralized and compact, wet walls for toilets and kitchens
- Separation of un heated spaces – by making them air tight with no cold bridging
- Obtain local climatic data to feed into the passive house software

c) Planning – Passive House certification

At this stage it is advisable that a more developed design is in place in order to be able to specify the wall, roof, floor, foundations and openings. It is advisable to look into the fabric orientated targets imposed by the standard which will give you an indication of insulation thickness and type. It is important to lower the exposure and conditions where cold bridging can occur by creating adequate insulation overlaps and avoid material conduction paths.
In terms of the services and any micro generation included inn to the building it is advisable at this stage to plan any service voids, cupboards and maintenance hatches for the adequate operation and servicing of the technology. Finished floor plans indicating pipe trajectories, waste water paths and air duct locations which are advisable to be tackled sooner rather than later.

d) Planning – Building fabric & openings

The fabric is key to the passive performance of the building. By keeping the generated heat or stored heat inside the fabric the building is lowering the need for any active heating systems. For this reason insulation plays a big part in how well the building will perform. The use of thermal mass is also a factor which absorbs any solar radiation which can be re-radiated back into the rooms. In many cases and depending on the volume of the home, thermal mass is used in ground floors that can have a concrete dense base that can act as a thermal store. Thermal mass is not present in all passive homes but insulation and effective fabric conditions are remain constant. Retrofitted homes would have to be properly insulated in line with the existing building fabric systems but the advantage these homes have is that thermal mass plays a big factor as many of their components are built using dense materials (brick, sandstone, etc)
For example, new buildings should have a U value of 0.15W/m^{2}K or better on all elements of the building while windows are required to obtain 0.8W/m^{2}K most often achieved by triple glazing.

In all design features it is essential to look into adequate detailing tackling thermal bridging and airtightness.
Glazing plays a big factor on the envelopes performance. It is influenced by the type of glazing, the frame material, glass area, and any shading.
With the above in place it is recommended that at this stage the PHPP could calculate the space heating demand in order to verify that the specifications are correct and that the targets are being met.

e) Planning – ventilation systems

Ventilation, as explained above, plays an important part in the adequate space heating of the passive house buildings. It is not only the efficiency of the MVHR system but also the conscious design of the services, pipe work and duct work.
It is important to keep cold duct of air outside the heated envelope, if this can't be avoided the ducts should be insulated as much as possible going through and into the heated zones of the building. The same applies to the heated warm ducts which should be kept inside the envelope. Flow velocities in these ducts should remain at 3m/s and both design measurements and flow balancing facilities or losses should be integrated into the system in order for its operation to efficient. Other design and installation elements like noise and fire should be considered.

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Other considerations should be dealt with as follows:

- Air inlets – avoiding short-circuiting air flows, widths, flow regulation and balancing
- Air exhausts – avoid locating them above heating systems if any
- Central ventilation and heat recovery
- Efficiency of the device – 75%
- Internal and surrounding air leakage
- High electrical efficiency consumption
- Ventilation controls
- Kitchen extractor needs
- Considerations over a ground heat exchanger to keep air frost free

f) Additional building technology

It is important to have al all round efficiency of services not only in the heating and ventilation of the home but also in the management of water and sewage water.
This section concentrates on the adequate hot and cold water making sure they are well insulated and installed in the inside of the thermal envelope (hot water). It is also making emphasis on installing water-saving taps, connecting dishwashers & washing machines to the hot water supply.
Any waste water flowing out of the property should not penetrate the airtight layer of the building and if it has to efficient seals should be installed, for example, gaskets, sleeves, tape or sealant. There are also considerations on the use of 'A' rated highly efficient appliances throughout the dwelling.

g) Construction Phase – building fabric/envelope

The site management at this stage should make sure that all materials are supplied correspond to the specified materials on the plans and passive house outline. Minimal waste should be procured at all times. The building construction method should involve small amounts of waste both in the delivery and packaging of the materials as well as the placement of materials. Adequate design should address this in order to use the materials as efficient as possible.

The following should also be addressed:

- Minimal thermal conductance between materials and components – cold bridging
- Integrity and quality of workmanship of insulation – minimal gaps and tampered materials
- Airtightness – making sure areas between walls and floors are sealed, as well as pipe work, wiring and service ducts or flues.

It is recommended that an airtightness test is carried out as early as possible in the construction phase; this can be performed as soon as the envelope is airtight.

h) Construction Phase – ventilation

Airtightness is also a concern at this stage and it is worth conserving the integrity of the air tightness envelope where duct-work and piping are being installed. All ducts and the central ventilation units need to be accessible and clean during installation for further inspection and maintenance. These should be leak free and acoustically insulated in service cupboards where noise reduction can be minimised.
The flow settings of the MVHR system should be tested in order to measure the intake and exhaust air flows making sure they are balanced, it is also critical to compare the fresh and stale air intakes and distribution. Electrical power should also be measured.

i) Construction Phase – additional building technology

The installation of low carbon technology, for example, solar PV and thermal panels, should be fixed and positioned without jeopardising the airtightness of the envelope. It would be good practice to create an internal installation void for the connection and fixing of such devices, which will limit the perforation and creation of gaps in the airtight layer of the dwelling.
All piping and fixtures should be properly sealed and adequate insulation wrapping round limiting cold bridging and air escaping.

