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Predictive Modelling of Heat Transfer and Thermal Bridging within the Building Envelope

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Abstract

This research dissertation examines the issue of heat loss and thermal bridging at the ground floor level applied to the Verschoyle Court project. Three dimensional finite element heat transfer software is used as a tool to investigate the existing problems and to validate proposed solutions. The research has shown that the use of horizontal perimeter insulation not only reduces thermal bridging issues at this critical junction, but also limits the loss of heat energy through the ground floor slab. This decreases reliance on high levels of insulation below the floor slab. The proposed method of insulation is applicable to both new build and refurbishment/retrofit building projects and should contribute to an overall reduction in energy loss in a building whilst saving money in construction materials. The construction details in this project have been value engineered to reduce resource consumption whilst exceeding current building regulation energy requirements by up to 66%.

Acknowledgements

I would like to express my sincere gratitude and appreciation for the help and advice I have received in writing this thesis. Of particular help were the academic staff of DIT including; Sima Rouholamin, Sarah Sheridan, David Wright, Malachy Mathews and Simon McGuiness. I would also like to thank Tomasz P. Kornicki for allowing me to use his software, AnTherm and for his valuable advice. I am most grateful for the support from my parents and grandparents, in particular my mother Fionnuala.

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1.0 Introduction

The function of a buildings thermal envelope is to provide a barrier to unwanted heat exchange between the internal and external environment. In order to have an efficient and affordable heating system it is desirable to retain heat rather than waste it through the walls or the ground. The position of the thermal barrier can also affect whether a building is able to take advantage of thermal mass; for example in a concrete slab floor.

Designing continuity of the buildings thermal envelope is the key to reducing the effects of thermal bridges and the associated risk of condensation and undesired heat loss.

It is not always possible to provide an uninterrupted thermal barrier. This can be a result of many reasons including aesthetic or structural design requirements. In this situation there are alternative strategies that can reduce the effect of the thermal bridge such as overlapping/extending insulation or using thermally broken components. These alternative solutions can be modelled and tested quickly and inexpensively with heat transfer software.

There is no single rule of thumb in designing to reduce thermal bridges. No two buildings are the same. Every construction project should be considered a prototype and as such it must be thoroughly evaluated and tested to confirm whether it will perform to the prescribed set of standards.

It has been suggested in research by F. Deque et.al that current statutory guidelines underestimate the heat loss through linear thermal transmittance in the building fabric (Deque, Oliver, & Roux, 2000). Joseph Little in research published in Construct Ireland suggests that organisations need to be prepared to revise old guidance based on new research (Little, 2010).

> *Accurately assessing the Linear Thermal Transmittance of each junction detail will become essential for progressive architects and developers of increasingly energy focused clients.* (Little, 2010)

In addition to the calculation of heat loss through planar elements using U Value calculations considerable attention must be given to linear thermal transmittance (thermal bridges).

TGD Part L of the Building Regulations (2007) says:

> *1.5.3.1 There should be no reasonably avoidable thermal bridging, e.g. due to gaps between insulation layers and at joints, junctions and edges around openings. Where unavoidable thermal bridging is provided for in the design, care should be taken to ensure that the chosen design detail is accurately constructed on site.*
>
> *2.1.3.1 To avoid excessive heat losses and local condensation problems, reasonable care should be taken to ensure continuity of insulation and to limit local thermal bridging, e.g. around windows, doors and other wall openings, at junctions between elements and other locations. Any thermal bridge should not pose a risk of surface or interstitial condensation.*

The Department of the Environment has published a set of Acceptable Construction Details to complement Part L of the Building Regulations. If a building project is detailed to the standards in the Acceptable Construction Details it is said to have met the requirements of reducing thermal bridges.

It should be noted that the minimum psi values quoted in TGD L are far below the high standard required for passive house design. With continually revised building regulations and increasing importance of energy conscious design it is likely that these minimum values will continue to be refined. This will pose a greater challenge for the technical designer and any tools that can aid in the design of good, compliant construction details should be welcomed.

In order to provide the best quality design it is proposed to use numerical simulation to analyse thermal bridging in the thermal envelope of the new build Verschoyle Court elderly housing project.

Different construction details will be examined through the use of computer simulation. The results of the simulation will inform the construction details that have optimised/reduced the energy loss through linear construction junctions.

The ground floor (slab on grade) set of construction details will be the major focus of the dissertation for the following reason; It is generally acknowledged that the ground detail is the most complex and therefore the most difficult to model and assess.

> *Frequently, the most difficult thermal bridges to avoid are the ones for below ground building elements. These thermal bridges are affected by the adjacent soil, which is why they must be handled differently.* (Feist, 2007)

The trend towards higher insulation of building elements has resulted in a need to change how heat loss in buildings is calculated. With higher levels of insulation, more sophisticated methods of quantifying heat loss have become necessary. This is reflected in the continually revised Building Regulations and such methods are being pioneered by the high-tech innovators in construction today such as the Passive House movement which was pioneered in central Europe and Scandinavia.

It is recognised (Ward & Sanders, 2007) that in order to develop novel solutions for detailing junctions that the use of finite element numerical modelling software is necessary.

This paper aims to use such modelling software as a vehicle to examine the physics of heat transfer, thermal bridging and to apply these findings in developing a set of ground construction details for the Verschoyle Court Elderly Housing project.

2.0 Scope

The aim of the thesis work is to develop a solution through building details that will optimise or reduce the amount of heat loss through the Verschoyle Court building. This will improve thermal efficiency and reduce whole-life energy costs for the owner/occupier. It is intended to follow the principles of passive house design for the thesis project. Super-insulation and the elimination of thermal bridges are important aspects of passive house design. The SEI Passive House Guidelines (SEI, 2007) recommend planar thermal transmittance values of less than 0.15 W/m^2K and the effective elimination of thermal bridging.

The dissertation will focus on, at minimum, meeting these objectives. This will be achieved by analysing *heat transfer* and *thermal bridging* in building construction.

Two separate but related avenues of investigation have been identified for the dissertation:

1. A study of thermal bridging applied to ground floor construction with an aim to reaching near passive house standard for the Verschoyle Court Elderly housing project.

2. Perform an analytical simulation of thermal bridging using heat transfer software. This will include three dimensional analyses. It will verify if the objective of aim 1 has been met.

3.0 Background

3.1 Thermal Bridges – What are they and where do they occur?

Thermal bridges can be the cause of many potential problems within the building fabric. Thermal bridging can result in inefficient energy use and may contribute to condensation problems (surface and interstitial). A thermal bridge occurs when there is a disruption in the building's thermal envelope providing a route of heat transfer between the internal and external environment

Thermal bridging often occurs when heat energy moves through *thermal pathways* within a building construction.

