An Adaptable Approach to Steady State Calculations for Thermal Upgrade within Existing Residential Housing in Ireland

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From 2013, the European Directive on the Energy Performance of Buildings (EPBD) will be superseded by the Recast EPBD placing a further emphasis on even higher thermal performance and efficiency levels of both new-build and existing buildings. This emphasis has been reinforced by the publication of the new Technical Guidance Document Part L 2011. Government aspires to achieve zero-carbon standards for new buildings from 2016 (domestic). However, since it is estimated that the existing building stock accounts for around 75% of 2050 housing targets, it is very clear that low carbon retrofit will have a huge role to play in achieving carbon emission targets. In response to this, thermal upgrade of existing external walls is proposed by policy makers / planners. To carry out thermal upgrade, calculations are needed to amalgamate the various technologies required to assess the risks and performance of proposed wall constructions. Standard steady state calculation methods for thermal upgrade are not understood throughout the construction industry which does not leave much hope for more complex non-steady state calculations within the industry. There is no explanation or in depth analysis available to demonstrate how to appropriately thermally upgrade an existing external wall to suit its local environment, either internal or external. Correspondingly, this paper aims to provide an understanding of what the issues are and to further research the need to address and provide an understanding of the complexity and restrictions involved with the current available manual calculation methods of thermal and moisture transmittance.

Key Words: EPBD, Insulation, Energy Efficiency, Emission Reduction, External Wall, Framework.

Introduction

Energy efficiency of buildings has become an important issue, due partly to strong links between improvements in the performance of buildings, energy savings and a reduction in CO_2 emissions. The basic principle of improving the energy efficiency of a building is to use less heating, cooling and lighting without affecting the health and comfort of its occupants (Nikolaou et al. 2011).

Previous research literature has identified that solid, cavity and cavity block walls constructed pre-building regulations; account for the least thermally efficient and largest heat loss element in Irish residential housing. With so much diversity in construction types, there is no ‘one size fits all’ solution to thermal upgrade. Furthermore, building users have different attitudes to, and understanding of, energy efficiency. The proposed solution is to test the current regulatory state-of-the-art and the non-standard state-of-the-art, in performance of energy efficiency and renewable energy measures, and to ensure that all involved in specifying, fitting and using those measures are sufficiently informed to ensure they function satisfactorily. There is a need to make sure that standards are set and followed, taking into account; national, regional and local variations. In this way low carbon and low energy homes can be delivered, which cost less for occupiers to heat.

Energy efficiency improvements in buildings are ultimately required by overarching regulatory commitments stemming from the 1992 United Nations Framework for the Convention on Climate Change (UNFCC). This focuses on the stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous manmade interference with the climate system. Furthermore, it sets the context and provides the basis for on-going development of global action to tackle climate change. However, commitments by industrialised countries under UNFCC to stabilise their greenhouse gas emissions at 1990 levels by 2000 were not legally binding. This led to Japan adopting the Kyoto Protocol on 11 December 1997. Ireland is a party to both the Convention and the Kyoto Protocol. Ireland ratified the Kyoto Protocol on 31st May 2002 which only became legally binding on 16th February 2005. As part of the EU target under the Kyoto Protocol, Ireland agreed to limit the growth in its greenhouse gas emissions to 13% above 1990 levels by the first commitment period of 2008-2012 using the National Climate Change Strategy 2007-2012. The EU has an overall reduction target of 8% below 1990 levels and has adopted a burden sharing agreement that recognises the different economic circumstances of each member state. Ireland's target is to limit the increase in its greenhouse gas emissions under the Kyoto Protocol to 13% above 1990 levels by 2008-2012.

The EU Directive on the Energy Performance of Buildings (EPBD) was published in 2002 and adopted into Irish law as the Energy Performance of Buildings Regulation 2006 (S.I. No. 666 of 2006) to implement the requirements set out by the Kyoto Protocol. This regulation enforced the introduction of Building Energy Rating (BER), more commonly known as Energy Performance Certificate (EPC) in Europe. These certificates are required by law to be provided by owners when they sell or rent out a home. The certificates inform the new buyer or user about energy use and retrofit options based on manual calculations such as u-value calculations and heat loss figures from Dwellings Energy Assessment Procedure (DEAP) methods. The EPBD states that buildings account for more than 40% of final energy consumption. From 2013, the 2002 EPBD will be superseded by the Recast EPBD. This recast EPBD states that retrofit measures should take into account climatic and local conditions as well as indoor climate environment. So, using the available methods of heat and moisture transfer calculations from standards and design guides alike, this research will seek to establish whether manual calculations; steady or non-steady state, are coherent and accurate enough to achieve required levels of performance.