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j) Occupiers engagement

In all highly efficient buildings it is essential to brief the tenant and owners to create added knowledge on the functionality and operation of the dwelling. All technology should have an owner's manual in which all the operation and maintenance elements are explained. This will make the users aware of what to expect from a highly insulated building with low carbon technology which requires bespoke operation in comparison with conventional heating and ventilation systems.
In some Passive houses the use of conventional radiators is seldom used and this can create concerns to the occupier as there are no heated tactile devices (radiators or secondary heaters)
The operation of renewables is also essential that is conducted properly as failure to do so will lower their efficiency and create discomfort.

3.0 PASSIVE HOUSE RETROFIT APPLIED TO THE PROJECT

In basic terms the passive house standard is achieved with the following criteria and methodology which is calculated by the PHPP software.

3.1 PASSIVE HOUSE BASIC CRITERIA

The standard concentrates on the following:

- Space heating demand - The amount of energy from active sources to generate space heating within the building. This could come from boiler use, the MVHR system and any other that contribute. Measured in $kWh/m^2/year$.
- Maximum heating load – The capacity of the heating systems load measured at W/m^2
- Cooling demand – The opposite of the space heating and dependant on its location and needs, hot regions will have to focus on this. Measured in $kWh/m^2/year$.
- Primary energy use - All other energy needed to operate the dwelling including heating, cooling, lighting, domestic hot water, appliances etc.
- As built airtightness – The building should achieve airtightness from an average between the pressurisation and the depressurisation tests performed after the building has been completed. Measurements can be given in air changes per hour or at 50 Pascal's $m^3/(m^2h)$
- Opaque components U value – This includes walls, ground floors and roofs adequately insulated measured in W/m^2K. The external wall insulation must be carried out externally on at least 75 % of the area. Insulation on the interior of up to 25 % of the area is only permissible if external insulation is not practicable, not allowed or definitely not cost-efficient[1].
- Windows U values – all windows and roof lights including frame and glazing should reach certain thermal transmission values measured in W/m^2K. It is recommended that windows are certified by Passive house suitable components using triple glazing, low-e glass and insulated frames.
- Thermal bridging – Linear thermal bridging should be avoided as much as possible wrapping insulation round components and sealing properly
- Summertime comfort – overheating is a big concern. Internal temperatures should be ≤25˚C
- Moisture protection – components insulated internally should be analysed further and indoor air behind insulation layers should be prevented on a permanent basis.

As explained, there are some differences on the new build targets and the refurbishment.

Table 01 indicated these criteria differences:

[1] PASSIVE HOUSE INSTITUTE Dr. Wolfgang Feist - www.passiv.de

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Type of project	New Build	Refurbishment
Sapce heating demand (kWh/m^2/year)	15	≤25
Maximum heating load (W/m^2)	10	≤16.5
Cooling demand (kWh/m2/year)	15	≤25
Primary energy use (kWh/m2/year)	120	≤156 i)
As-built air tightness [@Pa m^3/(m^{2}h)] or ach	1.67 (0.6ach)	Limit: 1.0ach Target: 0.6ach
U-values for opaque elements (W/m^{2}K)	0.15	Interior insulation: 0.15 Exterior insulation: 0.30 ii)
U-values for windows (W/m^{2}K)	0.8	0.85
Thermal bridging (W/mK)	0.01	0.01 with exceptions
MVHR efficiency (%)	75	75

Table 01 - Criteria differences between new build & refurbishment- Source Passive house Institute criteria 2012

i) Calculated using the following equation: 120 kWh/m2/year + (Q_H-15 kWh/m2/year)*1.2

ii) Other U values apply: External wall to ground: 0.15 W/m2K, Roof or top floor ceiling: 0.12W/m2K, Roof terrace: 0.15W/m2K & ceiling of an unheated basement 0.15W/m2K

3.2 REDUCING HEATING DEMAND – OVERVIEW & PROPOSALS

The building in question has been briefly described in section 1.4 as a typical Scottish fishery town dwelling that has had numerous upgrades requiring radical upgrades on both aesthetic and thermal issues.
At present very little insulation is fitted in the building elements, the roof has minimal mineral wool insulation between joists and rafters. The windows are performing relatively well but will not fulfil the passive house criteria. The replacement of these will be straight forward as there are no restrictions over planning as the current windows are not original and authentic period windows. The walls and other elements of the house have no insulation or any thermal bridging solutions.