Totten et al. (2010) describe a thermal pathway as follows:

> *A thermal pathway is the path in three-dimensions that heat travels across any element of the building enclosure. The pathway can be calculated based on material properties and configurations and better visualised using two and three-dimensional heat transfer software..*

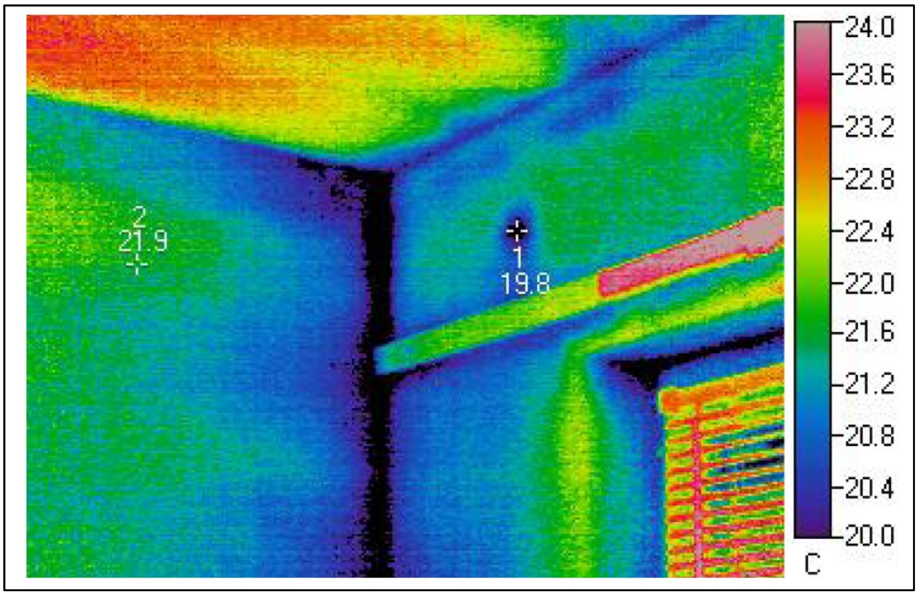


Figure 1 Thermal camera image taken at an existing bedsit in Verschoyle Court. The image shows a drop in temperature at the corner junction. Corners and linear junctions are often weak points in a building's thermal envelope.

Following on from this a *thermal barrier* can be defined as an element in a construction detail that controls or diverts the thermal pathway -the route of heat transfer through a building. Insulating materials such as polystyrene and polyurethane are commonly used as thermal barriers and are an essential ingredient in designing to reduce thermal bridges.

Thermal bridges may occur at junctions of different materials in a building, in constructions of geometric irregularity and in areas suffering from poor build quality or workmanship.

There are three primary types of thermal bridge;

1. Linear Thermal Bridge – Such as the junctions of a window within a wall
2. Point Thermal Bridge – Examples include steel fixings and other irregularities in the building envelope
3. Constructional or Repeating Thermal Bridge – Such as timber studs in an otherwise insulated wall

When calculating overall heat loss in a building, the heat loss through a repeating thermal bridge is accounted for in U-Value calculations. Point thermal bridges are measured using X-Values.

Linear thermal bridging is measured in W/K (Watts per Kelvin) and is often referred to as 'Psi' or 'ψ'. Linear thermal bridging can be considered as the additional heat loss through a building junction that is not accounted for in planar heat loss calculations (U-Values).

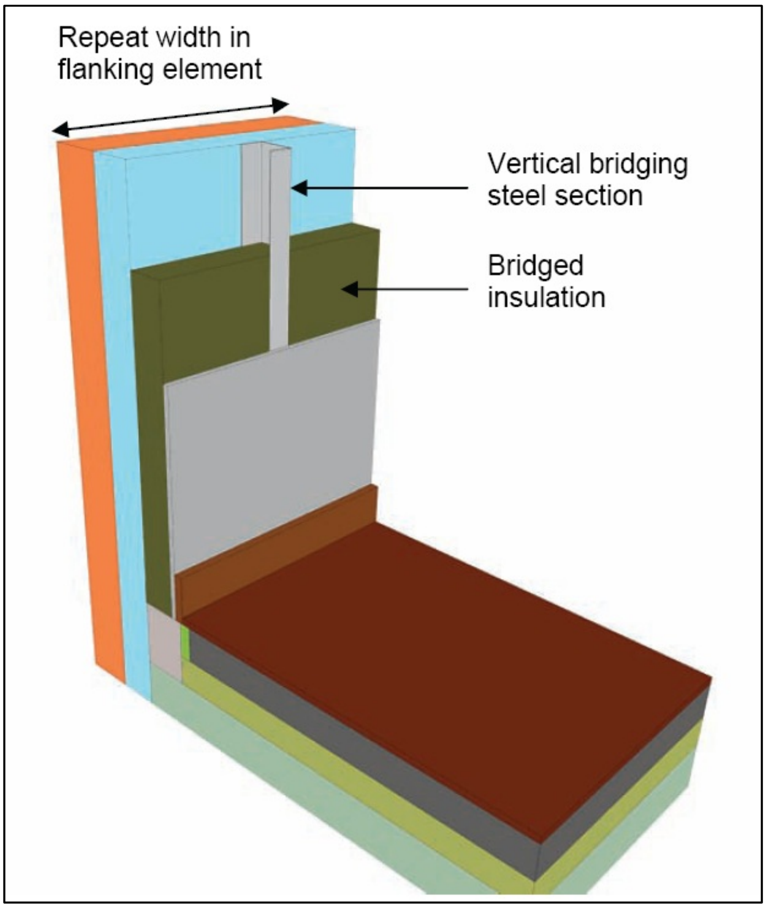


Figure 2 Building detail with repeating thermal bridge. The image also shows a potential linear thermal bridge at the wall/floor junction (Ward & Sanders, 2007)

3.2 Condensation

Condensation is the phenomenon that occurs when water vapour transforms to a liquid upon contact with a cold surface. It is condensation that causes many of the undesirable effects associated with thermal bridging. Condensation occurs when humid air comes in contact with a surface that has a temperature below dew point. Dew point is a temperature that is calculated as a function of relative humidity and ambient temperature (see Appendix B for Irish weather data appropriate for the calculation of dew point temperatures).

Condensation, apart from being unsightly, can be damaging to surface finishes. It can assist in producing conditions suitable for the propagation of mould and fungus. Conditions favourable to condensation should be eliminated at design stage (McGrory, 2010). Permanent condensation (as opposed to temporary condensation) can only be eliminated through good building detailing and the careful use of insulating materials.

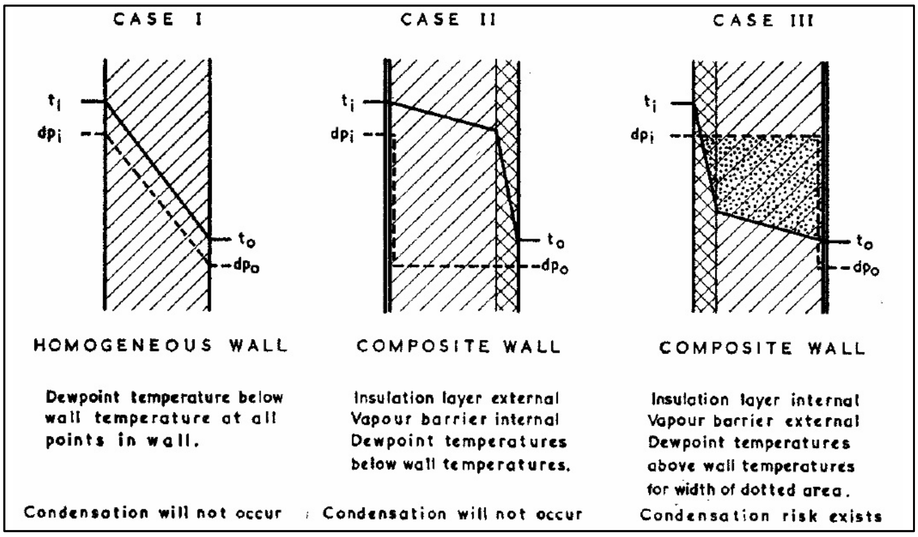


Figure 3 Condensation within walls (McGrory, 2010)

Of equal importance to surface condensation is the problem of interstitial condensation. Interstitial condensation may occur when the dew point occurs within the temperature gradient of a building structure. Interstitial condensation must be avoided and thermal analysis of structures should be performed to determine the point at which condensation may occur within a construction detail.