Landscape of Existing Housing Residential in Ireland

In 2008, the Sustainable Energy Authority Ireland (SEAI) published an evaluation on the energy efficiency opportunities within buildings in Ireland. Here it is noted that the Irish building sector is broken down into 3 subcategories - industrial, commercial and residential; residential buildings accounting for 50% of the total building stock (Kema 2008). Total CO_2 emissions within the residential sector decreased from 35% in 1990 to 25% in 2006, despite actual CO_2 increasing by 9.8% (0.6% per annum on average) to reach 11,896 kt CO_2. Further to this, residential sector contributed the second largest emission count of 35% after transport (O'Leary et al. 2008). A brief international context shows the average Irish dwelling in 2005 emitted 47% more CO_2 than the average dwelling in the UK. Emissions were 92% higher than the average for the EU-15, 104% more than the EU-27 (SEI Renewable Energy Information Office and MosArt Architecture 2009). Most notably, primary energy consumption of the residential sector accounts for the greatest (50%) of all the building stock. Possibilities exist to reduce this figure resulting in the least primary energy consumption within the residential sector through upgrades to the thermal envelope of the buildings along with heating and lighting upgrades (Kema 2008). Thus, the largest energy savings possible are within the residential sector and moreover, within heating and cooling within the residential sector.

In an effort to clarify the performance levels and opportunities within the residential sector, the Building Regulations must be analysed. Irish Building Regulations were implemented as a medium of standardising the Irish residential housing stock, thus allowing comparable performance criteria which could be developed and improved. Previous to 1976, akin to many other countries, building regulations did not form part of the legislative framework of the residential housing sector in Ireland. However, in 1976 a draft regulation was developed to give a benchmark in terms of expected building performance criteria. Thereupon, the Irish Building Regulations were developed and improved. Accordingly, Irish Residential dwellings were constructed to reflect the following applicable guidance documents:

- 1976 Draft Building Regulations,
- 1981 Revised Draft Building Regulations,

Non - Mandatory

- 1991 Building Control Act & Building Regulations – Guidance Documents Part A - M,
- 1997 Building Regulations – Guidance Documents Part A - M,

- 2002 Building Regulations – Guidance Documents Part L,
- 2005 Building Regulations – Guidance Documents Part L,
- 2007 Building Control Act & Building Regulations Guidance Document Part L
- 2008 Building Regulations – Guidance Documents Part L & G,
- 2011 Building Regulations – Guidance Documents Part L.

(National Consumer Agency 2008)

Documentation of building construction & energy data is a significant tool for construction and energy benchmark establishment. There exists at present, an incredible amount of information on the existing Irish building stock. However, this information is dispersed across numerous publications and databases due to recent acquisition by various sources rather than 'as built' by a single source. At European level, the deficiency of building energy use databases has restricted the development of benchmarking tools. Intelligent Energy Europe has studied the complexity associated with the complexity of the creation of this database; applying the EPBD to improve the Energy Performance Requirements to Existing Buildings (ENPER-EXIST).

The most notable and comprehensive documentation of the existing building stock is the Central Statistics Office (CSO) Irishx Housing Survey which categorises dwellings by tenure, occupancy, type, size, location and local area. Although the Government is attempting to address the low carbon agenda with respect to new build via progressive regulation towards a low carbon standard, it remains that around 75% of the 2050 housing targets are at present, constructed based on the assumption that the average person per dwelling remains akin to the current level of 2.81 (Ministry of Infrastructure of the Italian Republic 2006). Furthermore, of the 75% of the 2050 housing stock, 52.5% will consist of pre-1985 buildings, (i.e. will pre-date the introduction of Part L of the Irish Building Regulations (Central Statistics Office 2006)). Approximately 750,000 of current homes were constructed prior to any thermal insulation requirements (introduced 1979), while 24% of all households surveyed in 2001 had no insulated walls (SEI Renewable Energy Information Office and MosArt Architecture 2009). For this reason, low carbon retrofitting of existing buildings is a vitally important factor in the transition.