AIRTIGHTNESS

This is one of the most critical aspects when reducing buildings CO_2 emissions. Elements like chimney breast, gaps in plasterwork, service penetrations, and poorly fitted windows and doors can all contribute to poor airtightness, creating draughts and leaking heat from the building.

To ensure the building is airtight, it is recommended that a draught-free layer is formed by continuous layer of internal plaster linked to building membranes around walls, ceilings and floors.

An air permeability test should be conducted before and after the buildings works. It is estimated that this building can currently be leaking between 16.0 and 20.0m^3/m^2/h. The recommended passive house standard should be 1.6 m3/m2/h or 0.6 air changes per hour. In contrast the Scottish Building regulations section 6 Energy doesn't require an air leakage test or a figure to be achieved. It considers that if the building is built or in this case, refurbished, using the accredited standard details, airtightness is achieved in the region of 5 & 10m^3/m^2/h.

a) WALLS

The existing configuration of walls is divided in: external front and back elevations, two party walls (homes on either side of the dwelling) and the internal partitions.

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EXTERNAL WALLS


Fig. 04 Front elevation wall render (left)

Front elevation

Front elevation faces south obtaining the majority of the mid day solar radiation. The back elevation faces north located 900mm above street, it sits sheltered the majority of the day with the back garden slope and adjoining dwellings casting a shadow. This creates some moisture and dampness accumulating on the ground floor.

The front wall elevation consists of the following exterior to interior build up: 20mm of mortar render; 500mm sandstone rumble; 50mm timber studs (no insulation); 13mm plaster board. This gives an estimated U-value using the BRE U value calculator and CYMAP software of 1.1 W/m^2K

The front elevation has 5 windows that have stone sills, lintels and vertical supports which are a potential thermal bridge if not dealt with appropriately. The reveals and junctions with the front door are also important to address. See figure 02.

Back elevations

This elevation has various internal and external finished that have been analysed equally in order to obtain an estimated U value. The different configurations with estimated U values are as follows:

1. Wall right hand side, ground floor: 20mm lime/mortar; 500mm sandstone rubble; 50mm timber studs (no insulation); 13mm plaster board. U value: 1.09 W/m^2K.
2. Wall right hand side, first floor (leading to attic space): 20mm lime/mortar & bare 500mm sandstone rubble. U value: 1.60 W/m^2K.
3. Wall in bedrooms left hand side, ground and first floor: 500mm sandstone rubble; 50mm timber studs (no insulation); 13mm plaster board. U value: 1.12 W/m^2K.
4. Curved wall in staircase: 500mm sandstone rubble; 50mm timber studs (no insulation); 12mm timber internal finish or 13mm plasterboard. U value: 1.12 W/m^2K.


Fig. 05 Curved stair case and bedroom rubble stone walls


Fig. 06 Contrast of the finished on the back walls

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Fig.07 Stair leading to attic – bare wall

Fig. 08 Stair case leading to first floor

Fig. 09 Kitchen interiors – window facing main road at front elevation

Party Walls

The dwelling shares two walls regarded as the party walls. It is unsure whether the walls are separated and each dwelling shares or has its own walls between them. From figure 10 we can observe with the use of a coping stone that the wall with the dwellings chimney on the left hand side falls separately beside the higher neighbour's gable wall. This is not the case when we notice the right hand side stepped coping stone which falls on the neighbour's wall. Interestingly by observing the walls render, there is a clear un-textured vertical rim on either sides of the dwelling which may signify that all three dwellings have their own walls. If this is the case the refurbishment will be easier as insulating such walls will be straightforward without compromising any other dwellings beside it.

Fig. 10 Front elevation and party walls in detail

Fig. 11 Back elevation with stepped coping stones above party walls

It is assumed that the party walls have the following build up (exterior to interior): 200mm sand stone rubble, 50mm timber studs (no insulation), 13mm plaster board. U value: 1.6 W/m^{2}K.

Other walls

Partition walls are all plasterboard stud walls that are not original to the building. They will be expected to be demolished appropriately as they don't appear to be of significance to the new layout of the building.

The walls belonging to the dormer referred to as "dormer cheeks" are a particular heat loss pathway. Most dormer structures sit on the roof and are considered a light weight element therefore they aren't made of masonry. In this case it is assumed they are made of timber with an internal plaster board finish and an external slate finish.