Figure 3 shows examples of thermal gradients within a wall structure –case III (internal dry-lining) is a condensation risk.

Condensation is particularly prevalent at surfaces with non-uniform temperature distributions –namely thermal bridges. Floor slab junctions have traditionally been very susceptible to condensation problems with problems often occurring and hidden below floor finishes such as carpet or linoleum.

Figure 4 Fungus sprouting form skirting board area in the Balgaddy Development, built in Dublin in 2004. The fungus is a result of damp and condensation (Images form the Irish Times (Holland, 2011))

Figure 5 Mould visible on the walls in Balgaddy (Holland, 2011)

3.3 Heat Transfer

There are three ways in which heat can be transferred from one medium to another:

- Conduction
- Convection
- Radiation

In order to have transfer of heat there must be a temperature difference. This is analogous to the potential difference or voltage present in an electrical circuit. At a micro scale heat occurs through minute vibrations in the molecules of solids or so called *lattice vibrations* and by the flow of free electrons. A material with a highly ordered lattice system such as steel will have a very high conductance however materials with a less structured lattice system such as timber will be of lower conductance

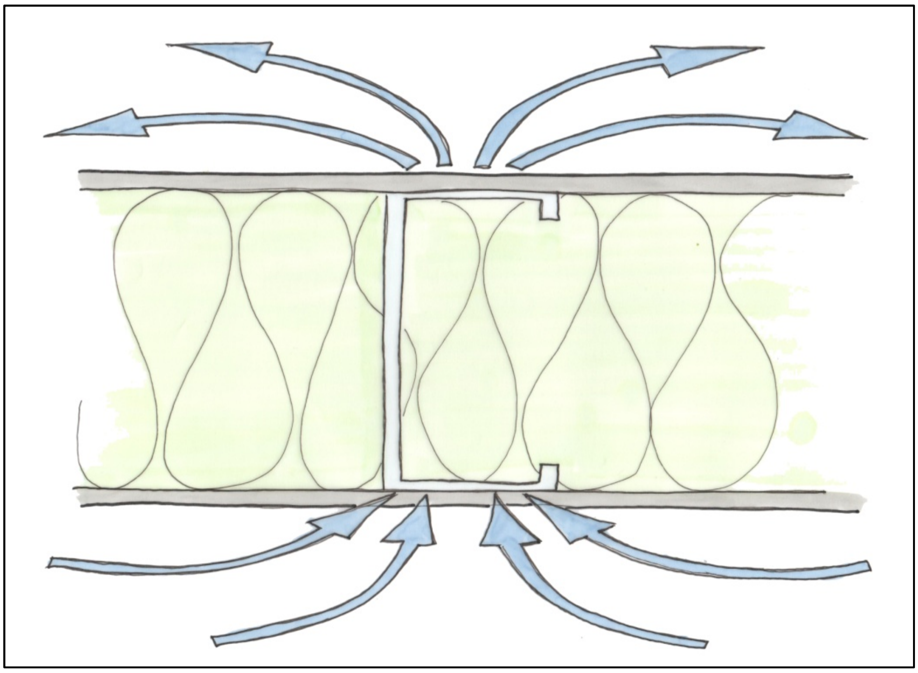


Figure 6 Heat transfer through a building element. Heat energy will conduct through the weakest element in a constructions thermal envelope – in this case the steel stud in an otherwise insulated wall.

The three methods of heat transfer are all applicable to thermal bridges however conduction is the dominant method of heat transfer in solid structures

Heat energy will follow the path of least resistance when passing through the building fabric, thus when designing building details the resistivity of materials should play a critical role in making decisions. When materials of low resistivity such as steel are used without a thermal break there is effectively a short circuit of the thermal pathway (Totten, O'Brien, & Pazera, 2010). A common example of a potential thermal bridge is the use of sun shading devices or *brise soliel*. These are often quite heavy structures and must be securely fastened to the building frame, often requiring steel fixings through the thermal envelope, providing a thermal pathway.

3.4 Simulation and Prediction of Heat Transfer

Heat transfer and thus thermal bridging can be predicted and quantified using computer software. Many of the software packages available for heat transfer analysis are programs from the family of Finite Element Analysis and Computational Fluid Dynamics.

These programs are traditionally used by Mechanical, Structural and Services Engineers to model complex heat flows, fluid movements and structural problems. The use of these programmes is becoming more widespread in non Engineering circles: for example, the program Therm 5.2 is commonly used in Ireland to calculate psi values, with many building energy consultants offering analysis of building details and/or training in the use of this software.

Although the theory and programming of heat transfer can be quite complex and mathematically based, there is no reason why an Architectural Designer can't take advantage of the software's predictive analysis capabilities. Moreover the ability to visualise heat transfer lends itself quite well to the working practice of the Architectural Technician who can use this visual information to reinforce the mathematical principles behind heat transfer. This can have an end result of understanding potential problems better and ultimately producing better construction details.

3.5 Important Local Factors / Boundary Conditions

One of the problems encountered in analysing heat transfer is establishing accurate boundary conditions. The majority of construction details will have one of three boundary conditions and an associated set of parameters such as;

- Internal Room T = 20°C
- External Room T = -10°C
- Adiabatic Q = 0

Typically an internal/external temperature difference and boundary conditions are selected that will model conditions most likely to cause condensation. These conditions can be determined from a matrix of Temperature/Humidity/Time of year. See Appendix B for weather data applicable to the Irish climate.

Of particular note is the ground or threshold detail, which has a further boundary condition with the soil or earth. Simplified analyses would have the ground modelled either as an external zone or a room with external temperature conditions.

Research on annual soil temperature in Ireland (Garcia-Suarez, Butler, & Morrow, 2002) shows that below the frost level, ground temperature in Ireland can range from between 4 and 16 degrees centigrade depending on the time of year. To achieve accurate visualisations at ground junctions, ambient soil temperatures must be included as an additional boundary condition. The variation of temperature with depth should be modelled. Useful data on soil temperature is included in research conducted at Armagh Meteorological Observatory (Garcia-Suarez, Butler, & Morrow, 2002).

3.6 Legislation

When designing to reduce Thermal Bridging, the Architectural Technologist looks primarily to Technical Guidance Document L of the Building Regulations. Two pages of guidance are included as Appendix D of TGD L (2007). The guidance document primarily recommends the use of the accredited construction details as published by the Department of the Environment for the use of reduced Psi value figures when numerical modelling is not available. If one chooses not to use the Acceptable Construction Details, Psi values should be less than or equal to the values given in table D1 (Figure 7).

In the calculation of overall heat loss for a building heat loss at interface junctions is often underestimated or at least approximated by the use of tabular values. It is the opinion of the author that this may be the case when using the Acceptable Construction Details. This may lead to an inaccurate picture of a buildings thermal performance and in extreme cases may even lead to a building achieving a Building Energy Rating that does not reflect the buildings true performance.

Through the energy modelling of building details both in 2D and 3D the energy loss at building interface junctions can be analysed. This will progress building design to the next step beyond simply meeting the legislative requirements.

An important note of reference is that Irish legislation regarding thermal bridges is based on the British system. TGD L Appendix D recommends BRE Information Paper 1/06 *'Assessing the effects of thermal bridging at junctions and around openings'* as the method to calculate linear thermal bridges. This is in contrast to other European systems where linear thermal transmittance is measured on the external face of a junction rather than the internal face.