A further study of the existing building stock is The Typology Approach for Building Stock Energy Assessment (TABULA), developed by Intelligent Energy Europe. In Ireland, the building typology aims to identify the most common residential building types and provide relevant building energy information for each type. This Irish typology details 29 houses types assessed using BER and DEAP methods along with the Irish Census 2006.

This paper offers a breakdown of the common wall constructions along with manual thermal and moisture transfer calculations. Remarkably, 70% of existing residential buildings were erected pre-building regulations in 1991. The least efficient and most common wall construction types are pre-building regulations; Solid Brick, Cavity Block Wall and Cavity Wall construction. For the purpose of this paper, cavity block wall construction will be investigated with thermal upgrade solutions and performance calculations.

Focus of Research

This research stems from the ultimate question of thermal upgrade and informed designed; what is the most appropriate way to thermally upgrade an existing external wall? This research question is a seemingly simple question with unresolved solutions. Performance predictions in general tend to be based upon an assumption of ideal behaviour of materials and products under standard, steady-state conditions, combined with perfect installation. Wall construction has advanced since the introduction of the building regulations, but building regulation calculation methods have remained quite the same. It is therefore perhaps not surprising that in reality, performance rarely matches expectations (Centre for Low Carbon Futures 2011). External walls were built to achieve standards of their construction era, which have evolved along with construction methods throughout the years.

The aim of this paper is to improve the current approach to thermal upgrade of existing external walls, in particular, that of cavity block wall construction. For the purpose of this paper, measures will be taken to evaluate current practice, environmental factors affecting calculation results and the allowances to be considered when designing the appropriate thermal upgrade system to promote sustainable development. Commonly used construction details for thermal upgrade are evaluated using application and analysis of standard regulatory and non-standard steady and non-steady state calculations. These calculation methods are extracted from regulations, standards and common design manuals to illustrate the current deficiencies within regulatory building performance calculations and challenged with a view to raising the performance of actual building performance.

The Overall Research

In validating this research, the aim is to contribute to social knowledge. To do this, the researcher must understand their relationship with that being researched (Dainty 2008). A methodology refers to the philosophical framework and fundamental assumptions of the entire process of research. In any research project, it is important to illustrate an understanding of the research approach to increase the validity of the research. Further to this, research design stems from the chosen methodology which refers to the ways in which the data will be collected and analysed in order to answer the research questions posed. For the purpose of selecting the correct methodology, it is vital to understand the various practiced methods. Quantitative research is structured and theory precedes observation. In a qualitative study, the activities of collecting and analysing data, developing and modifying theory, elaborating or refocusing the research question, and identifying and dealing with validity threats are usually going on more or less simultaneously, each influencing all of the others. Qualitative research is open and interactive and observation precedes theory whereas qualitative research stresses 'ecological validity'; the applicability of social research findings to those that exist within the social situation studied. The research design stems from the research methodology. By clarifying the classification of each task, the methodology is explained and the objectives area obtainable. For the purpose of this paper, a quantitative methodology is utilised, each objective contributing to the success of to the next.

The most complex wall construction is identified and tested using standard regulatory and non-regulatory steady and non-steady state calculations with these results then evaluated. Utilising SEAI data, varying methods to thermal upgrade within external walls are identified; internal, external and cavity fill insulation. Moreover, Technical Guidance Document (TGD) Part L Acceptable Construction Details (ACD's) establish detailing of each. Thermal upgrade of cavity block wall construction will be studied.