They are as follows (exterior to interior): 5mm slate, 10mm of timber batons, 50mm timber studs (no insulation), 13mm plaster board. U value: 1.75 W/m^{2}K

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Summary of current state U values:

Element description	U value (W/m^2K)
Front Wall	1.1
Wall right hand side, ground floor	1.1
Wall right hand side, first floor	1.6
Wall in bedrooms left hand side, ground and first floor	1.1
Curved wall in staircase	1.1
Party walls	1.6
Dormer Cheek	1.70

Table 02 Summary of U values current state

WALL SOLUTIONS

The Cellardyke dwelling, as described above, has no insulation in any of the walls. In order to achieve the passive house standard as indicated above in section 03 there are two alternatives. The best performing would be externally insulating the buildings walls which would lower the amount of expose surfaces and lower thermal bridging. This alternative was not used as the property is in a conservation area an technically it would of presented many problems. Insulating internally has been the better choice. This alternative means the interior floor area is compromised but it would be the better alternative given the expected open plan layout which is proposed in the living areas. There are two proposed alternatives to the internal insulation; one using ecological natural materials and another using man made insulation materials. The suggestion in order to deliver a profound thermal bridging solution is to strip all walls down to the sandstone wall and look at relining alternatives with new stud systems.
All external finishes on the front and back walls have been brought back to its original style, taking away all mortar renders and stripping back to the exposed sandstone with new lime mortar joints and pointing. This has been done to preserve the dwellings original features as the existing front elevation mortar render has been added recently.

Front & Back elevations

Alternative One
This alternative will use internal lime plaster followed by 60mm of wood-fibre insulation board to minimise thermal bridging to timber battens and provide a carrier for the internal plaster finish. In order to keep the airtightness and minimise the interstitial condensation inside the insulation layers, an airtight membrane/vapour control layer is installed behind the wood-fibre board. A further two 100mm layers of sheep's-wool insulation fitted between two layers of 50x100mm softwood timber battens.

The resultant U value of this build up was 0.15 W/m^2K

Alternative Two
A different approach was analysed implementing traditional insulation materials that are not naturally made. In simple wall sections the build-up was (internal to external): 20mm Cement/lime lining, 12mm OSB, 50mm timber studs for service zone (no insulation), 12mm OSB, 3 layers of 70mm phenolic insulation with timber battens within the middle layers, 500mm sandstone rubble.
A service zone has been created in order to create a continuous air tight layer which will limit the amount of perforations from electric cable runs and boxes. All services can go up this void but if any penetrations are needed to be made the use of grommets or sleeves should be fitted.

The resultant U value of this build up was 0.14 W/m^2K

Party Walls
Party walls have been treated in case heat loss can escape through to the neighbours. There are walls that co-inside but others that are creating thermal bridges where heat escapes and conducts easily. The proposed layering is as follows: 20mm Cement/lime lining, 12mm OSB, 50mm timber studs for service zone (no insulation), 12mm OSB, 60mm wood-fibre insulation, 200mm sandstone rubble.

The resultant U value of this build up was 0.4 W/m^2K which seems to be below the passive house limitations but it is important to point out that these walls are not external and share a wall with other dwellings that may be heated.

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Dormer Cheeks
It is important to address the two dormer cheeks in the property as they are built as a light weight element with little thermal response. A combination of two insulation products is suggested. It is first recommended to fill in the void in between the timber studs of the wall with 50mm rigid phenolic insulation followed by 12mm of OSB to form a base for 10mm of Aerogel insulation with a final internal finish of cement/lime plaster. This has improved the dormer cheeks by 75% giving a resultant U value of 0.4 W/m^{2}K.

b) FLOOR

It is difficult to know exactly what the floor is made of without an accurate survey. From the numerous visits it is assumed that the ground floor is a solid stone or concrete floor on top of a compacted hardcore. The ground floor has a very basic finish with a combination of laminate timber boards and carpet areas.
All intermediate floors have suspended timber joist attached to the party walls with timber floorboards.

Given the low floor to ceiling height in the ground floor (2.13m), it will be difficult to propose any upgrade to passive standard. In many occasions ground floors are suspended where insulation can be added underneath or the floor to ceiling height is sufficient to insulate adequately.

Intermediate floors could be insulted for acoustic purposes with 100mm sheep's-wool insulation between existing floor joists and retaining the existing floorboards and skirting boards.

c) CEILING/ROOF

Located in the accessible attic space used as a home studio, it has a floor to ceiling height of 1.9m but all ceiling joists are uncovered to give extra head height. The lower level of those joists is 1.7m which is not a comfortable height to use. Planning restrictions will object to this height.


Fig 12 Attic space used as a study


Fig 13 Storage space in the roof voids near the eaves of the roof

The ceiling leading over to the roof slope is not insulated and neither is the ceiling and void underneath the roof ridge which indicates a substantial heat loss occurs through the roof.

An alternative that is suggested to achieve the passive house standard is to add 300mm sheep's-wool insulation placed above the existing ceiling, above the joists in the small roof void underneath the top roof ridge. In the roof slope and stud wall on all four sides of the dwelling it is suggested that all plasterboard is removed and insulated with two layers of 100mm of sheep's-wool insulation between studs and 60mm of wood-fibre. The objective is to re line all the walls, some of which have a void behind them as they are close to the roof eves that are too low for people to walk under. There is sufficient space behind these existing stud walls to include the above insulation.