It should also be noted that TGD L is continually revised with the 2010 revision currently in pre publication consultation stage.

Table D1 Target linear thermal transmittance (ψ) for different types of junctions.	
Junction detail in external wall	**Linear Thermal Transmittance (Ψ) (W/mK)**
Steel lintel with perforated steel base plate	0.50
Sill	0.04
Other lintels (including other steel lintels)	0.30
Jamb	0.05
Ground floor	0.16
Intermediate floor within a dwelling	0.07
Intermediate floor between dwellings[1]	0.14
Balcony within a dwelling[2]	0.00
Balcony between dwellings[1, 2]	0.04
Eaves (insulation at ceiling level)	0.06
Eaves (insulation at rafter level)	0.04
Gable (insulation at ceiling level)	0.24
Gable (insulation at rafter level)	0.04
Corner (normal)	0.09
Corner (inverted)	-0.09
Party wall between dwellings[1]	0.06

Figure 7 Table D1 From TGD L (2007) outlines maximum acceptable Psi values for compliance with the Building Regulations

3.7 Why 3d over 2d?

Whereas 2D analysis will give an insight into thermal bridging issues along a linear element such as a wall / floor junction (Figure 8) 3D analysis will allow a greater understanding of constructional thermal bridges such as the corner of the room in Figure 9.

It has been shown that three dimensional modelling will highlight issues at junctions which may not become apparent through 2D analysis alone.

> *Only through 2 and 3 dimensional analysis and field verification can a thermal bridge be properly evaluated* (Totten, O'Brien, & Pazera, 2010)

Furthermore, guidelines such as British Research Establishments BR497 (As recommended in TGD L) state that it is essential to perform 3D simulations in details that are non-uniform in the third dimension, such as timber studs in a wall construction or corner details. In addition, BR497 states that for the corner of a ground floor and in the case of singular penetrations through the building envelope (point thermal bridges or X-Values) three dimensional modelling *must* be used.

Whereas two-dimensional modelling is enough to extract psi value information in certain situations, three dimensional modelling provides the bigger picture of what is going on in a building detail. Using a three dimensional model, one can take slices or section cuts through a model quickly and efficiently.

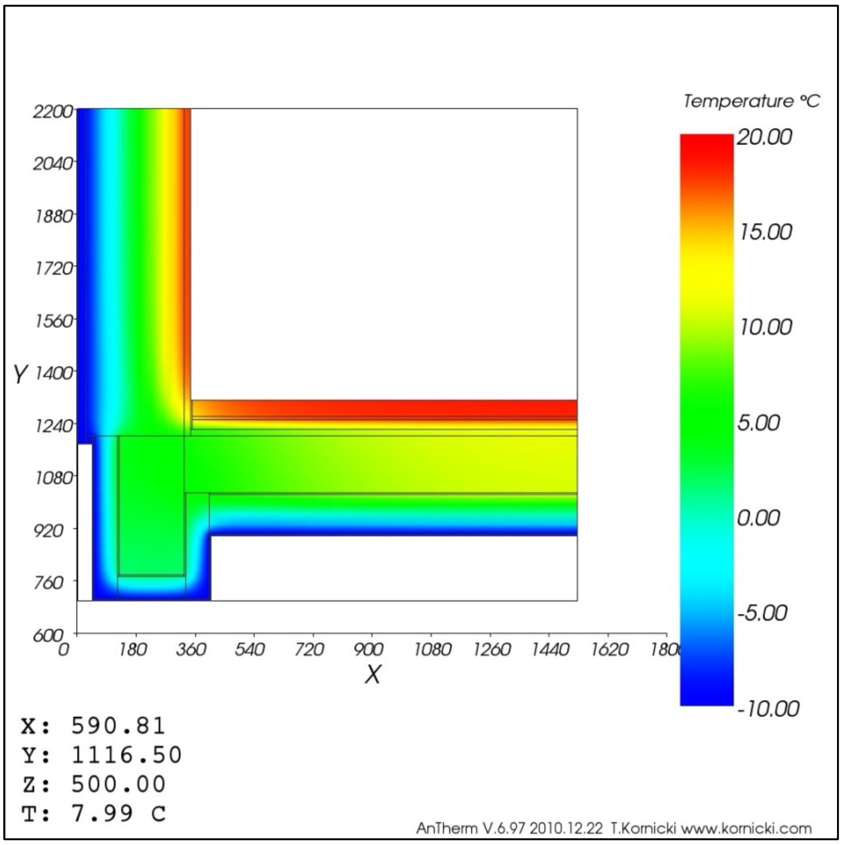


Figure 8 Temperature analysis of an externally insulated bay detail. AnTherm simulation.

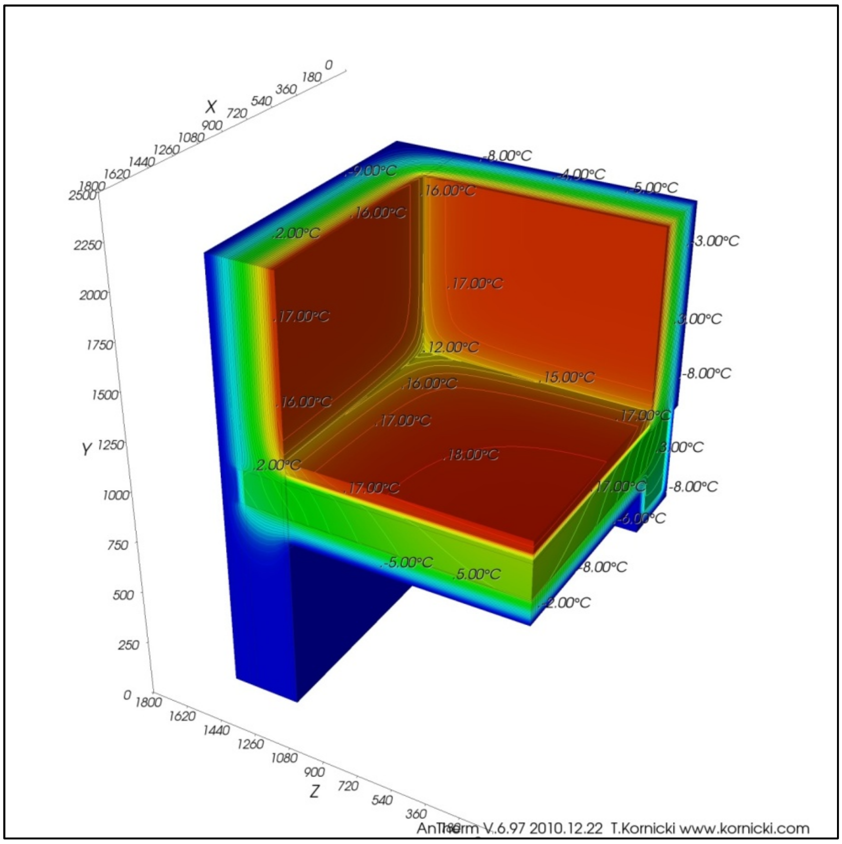


Figure 9 The same detail as Figure 8 modelled in three dimensions. Notice the detail at the room corner that was not apparent from the two-dimensional simulation. AnTherm simulation.

3.8 Case Study - RIAI Sustainable Design tools (O'Donnell, 2010)

The research focuses on applying Passive House standards to the refurbish/retrofit of a house in Rathdrum, County Wicklow. To achieve the high standards required, reducing heat losses through the building fabric was of paramount importance. The original 1980's built house required 190kWh/m^2 to heat whereas the new Passive House standard of 15kWh/m^2 was to be met.