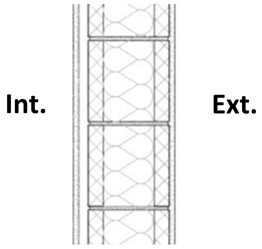


Figure 4 - Cavity Fill Insulation

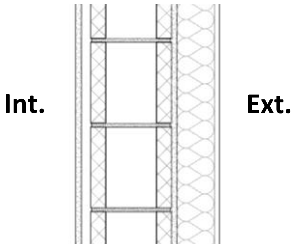


Figure 5 – External Insulation

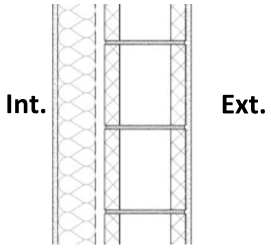


Figure 6 – Internal Insulation

Calculating the Performance

For cavity block walls, the choice is between insulating externally, internally or insulating the cavity (Sustainable Energy Authority Ireland 2012), as illustrated in *Figure 4*, *Figure 5* and *Figure 6*. External insulation cladding can be regarded as the better option for elimination of cold bridging, especially if windows and doors can be replaced and/or relocated at the same time so that the external insulation layer can be of uniform thickness (Centre for Low Carbon Futures 2011). However, in some areas it is not currently acceptable to alter the external appearance of buildings and the insulation may be hindered by restrictions for Areas of Conservation Architecture (ACA) or Protected Buildings. A more subtle consideration is internal wall insulation, which effectively reduces the apparent thermal mass of the building in question which may or may not be desirable. For example, internally insulated walls heat quicker than externally insulated walls (CIBSE 2006). Whilst this consideration is only one factor amongst many, it is a further example of the need to plan retrofit programmes in an integrated way from the outset. Cavity fill wall insulation is another consideration, if the wall has an empty cavity. This method of insulation is not altogether understood however, in terms of calculations, performance or materials used.

Numerous performance design methods for thermal upgrade systems are available such as the Technical Guidance Document Complimentary Details, matching the U-values as set out in Technical Guidance Document Part L, or using installer NSAI certified details. However, with the emergence of new technologies and computer analysis, those involved in the design and construction of these systems must question and detail them competently. Accordingly, certainty of how to design and build combining new and existing technologies appropriately must emerge. This will be further enforced by the upcoming Recast EPBD 2013;

'Measures to improve further the energy performance of buildings should take into account climatic and local conditions as well as indoor climate environment and cost-effectiveness.
(The European Parliament and the Council of the European Union 2010)

Thermal upgrade of existing residential buildings also requires consideration towards the original thermal and water diffusion properties through this combination of new and old technologies. Technical Guidance Document Part L suggests ISO 13788 to calculation this. ISO 13788 calculation methods are based on a steady state Glaser calculation method i.e. one point in time. However, the inaccuracies embedded in this type of calculation are clearly described in both CIBSE Design Guide A, and ISO 13788;

'The use of unrealistic values for thermal conductivities of building materials also contributes to the underestimation of U-values. Tabulated values are usually based on laboratory measurements using small well-prepared samples. In buildings, the thermal conductivities may differ appreciably from the laboratory measurements due to variations in quality during production, storage conditions on site and variations in construction techniques.'
(CIBSE 2006)

The main issue noted must be that the steady state calculation method is not a tool for calculation of transient conditions i.e. varying conditions over time. However, '*it should be noted that Glaser-calculations are no simulation of reality, but a tool to determine the risk of interstitial condensation only (Kunzel and Physics 2000).* So to comply with the Recast EPBD 2013, non-steady, state will be needed *'which predict the transient moisture behaviour of building components under real climate conditions (Kunzel and Physics 2000).*

This research paper will analyse thermal upgrade solutions as applied to cavity block wall construction using standard regulatory and non-standard steady state, non-steady state calculations to design for adaptable thermal upgrade of external walls within existing residential detached and semi-detached housing in Ireland.

Steady State Calculations

Steady state calculations are predictions of the performance of a construction build-up at one point in time. The three steady state calculation methods utilised in this paper are U-value, THERM and ISO 13788.

The U-value relates to a building component or structure, and is a measure of the rate at which heat passes through that component or structure when unit temperature difference is maintained between the ambient air temperatures on each side. It is expressed in units of Watts per square metre per degree of air temperature difference (W/m^2K). This measurement is the standard heat transfer calculation of a wall in Irish building regulations. However, it does not allow detail inspection of the heat flow through the wall construction as is enabled through THERM.

THERM is a Microsoft Windows™- based computer program developed at Lawrence Berkeley National Laboratory (LBNL) for the modelling of two-dimensional heat-transfer effects in building components where thermal bridges are of concern. THERM allows a detail to be analysed as a 2D heat transfer model. This calculation model is very informative in terms of the visual illustrations of heat flow and temperature analysis through the detail. However, interstitial condensation risk analysis requires a steady state calculation within ISO 13788 as stated in TGD Part L.

The risk of condensation occurring on or in a building material depends on the temperature and the humidity of the air on both sides of the structure, and also upon the resistance of the material to the passage of heat and vapour. ISO 13788 sets the calculation method using the u-value calculation. This u-value is used to calculate the point temperatures across the structure; with these plotted across the structure (red line). Following this, the vapour pressures are calculated and plotted with the point temperatures onto a psychometric chart which generates the dew point temperatures which are also then plotted across the structure (blue line). Thus, anywhere the point temperature drops below the dew point temperature, interstitial condensation is a risk. See *Figure 8*, *Figure 9* and *Figure 10*.