The estimated ceiling roof U value would be in the region of 0.11 W/m^{2}K

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d) WINDOWS & DOORS

The dwelling is located in a conservation area that limits all external modifications that are not in line with the towns & streets context which could clash and not relate to original features. All openings should be fitted with original or in line with the original window frames and doors or skylights.
For some reason the dwelling has been fitted with PVC framed double glazed windows and Velux type skylights with an estimated U value of 1.8 W/m²k. Both back and front windows have these window types except for two small steel framed windows in the rear elevation.

Fig. 14 Existing PVC window

Fig. 15 Draught lobby door

Fig. 16 Front double door

Fig. 17 Existing back door

To achieve the standard it is suggested all windows are replaced with timber framed triple glazed windows with a U value less than 0.8 W/m^2K. Most of the components used to achieve passive house are certified by the Passive House Institute and therefore it is recommended that approved windows already in the market are purchased. This applies both to windows and skylights.
In terms of the doors, there are currently two external doors in the dwelling. The front door, which is currently a double leaf solid timber door, has an estimated U value of 3.0W/m²k. Following this front door there is a draught lobby and a secondary fully glazed softwood timber door.
The draught lobby should be kept and an improvement in the existing door should be in place. It is suggested that Aerogel quilt is placed on the internal face of the door thus improving the U value to 0.7 W/m²k.
The back elevation at the curved stair case has an external wall to the garden and patio. This door is in poor state and should be replaced completely with an energy efficient timber door.

3.3 BUILDING SERVICES – HEATING & VENTILATION

Currently the building has a conventional gas boiler providing hot water to bathrooms and kitchen and also feeding in hot water to radiators for space heating. The device is more than 10 years old and in need of replacement. All radiators are placed in the arranged floor layouts and therefore will have to be dismantled for the new internal layout and design.

MECHANICAL VENTILATION WITH HEAT RECOVERY SYSTEM

It is recommended that a heat recovery ventilation system is installed so that fresh air can be brought into the house during the colder months without opening the windows. A Mechanical Ventilation with Heat Recovery (MVHR) can act as a recovery device that collects hot air produced in the kitchens and the bathrooms mixing it with fresh air while re distributing it to living areas. This provides fresh warm air to the house, recovering 92% of heat from the outgoing air. It is only when outside air temperatures drop below -3°C does small heating element need to be activated.
MVHR systems are essential in heavily airtight and insulated dwellings in order to re-circulate air and bring in heated fresh air.
Passive house certified MVHR systems require small energy efficient fans using little energy around 0.45W/cu metres/hour.

The energy used to run the unit is less than the energy that would be used to heat with conventional boiler and radiator systems. It is also good practice to have a conventional boiler for hot water in kitchens and bathrooms and also as means of back up heating during very cold months of the year.

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It is good practice to plan the location and duct work for the MVHR system before any work commences making it an important factor in the whole project. The voids around walls in the usable attic space is an obvious space for the system but it depends on the duct work and how well it can trickle down the house into different walls and ceilings. It is recommended that the system is accessible and in comfortable maintenance friendly spaces. Filter cleaning and replacement is a constant task every 3 months.

Careful consideration of placement of ducts and nozzles is important in order to achieve an efficient system that delivers high levels of comfort. Generally ducts are located at high level at the top of walls or in ceilings. Undercut doors allow air to escape from living rooms and enter bathrooms or kitchen. Planning the air paths maximises the feeling of freshness provided by the system. A high level of air quality is an important part of the increased comfort levels that the Passive House design philosophy.

3.4 ALTERNATIVE SOURCES OF ENERGY

A small study on the potential of the use of renewables was performed. Only the conventional micro-renewables were looked at and unfortunately both solar hot water and solar photovoltaic panels were not suited for the dwelling. Previous to the feasibility of the technologies (sizing and design exercises) a Solar shading study was conducted. This study indicated the hazards around the south facing roof top. It concluded that the neighbours tall gable end and chimney stack on the left hand side of the dwelling casted a big shadow eliminating the possibility of placing panels on that side of the roof. On the other side of the roof the neighbour's chimney and the dormer in the centre of the roof casted a shadow which eliminated the possibilities of an installation.

There was the alternative of placing panels on the plots rising slope at the back garden but this would compromise on the sites garden and the owner's use of a vegetable patch. The better tilts and constant undisturbed solar radiation gains are placed further back into the adjacent site (owned by the same client) which can be potentially used but it has been suggested by the client that other plans are destined to that site where a new build could be designed and constructed.

No other renewables were analysed.