The architect used the Passive House Planning Package (PHPP) software to analyse overall energy requirements of the house and also to help inform design decisions such as the use of heat recovery systems etc.

With the intention of fitting within a restricted budget it was determined that the optimum way of saving energy and complying with Passive House standards was to save energy through greater insulation rather than generate energy using renewable technology.

The author calculated planar thermal transmittance values using 'PHPP' and 'Buildesk U'. Linear thermal bridges were calculated using 'Therm'. These values were then inputted into the relevant formulae from ISO 10211:2007 and BRE BR 497 Conventions for Calculating Linear Thermal Transmittance and Temperature Factors.

The author successfully used the Therm software as a tool to improve his design details by reducing thermal bridging and thus kept heat loss through the building structure to a minimum.

3.9 Case Study - Evaluation of thermal bridges by means of numerical simulation (Gudum, 2008)

This is a report that used the 'Heat 2' software to analyse thermal bridges applied to a domestic roof/parapet detail in the Danish environment. The Danish building regulations state that significant thermal bridges may not occur. The report defines a significant thermal bridge as one where there is a risk of condensation that may cause mould growth. The analysis for cold bridges presented in the report was based on the standards of ISO EN 13788.

The author studied Danish weather data to establish the time when conditions for significant thermal bridges would be most critical. It was established that at a condition of 80% relative humidity and a mean outdoor temperature of -1.1°C the conditions for mould growth at a thermal bridge was critical. This would occur during the month of February.

The report took an internally insulated wall/parapet junction and modelled this in a two-dimensional format in the Heat 2 software. A steady-state simulation was performed and the isotherms produced were evaluated to find the minimum surface temperature on the internal surface of the wall. The simulation found the temperature to be 16.4°C, which was higher than the critical temperature established for condensation to occur.

The study concluded that the method of numerical simulation used was suitable for evaluating construction details and establishing the minimum internal surface temperature. This internal temperature can be cross checked against data to predict whether internal condensation may occur for the given external/internal temperature difference and relative humidity.

3.10 Case Study – Balgaddy Housing Development

The Balgaddy Housing project, near Clondalkin in County Dublin, won the RIAI Irish Architecture Award for Best Housing in 2004. The scheme ranges from four bedroom houses to one bedroom apartments and was built between 2004 and 2007 by Gama Construction.

7 years later, in March 2011 The Irish Times newspaper (Holland, 2011) reported problems of serious mould and damp problems in the development. The newspaper reported a tenant from the Tór na Rí part of the Balgaddy development having to move his bed into the kitchen as a result of green and black mould reaching four feet up his bedroom wall. The newspaper also reported mushrooms four inches in size sprouting from skirting boards in the bathroom. The newspaper article reports similar stories from other tenants in the development.

While a specific cause has not been cited, other than damp in general, this situation should be taken as a warning to the dangers of poor design and construction. The problems in Balgaddy are reported to be so bad that tenants are suffering health problems. Poor attention to the problems of thermal bridging and its associated mould and condensation issues is not an option.

John Graby, director of the RIAI commenting on the project for the Irish Times stated '*When there is a systemic problem with a building project it may be due to bad design, bad workmanship, bad materials or a combination of these*.'

The problems at Balgaddy bring to light the real dangers that designers might face when designing details. There is a responsibility both legally and morally to ensure that buildings perform to a safe and compliant standard. Using predictive design tools gives the designer validation that a detail with meet these standards.

4.0 Testing

4.1 Overview

Primary testing began with self learning of the heat transfer programs. Research started initially with 2D analysis using the freely available Therm 5.2 software from Lawrence Berkley National Laboratory (LBNL). Due to the limitations of the Therm software research was then moved towards the AnTherm software written by Tomasz Kornicki. AnTherm was used because it has greater processing capabilities than Therm 5.2 and also includes 3D and periodic simulation functions.

AnTherm was the primary software used, however Therm 5.2 continued to be used for reference and comparison purposes.

Tests were used to examine existing details, manufacturer's suggested details and to refine construction details for studio thesis work.

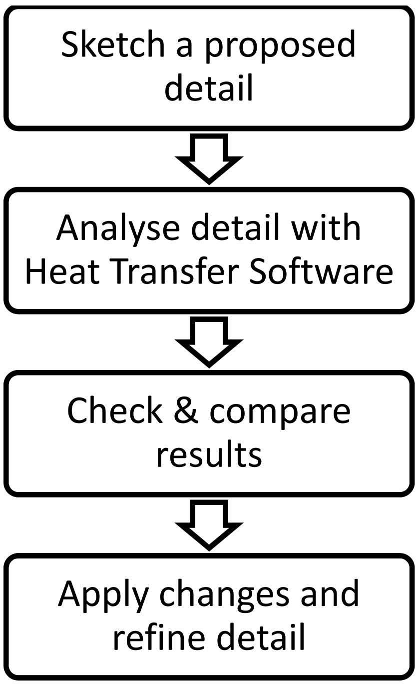


Figure 10 Testing Process

4.2 2D Modelling

2D heat transfer analysis is commonly used for simple heat transfer visualisations and thermal bridge calculations. For a large amount of Thermal Bridge calculations analysis in 2D will be sufficient

Therm 5.2 can be used to visualise simple two dimensional heat flow or to quantify L_{2D} for thermal bridging calculations. The main advantage of Therm 5.2 is its availability and that it is free for use.

It was found Therm was not ideal for advanced heat transfer calculations such as the inclusion of heat generators (e.g. underfloor heating) and transient analysis. However Therm is an excellent tool and has a quick learning curve. Therm could easily be used for simple visualisations and thermal bridge analysis.

AnTherm when used in 2D mode alone has the same functions as Therm; however it possesses greater features such as an inbuilt psi value calculator, detailed output reports, virtually unlimited mesh size and excellent graphical evaluation tools.

It was found that while Therm could do a more than adequate job with heat transfer simulations, AnTherm was easier to use, provided better accuracy and comprehensively better visualisation tools.

It is recommended that for thermal bridging calculation alone Therm 5.2 will suffice but for better heat transfer visualisations AnTherm is superior.

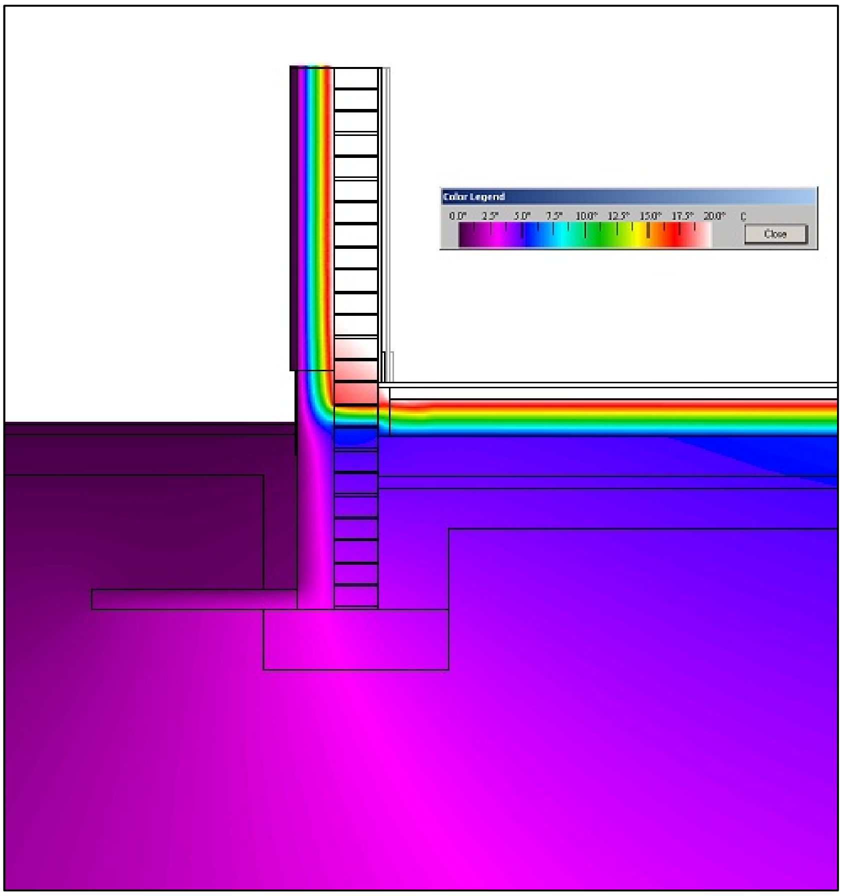


Figure 11 Example of output showing temperature distribution (isotherms) in Therm 5.2