Non Steady State Calculations

Non-steady state calculations are predictions of the transient performance of a construction build-up over time. The non-steady state calculation methods utilised in this paper are taken from CIBSE Guide A. From this, Decrement factor, Surface Factor methodologies are extracted. These calculations are proposed as an approach to identify the appropriate methods required to achieve adequate standards as per EPBD and TGD Part L. They take into account thermal characteristics, during a diurnal (24 hour) cycle which determines how long each build-up should take to cool down and heat up respectively i.e. thermal response times. Mathematical software tool MathCad is utilized for calculation of these, which allows efficient analysis of multiple calculations.

The decrement factor is the ratio of heat flow through the structure to the environmental temperature in the space for each degree of deviation in external temperature about its mean value, to the steady state rate of flow of heat (u-value) with the associated time dependency to cool down (Ø). The surface factor is the ratio of the variation of heat flow about its mean value readmitted to the space from the surface, to the variation of heat flow about its mean value absorbed by the surface with the associated time dependency to heat up (Ψ).

Results

To carry out the calculations outlined, a structured approach is taken. An excel data sheet was composed to carry out the steady state, while MathCad files were composed to carry out the non-steady state. The interstitial condensation calculation results are plotted onto a sectional illustration of the wall types with the results of the dew point calculations also plotted on the drawing. This in turn is analyzed through THERM modeling, overlaid onto the sectional detail to ensure similarity of results and clarity of information. Steady and non-steady state calculation results are illustrated in *Figure 8*, *Figure 9* and *Figure 10*;

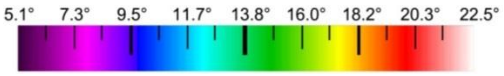
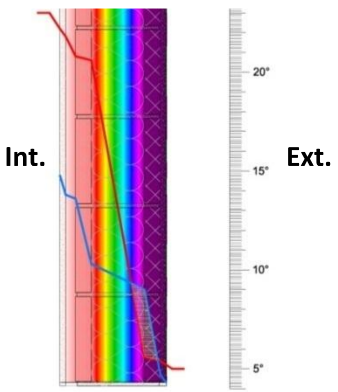
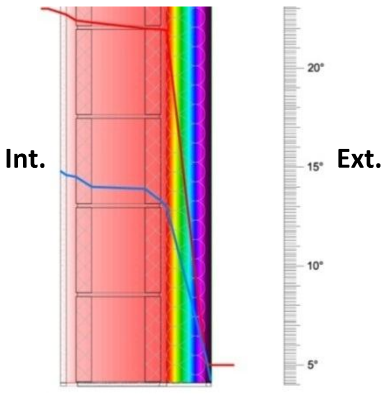


Figure 7 – Temperature Bar



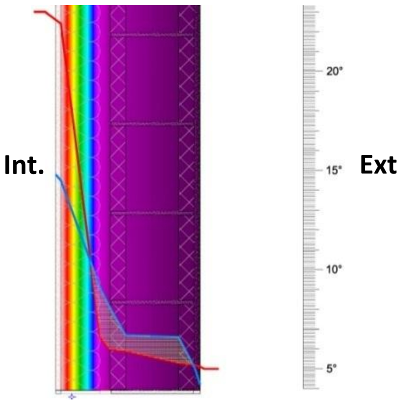
U-value: 0.33W/m^{2}K
(Ø): 4.25 hours
(Ψ): 2.58 hours

Figure 8 – Cavity Block Wall with Cavity Fill Insulation



U-value: 0.10W/m^{2}K
(Ø): 1.49 hours
(Ψ): 2.98 hours

Figure 9 - Cavity Block Wall with External Insulation



U-value: 0.18W/m^{2}K
(Ø): 3.13 hours
(Ψ): 0.60 hours

Figure 10 - Cavity Block Wall with Internal Insulation

Wall Type 1 - *Figure 8*	Wall Type 2 - *Figure 9*	Wall Type 3 - *Figure 10*
12.5mm Plasterboard **25mm Cavity with** **25mm Timber studs** **140mm Cavity Block with** **EPS cavity fill insulation** **15mm Render**	**12.5mm Plasterboard** **25mm Cavity with** **25mm Timber studs** **140mm Cavity Block** **15mm Render** **200mm Phenolic insulation** **15mm Render**	**100mm Phenolic insulation on** **25mm Cavity with** **25mm Timber studs** **140mm Cavity Block** **15mm Render**