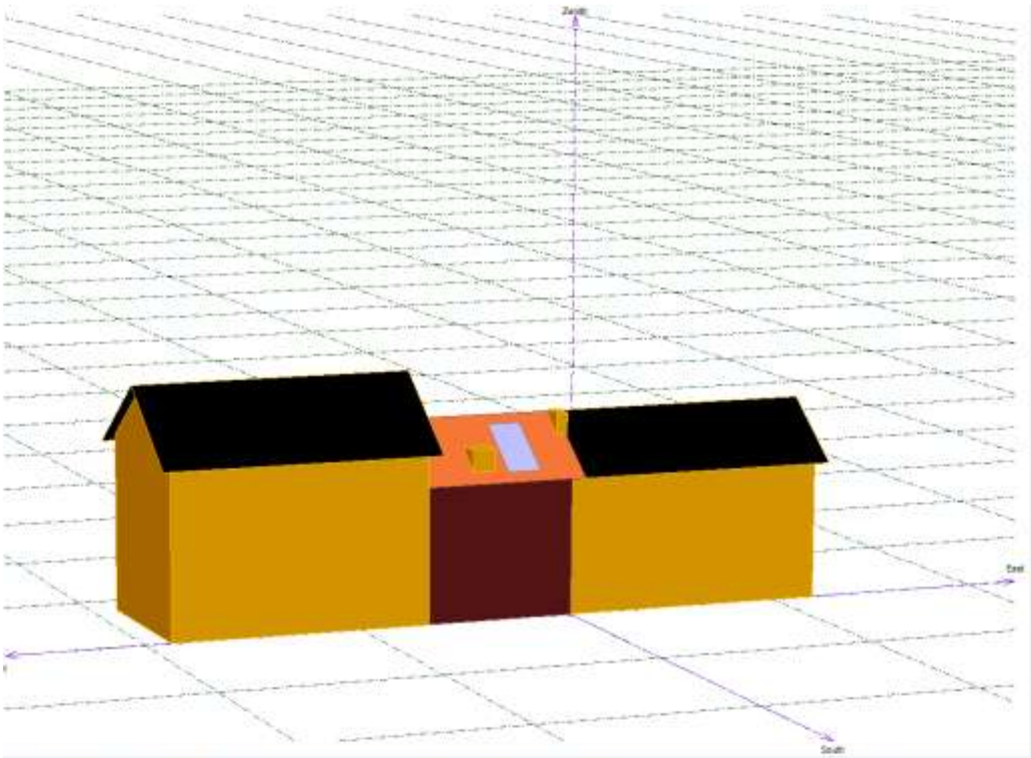

Fig. 18 Image showing solar shading analysis produced by solar PV software

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4.0 DOCUMENTATION NEEDED TO ACHIEVE STANDARD

The following information has been supplied by the Passive House Institute focusing on all the documentation needed and elements to be verified and added in order to obtain certification.

Documents necessary for certification
3.1 Signed PHPP with at least the following calculations
Worksheet
(Please also attach the calculation as Excel file or send via E-mail) **from PHPP**

- Property data and specific demands ....**Verification**
- Organisation of areas with allocation of U-values, radiation balance data, and thermal bridges .... **Areas**
- Calculation of U-values of regular building elements .... **U-values**
- List of building elements used... **U-list**
- Calculation of window U-values .... **Windows**
- List of windows and glazing used...**WinType**
- Reduction factors for the ground, if used .... **Ground**
- Calculation of the shading factors ....**Shading**
- Calculation of the air quantity and the heat recovery efficiency as well as evaluation of the pressure test results....**Ventilation**
- Verification of the specific heat demand according to the PHPP annual method.. **Annual Heat Demand**
- Verification of the heat demand according to the monthly method, if selected in the Verification Sheet .... **Monthly Method**
- Verification of the heating load according to the PHPP...**Heating Load**
- Calculation of the frequency of overheating in summer ....**Summer**
- Calculation of the summer shading factors ....**Shading-S**
- Determination of the summer ventilation, if used ....**SummVent**
- Calculation of the heat losses from heating and hot water distribution systems...**DHW+Distribution**
- If a solar collector is used, calculation of the solar fraction for domestic hot water ....**Solar DHW**
- Verification of the annual utilisation factor for the heat generator.....................................**Compact, Boiler order District Heat**
- Calculation of the electricity demand.. **Electricity**
- Calculation of the auxiliary electricity demand.. **Aux Electricity**
- Calculation of the primary energy value................. ....**PE Value**
- Selection of climate data, if not standard ....**Climate Data**

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3.2 Planning documents for design, construction, building services:

- Site plan including the building orientation, neighbouring constructions (position and height), prominent trees or similar vegetation, possible horizontal shading from ground level elevations; photographs of the plot and surroundings. The shading situation must be comprehensible.
- Design plans (floor plans, sections, elevations) as pre-construction plans 1:100, or implementation plans 1:50 with comprehensible dimensioning for all area calculations (room dimensions, envelope areas, unfinished window opening sizes).
- Location plan of envelope areas and windows, also thermal bridges if present, for allocation of the areas or thermal bridges calculated in the PHPP.
- Detail drawings of all building envelope connections, e.g. the external and internal walls at the basement ceiling or floor slab, external wall at the roof and ceiling, roof ridge, verge, installation situations of windows at sides, above and below, anchorage of balconies etc.. The details should be given with dimensions and information about materials and conductivities. The airtight level should be indicated and its connection points for the implementation should be described.
- Proof of aw ≤ 80 % (in case of doubt)
- Building services plans – ventilation: representation and designing of ventilation units, volumetric flows (Specification Sheet Planning, see PHPP CD), sound protection, filters, supply and extract air valves, openings for transferred air, external air suction and exhaust air outlet, dimensioning and insulation of ducts, sub-soil heat exchanger (if present), regulation, etc..
- Building services plans – heating, cooling (if present), plumbing: representation of heat generators, heat storage, heat distribution (pipes, heat coils, heating surfaces, pumps, regulation), hot water distribution (circulation, single pipes, pumps, regulation), cold water pipes, drainage with aeration including their dimensioning and insulating standards.
- Building services plans – electrical (if used): illustration and designing of lighting and elevator.

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3.3 Proofs, technical information, with product information sheets if applicable:
Manufacturer, type and technical information sheets, especially of insulation materials with very low conductivity (l < 0.035 W/(mK)).

- Itemisation of a comprehensible calculation of the treated floor area.
- Information about the window and door frames to be installed: manufacturer, type,
- Uw value, YInstall, YGlazing Edge, graphical representation of all planned installation situations in the external wall. The calculation values should be mathematically computed according to DIN EN 10077-2. For products which have been certified3 by the Passive House Institute, these verifications are available.
- 5 Data sheets for certified components can be found on the internet at www.passiv.de

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- Information about the glazing to be fitted: manufacturer, type, build-up, Ug value according to DIN EN 673 (to two decimal places) g-value according to DIN EN 410, type of edge spacer.
- Evidence of the thermal bridge losses coefficients used in the PHPP according to DIN EN ISO 10211. Alternatively, comparable documented thermal bridges can be referred to (e.g. from certified Passive House construction systems, PHI publications, Passive House thermal bridge catalogues).
- Short description of the planned building-technical supply systems, with schematic drawings if applicable.
- Manufacturer, type, technical data sheets of all building-technical components: ventilation system, heat generator for heating and hot water, heat storage, insulation of ductwork and pipes, heater coils, frost protection, pumps, elevator, lighting etc..
- Information about the sub-soil heat exchanger (if present): length, depth and type of installation, soil quality, size and material of tubing, verification of the heat recovery efficiency (e.g. with PH-Luft4). For sub-soil brine heat exchangers: regulation, temperature limits for winter/summer, verification of the heat recovery efficiency.
- Information about the length, dimensioning and insulation level of the supply pipelines (hot water and heating) as well as the ventilation ducts between the heat exchanger and thermal building envelope.
- Concept for efficient electricity utilisation (e.g. specified devices, explanation and incentives for the house or apartment owner). If efficient electricity utilisation is not verified, average values of devices available on the market will be set (standard values of PHPP).
- Proof of summertime comfort must be provided for the buildings which are to be certified.
- The PHPP procedure for determination of summertime overheating only shows the average value for the whole building – however, individual parts can get overheated. If this is suspected, a detailed analysis should be carried out.

5.0 CONCLUSIONS

It is important to point out that this report and study was not a design and detailed construction out line for the dwelling in question. The work developed in this report has pointed out all the elements to consider with some alternative approaches to achieving the Passive House criteria. This was especially developed for the fabric interventions on the building.
The report will be a guide into what elements and constrains the building may present when looking into a more detailed design and construction method.
A lack of plans and sections of the building and an appropriate survey of the dwelling have limited the accuracy of the suggestions and alternatives needed to achieve the standard.
It was also not feasible to conduct the PHPP heat loss analysis and calculation as the lack of information would have made an attempt to fill in the spread sheet an immense task which would prove to be time consuming with many assumptions and inconclusive results.

The fabric intervention alternatives have given some scope of what is needed to be achieved in order to obtain lower heating demands and regulated thermal losses. It is important to focus on the airtightness of all elements, junctions and service punctures. It is of extreme importance to have a carefully stripped internal finishes and core of the building in order to point out any possible decay or damage imposed on the building because of the passage of time and the lack of maintenance. This will be a worthwhile investment in time and money as it will ensure that all subsequent work is done from a sound starting point.

As well as airtightness, thermal bridging has a very pronounced effect on energy loss for well insulated buildings. If these bridges are not addressed they can undermine the performance of the building significantly and even lead to defects such as mould problems.

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In summary, there have been some alternatives that are worth considering when designing further and investing into the passive house systems.

The following table indicates the improvements suggested in thermal transmission.