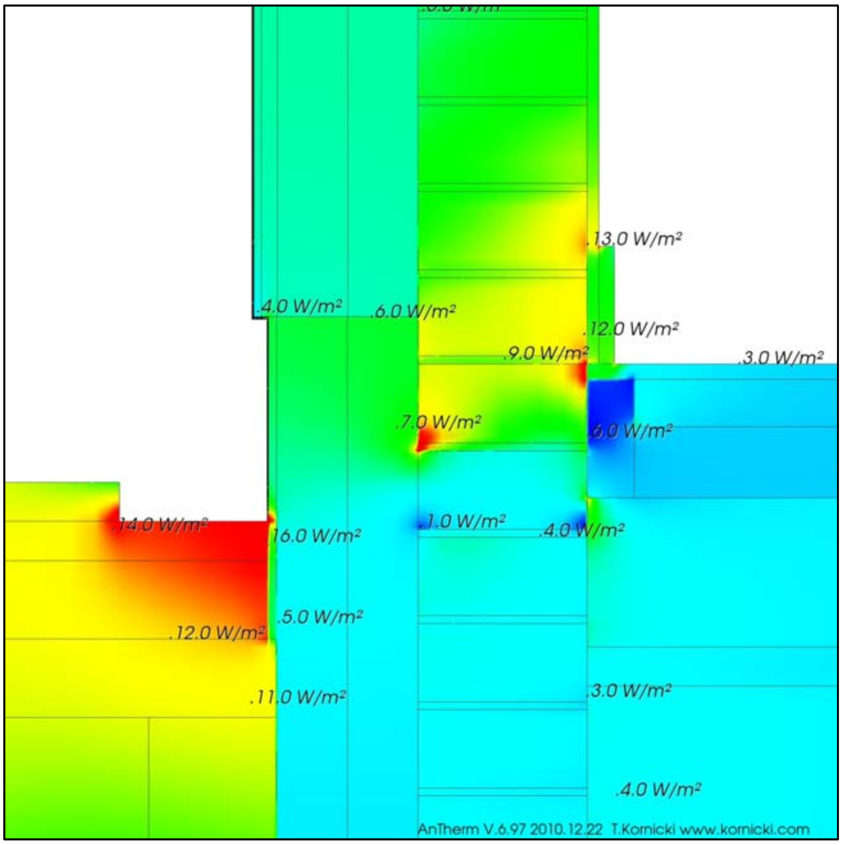


Figure 12 A heat flux visualisation from AnTherm, showing a high resolution close up of the wall/floor junction shown above.

4.3 3D Modelling

AnTherm was used for 3D analysis in this project. The creation of a 3D heat transfer model takes a much larger amount of time and is usually based on a 2D model. Using a 3D model, one can take slices or section cuts through a model quickly and efficiently. To take multiple section cuts in 2D software would take a significantly larger amount of time. 3D modelling allows the critical areas of a detail to be identified.

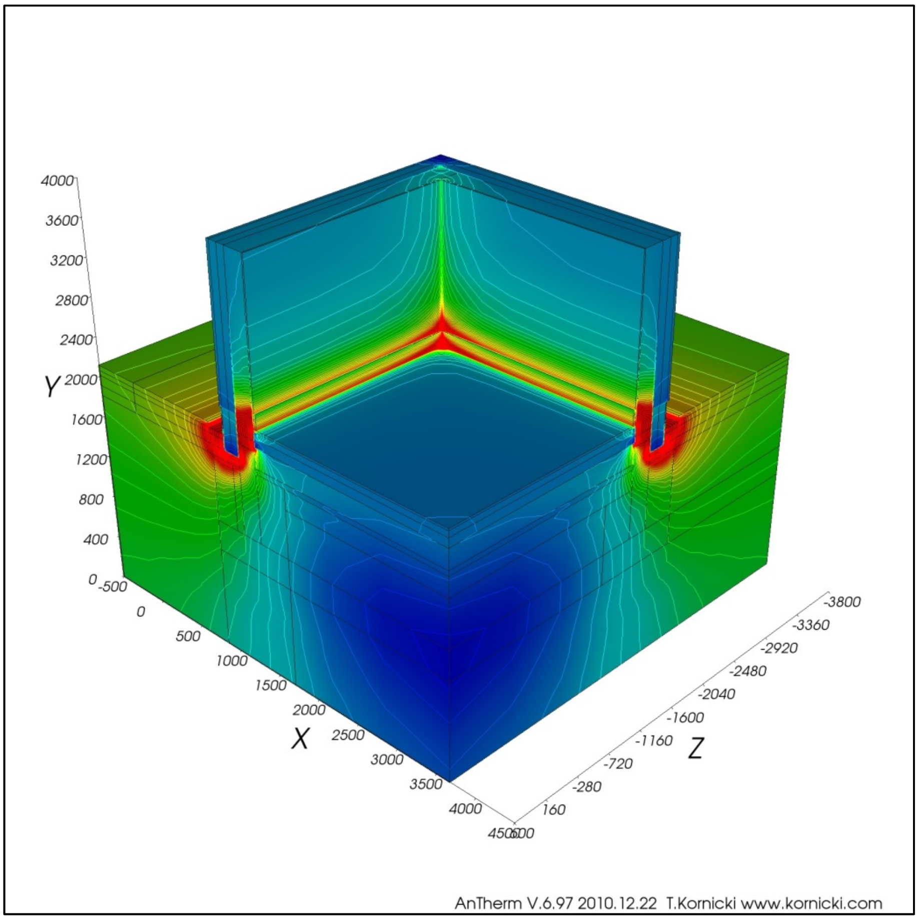


Figure 13 3D Heat flux model of the ground floor detail using AnTherrm. A large thermal bridge is easily identified in red. The problem is intensified at the internal corner of the detail.

4.4 Pricing 2D Vs. 3D

An important part of the practicality of any software tool is its cost. There is a clear scale of costs from the simplest heat transfer software to tools with more advanced capabilities and functions.

A capability / cost matrix of a selection of available thermal simulation programmes is shown on the next page.

At no cost, Therm 5.2 is a very capable tool that could be used in all design situations where more costly applications are impractical. It is recommended that 3D software is used for all analyses beyond simple visualisations and 2D thermal bridge calculations. It may be more cost efficient for a smaller practice to use a specialist consultant for 3D validation of details.