- Wall type 1 allows the lowest achievable u-value. The build-up results in a long heating time lag, but also the longest cooling time. It is noted that there is a risk of interstitial condensation.
- Wall type 2 allows the highest achievable u-value. This build-up results in a long heating time, but a shorter cooling time which is not desirable. However, there is no risk of interstitial condensation.
- Wall type 3 allows the second highest achievable u-value. This build-up results in the shortest heating time lag, with a long cooling time. This indicates that this wall allows the greatest thermal control response. Albeit noted that there is a serious risk of interstitial condensation present.

Discussion

Retrofitting of existing buildings for improved energy performance will play a vital role in achieving carbon reduction targets in Ireland, but the problem is complex and the route to optimum effectiveness is not yet clear. Previous research literature has identified that a solid, cavity and cavity block wall, detached and semi-detached residential dwelling built pre-building regulations would be the ideal building type to consider refurbishment options incorporating internal, cavity fill or external insulation.

It becomes evident from *Figure 8*, *Figure 9*, *Figure 10* and the resulting data that numerous considerations must be made to combine the technologies and systems related to thermal upgrade. The aforementioned calculation methodologies do not incorporate transient environmental conditions, either internal or external. Also, they allow only analysis of dry assemblies, with limited water diffusion properties. To design for use by people, analysis / calculation methodologies must incorporate insofar as possible; living, transient environmental conditions. Thus, calculating predicted wall performance will need further investigation incorporating combined transient heat and moisture transfer as well as incorporating hygroscopic and capillary action within the construction.

These limitations associated with the standard regulatory steady and non-steady state calculation methodologies as outlined in building regulations and design guides are based upon a 1D, flat composite assembly. This means that only solid (non-bridged) layers may be analysed i.e. cavities with battens are calculated as a full cavity overlooking the bridging of the timbers. Thus, the concrete flanges of a cavity block are overlooked as illustrated in *Figure 11*. It is clear that the standard regulatory calculations could not be correct or clear, if the 2D analysis (*Figure 11*) differs so vastly from the comparable 1D assembly (FIGURE 5).

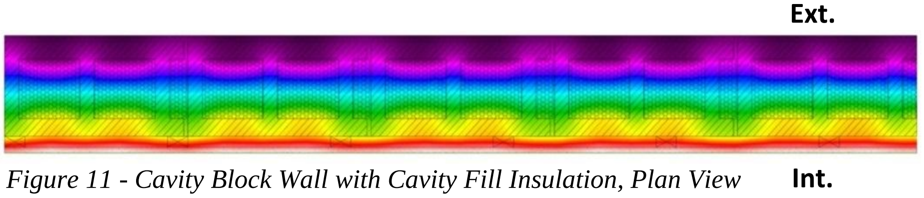


Figure 11 - Cavity Block Wall with Cavity Fill Insulation, Plan View

A reason for calculation methodologies not yet incorporating non-steady parameters could be their problematic and intricate nature as experienced throughout this research. Within CIBSE Design Guide A, the thermal decrement and surface factor calculation sample is simplified using a 1D flat single layered assembly, whereas the calculation of a composite assembly requires numerous cross-matrix multiplication and focused analysis to extract the final results. Carrying out these calculations requires much due care and consideration for the reasoning behind mathematical symbols and equations (McNaboe and Stevenson 2011). Furthermore, the use of correct material data is debatable; using data from one source i.e. TGD Part L can vary considerably from CIBSE Design Guide A, BS 5250 and ISO 13790.

The next phase of research leading on from this is the exploration of numerical calculation (computer modelling analysis). The calculations thus far analyse assembly performance in isolation from critical factors. U-values and Therm calculations are calculated in isolation from moisture, and moisture transfer calculations from ISO 13788 are in isolation from an actual life cycle and other environmental factors. To reach the prospect of calculating coupled heat and moisture transfer and progress the next phase of the research, the following steps are proposed;

1. Analyse and apply numerical calculations
2. Evaluate and assess actual thermal & hygrothermal performance in the detail.
3. Design a framework for appropriate thermal upgrade of existing external walls from issues encountered.
4. Develop a set of adaptable construction details for thermal upgrade.

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