Element description	Current state U value (W/m^2K)	Improved alternative U value (W/m^2K)
Front Wall	1.1	0.15/0.14
Wall right hand side, ground floor	1.1	0.15/0.14
Wall right hand side, first floor	1.6	0.15/0.14
Wall in bedrooms left hand side, ground and first floor	1.1	0.15/0.14
Curved wall in staircase	1.1	0.45
Party walls	1.6	0.4
Dormer Cheek	1.70	0.4
Floor	-	-
Roof	1.80	0.11
Windows	2.15	0.75
Doors	3.00	0.70

Table 03 Summary of suggested fabric alternatives

It is evident that the walls can achieve the target criteria imposed by the Passive house standard with many layers of insulation and different formations. The problem is in the reduction of floor space which in some spaces may not be a concern but other more reduced spaces it may be awkward. This is the case in the curved wall which may prove to be technically and architecturally difficult to increase its insulation layering. Thinner alternatives could be incorporated but may prove to be very costly.

In terms of the windows and doors it is unfortunate that all the double glazed windows will have to be changed into more environmentally sourced timber framed triple glazed units. The glazing will bring back some originality to the buildings appearance as the wooden framed windows will integrate properly with the context of the street and area with similar period type dwellings.
Doors have been suggested to be replaced, in particular the back door that is not in a good state. The front doors could be upgraded and insulated with aerogel but the awkwardness of having two leaf double doors is uncomfortable to access and exit the dwelling because of the reduced opening dimensions.

The heating and ventilation system is key to achieving low heating demands in the dwelling and also providing, to what can be a very air tight building, with controlled fresh heated air into the rooms. Evidence has shown that in many of the dwellings that have these systems can present some noise issues underneath the air vents and outlets as air makes a noise while being sucked in and released out. This may be an issue to the residents.

The MVHR systems have to be approved by the Passive House Institute and it is suggested a certified supplier is sourced. In the past the use of the German company “Paul” in particular the Focus model has proven to be a reliable and well operating system. In this new model a combination of efficiency with ease of access, operation and maintenance have been proven to be cost effective and worth the investment. The equipment is of a large size therefore an appropriate location is recommended so that it can be isolated from the living areas but at the same time be in an accessible area for maintenance.
It is recommended to keep a backup of heat for when temperatures are very low for longer periods of time. This will allow comfort level to be maintained.

It is unfortunate that both solar thermal and solar PV were not able to be implemented into the dwelling. Further analysis should be done on other renewables as this was not able to be done because of the lack of site information.

From the outlines of the standard mentioned in at the beginning of the report it can be observed that the Passive House standard can be a very regimental and disciplined standard that doesn’t leave much flexibility to the design. The use of passive methods should be implemented as much as possible making the design less dependent on MVHR systems that can become faulty over the time. MVHR systems are required given the fact that airtightness is less than $5m^3/m^2/h$ otherwise air quality would be jeopardised and lack of adequate air for the occupiers would lower the thermal and health standards in the dwelling.

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One critical aspect of the whole standard is that is primarily focuses on the whole house building standard with the potential to use renewable energy as a backup and alternative energy system. The standard does not focus on other important areas in sustainable and energy efficient buildings, for example, ecological elements on site, embodied energy of materials and their origins (sustainable timbers), toxicity and low VOC's, the environmental impact of the site type (green areas or brownfields).
Overall the standard focuses too much on the building and too little on the surroundings and the site. Little consideration is taken on the occupier and the thermal comfort that may be reduced with faulty equipment or lack of maintenance.

Debate over the necessity into investing on "certified" Passive House products and achieving all the criteria as required by the institute poses the question of whether the passive house standard is cost worthy and worth the investment. It also poses the question whether applying this standard into the retrofit of older properties and hard to treat dwellings is technically viable and worth applying to the passive house criteria. It is evident that dealing with heat loss through the fabric is a concern and something that should be addressed, but should this be achieved using this standard or should it be achieved using similar criteria with a more environmental, conservational and cost effective manner rather than investing into over disciplined methods that may pose an enormous task in hard to treat buildings.

A more sustainable and holistic approach is preferred, that can take into consideration all fabric interventions as best as possible in conjunction with efficient heating systems as passive as possible with the use of an ecological conscientious approach too with low carbon methods, low embodied energy of materials and healthy environmental alternatives that can create a building that blends in with the context and also with kits surrounding environment.

Finally, it is worth pointing out that added analysis and design is required to take this project forward and to achieve the standard and the certification. The involvement of a Passive house designer in conjunction with an experienced contractor can make this project a reality.

6.0 REFERENCES

- Passive house Institute web site: www.passiv.de
- EnerPHit – Certification as "Quality-Approved Energy retrofit with passive House Components" – Criteria for Residential-Use refurbished Buildings
- Retrofit projects - www.greentomatonenergy.com
- Towards Passivhaus Retrofits – Mark Siddall of Devereux Architects

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