Table 1 Comparison of a selection of Heat Transfer Programs. Information adapted from Centre for Window and Cladding Technology UK (CWCT Thermal Pages, 2011)

	Therm 5.2	BISCO 8.0w	Ansys	Flixo	AnTherm
Polygon Geometry	Almost any shape	Any shape	Any shape	Any shape	Must be a combination of rectangular shapes
Stability	Underlay can cause problems when zooming in on fine details	Good	Good	Good	Good
Drawing Detail	Large and fine cross sections can cause problems	Can accommodate fine details	Fine details no problem	Fine details no problem	Fine details no problem
Output	To screen, printer or file	To screen	Printer or file	To screen	To screen, printer or file
Point Temperature	Yes, temperature at cursor	Yes by adding temperature sensors	Yes	Yes	Yes by adding temperature sensors
Heat Flux Vector and Contour Plot	To screen or printer Full image only	To screen, printer or file Zoom permitted	To screen, printer or file Zoom permitted	To screen, printer or file Zoom permitted	To screen, printer or file Zoom permitted
User defined contours	No	Yes	Yes	No	Yes
High Resolution Graphics	No	Yes	Yes	Yes	Yes
3D Capability	No	Available (TRISCO)	Yes	No	Yes
Transient Capability	No	Available (SECTRA)	Yes	No	Yes
Price	Free	£2800	£8000 (Annual licence)	€3000	€1393.66 (1 Year with 3D & Transient: 50000 Cells)

4.5 Transient Simulation

Transient (also known as periodic or harmonic simulation) is the modelling of heat transfer over a period of time such as 24 hours or one year. Steady state simulation such as that used in Therm 5.2 models the heat transfer in a situation of unchanging heat flow. In reality, external conditions vary with time -the obvious example being the warming effect of the sunshine during the day and the cooling night time period. This periodic heating cycle results in a time lag in the storage and transfer of heat. The thermal mass of a concrete floor slab or the mass of the earth itself below a building are examples of elements with a high thermal lag.

EN ISO 13370:2007 provides provision for the calculation of periodic heat transfer coefficients. The periodic heat transfer coefficient is defined as the amplitude of periodic heat flow divided by the amplitude of temperature variation over an annual cycle. Specific heat capacity of unfrozen ground (J/KgK), density (Kg/m^3) and thermal conductivity (W/mK) are included in these calculations. Periodic calculations should be taken as more accurate than steady-state.

Category	Description	Thermal conductivity λ W/(m·K)	Heat capacity per volume ρc J/(m^3·K)
1	clay or silt	1,5	$3,0 \times 10^6$
2	sand or gravel	2,0	$2,0 \times 10^6$
3	homogeneous rock	3,5	$2,0 \times 10^6$

Figure 14 Thermal Properties of the ground including specific heat capacity (EN ISO 13370:2007)

The Passive House Institute (Feist, 2007) suggests that in Passive House details the periodic thermal bridge heat loss coefficient may be replaced with the steady-state value. The prerequisite for this is that the additional heat losses through the detail remain smaller than through the undisturbed construction.

It was decided not to use transient psi-value calculation for the Verschoyle Court project; however an understanding of the principles is important in visualising and developing construction details in contact with the ground.

4.6 The Relationship between U-Values and Psi-Values

The Irish Building Regulations have clear requirements to be met in terms of heat loss through the building fabric, such as;

Planar heat loss: U Values [W/m^{2}K] and
Linear heat loss: Psi Values [W/mK]

In addition to the visual method of analysing isotherms and heat flux patterns used in this project, Psi values were used as a tool to quantify the effectiveness of the details in this project. This was important for two reasons; firstly, Psi values give an accurate value of heat loss through a linear thermal bridge and secondly, Psi values confirm whether a proposed detail will meet the required building regulations.

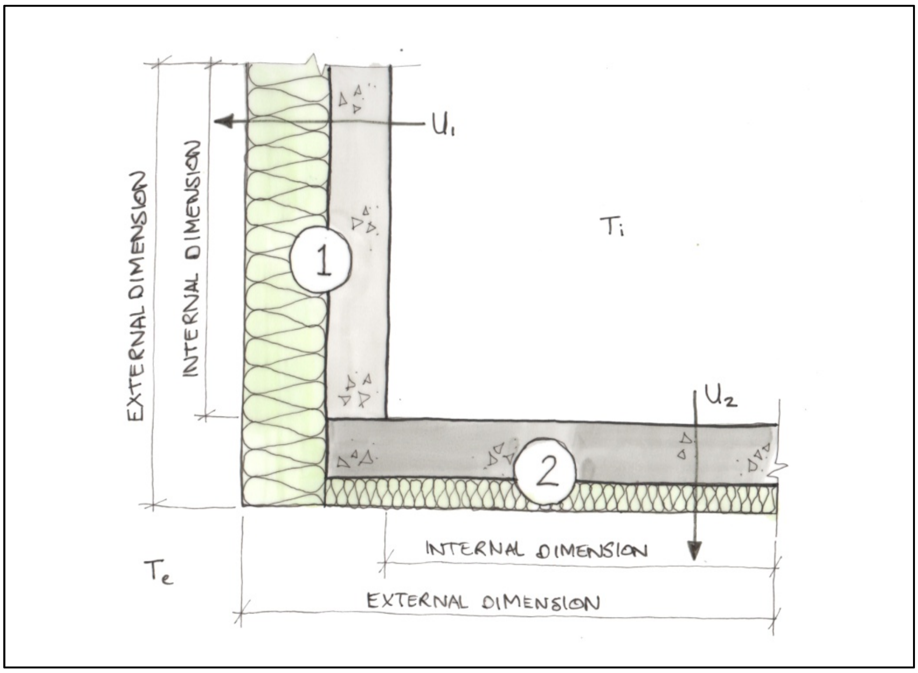


Figure 15 Image showing the important elements modelled in a two dimensional thermal bridge calculation. The image also illustrates the important difference in using internal and external measurements in thermal bridge quantification. (Image modified from Passive House Planning Package manual (Feist, 2007))

It has been a common trend in the latter part of the twentieth century to apply ever increasing amounts of insulation to walls, floors and ceilings and thus decrease the U Value of building planes. As we move toward near Passive House standard (0.15W/m^{2}K or less) the proportion of heat lost through linear thermal bridging increases vastly. It is simply not enough to apply low U values to a building and expect details to perform well. More than ever it is difficult to eliminate cold spots and condensation at these junctions. Indeed, it can be near impossible to verify the 0.01 W/mK Passive House Psi values without accurate thermal modelling.

Regarding the Acceptable Construction Details or ACDs, when moving towards high performance details it is questionable whether effectively selecting designs from a catalogue of details is appropriate to the individual and prototypical nature of building construction. This is particularly the case when the ACDs specify no specific value for wall insulation thickness or conductivity. Psi values are a function of the insulating planes adjacent to them, in other words –a higher wall and floor U-Value may lead to a higher Psi value. This argument is echoed by the writings of Joseph Little in Construct Ireland magazine;

> *The Psi-values listed in table D1* (of TGD L) *become harder and harder to achieve as the U-value of the plane element increases (in both new-build and refurbs). Thus a Psi-value of 0.04 W/mK for a sill where the wall is 0.6 W/m2K is much easier to achieve than with 0.27 W/m2K*. (Little J. , 2009)

Little goes on to say;

> *The regulatory requirements for conserving fuel and energy in relation to thermal bridging in dwellings are currently inadequate, however a great opportunity exists in the upcoming review of Technical Guidance Document L to put this to rights.* (Little J. , 2009)

4.7 The Thermal Mass of the Earth

A peculiarity of heat transfer calculations in direct contact with the earth itself is the thermal mass effect. The land and oceans of the world are the largest heat sinks of the sun's solar radiation. This thermal mass of the earth is already used to advantage in sustainable energy systems such as geothermal heat pumps.

The temperature of the ground fluctuates constantly with time. These temperature fluctuations can be approximated to a sine wave with an amplitude approximately equal to half the difference between the corresponding average maximum and minimum monthly temperatures (Feist, 2007). This is supported by temperature data recorded in Ireland (see Appendix B).

When using steady-state heat transfer software it is difficult to replicate the effect of a heat sink so massive in size. Transient heat transfer calculations should deal with this phenomenon to a higher accuracy however, it is near impossible to replicate this condition with 100% accuracy.

Linear heat loss calculations address the problem by including a significantly large mass of earth in the simulations. Up to twenty metres (width and depth) of earth is often included in these calculations. To model any more would require considerable time and computing resources.

A simplified approximation of the ground effect would be to model greater than twenty metres width and depth of earth and to include a heat generation source within the ground. When using this method it is essential to model geothermal conditions specific to the location of the building.

It is not sufficient in the accurate visualisation of heat transfer within building details adjacent to the ground to ignore these ambient ground temperatures. To do so would present inaccurate results.

It was found in this project that the inclusion of an approximated thermal mass had significant impact to the temperature profiles of any details modelled.

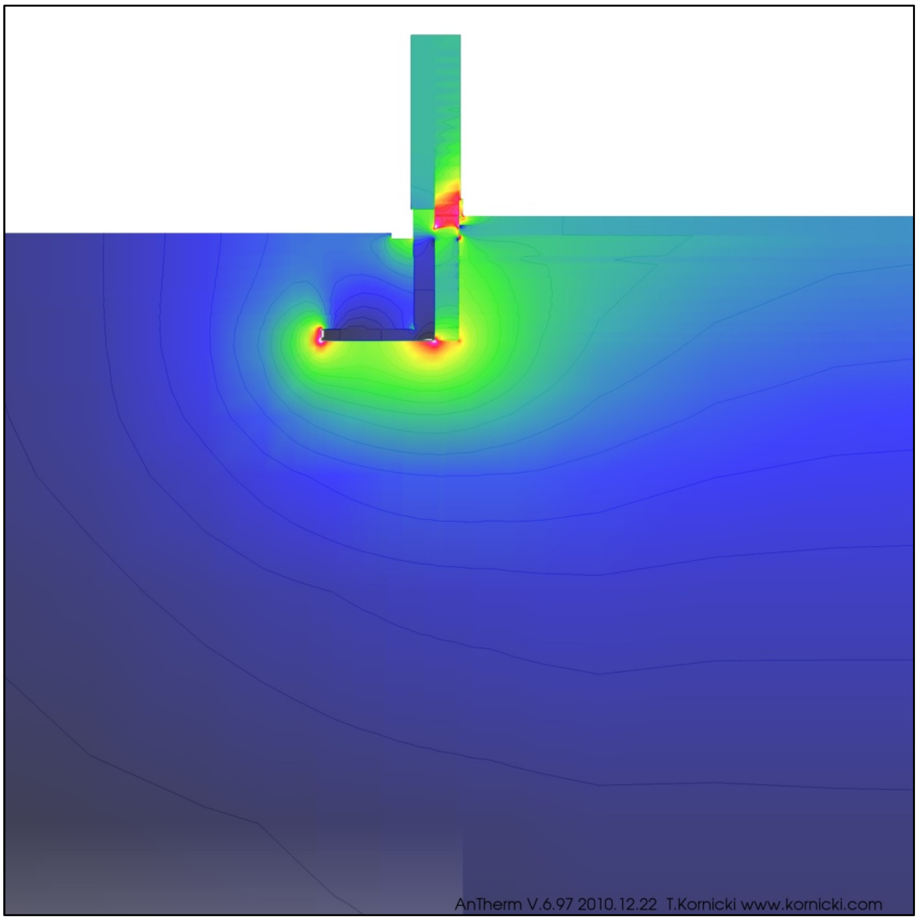


Figure 16 Image showing heat flux in the ground. Approximately 50% of the ground that should be included in the model is displayed in this image. Typically the ground will be modelled to a 20m depth for accurate results. Simulated in AnTherm.

4.8 PHPP and the ground

The Passive House Planning Package (PHPP) published by the Passive House Institute (PHI) (Feist, 2007) and its associated software include parameters for the inclusion of thermal bridges at the ground level. The software also includes functionality to factor in the effects of perimeter insulation and the heat storage capacity of the ground. The PHI recommends thermal bridge free construction and defines this as a detail with a Psi value of lower than 0.01 W/mK (exterior dimensions used). See Figure 15 (Page 28) for an explanation of the differences between internal and external dimensions.

PHPP recommends validating thermal bridge details using finite element software. The “Ground” worksheet in the PHPP software allows for the calculation of an overall reduction factor (which is then inputted to the “Annual Heat Demand” worksheet) when the effects of an insulated slab on grade are calculated. The software also includes inputs for additional perimeter insulation.

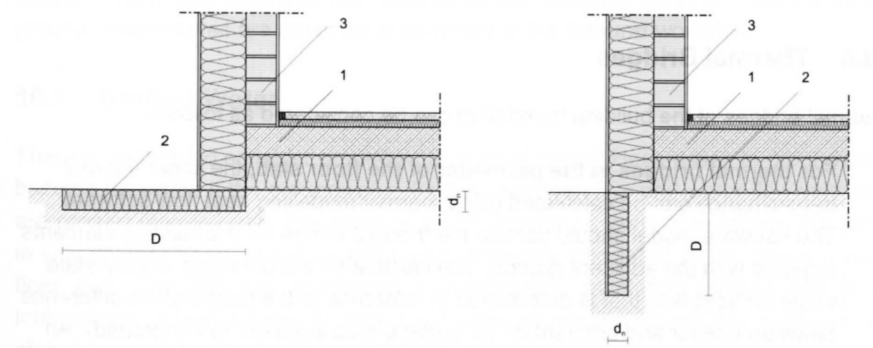


Figure 6: Horizontal (left) and vertical (right) perimeter floor slab insulation on grade with corresponding dimensions. 1 - Floor Slab, 2 - Perimeter Insulation, 3 - Exterior Wall.

Figure 17 Image from the Passive House Planning Package manual showing perimeter insulation options (Feist, 2007)

PHPP suggests that vertical perimeter insulation is more efficient than horizontal, however PHPP also recommends a thermal bridge calculation using multidimensional (3D) simulation to quantify the heat conservation effect of perimeter insulation. In the Verschoyle Court situation it was found that the horizontal perimeter insulation was in fact the most efficient solution when combined with vertical perimeter insulation.

4.9 Developing a Ground Floor Detail

The ground / wall junction detail of Verschoyle Court was developed through accurate heat transfer simulations in both two and three dimensions. The use of three dimensional simulation was important as both BRE BR497 and IS EN10211 state that ground details must be examined in 3D to achieve accurate results.

The research has shown that it is possible that the heat storage capacity of the ground is often underestimated in Irish building details. It was found through simulation and taking into account the ambient temperature of the ground that heat loss through the ground was of much less significance than through the wall and corner elements. A significant reduction in floor insulation (nearly 50%) yielded similar results in the thermal simulations.

When reducing the amount of floor insulation it is important to negate the effects of cold penetration below the slab. This was achieved by carrying the wall insulation down to foundation footing level and extending perimeter insulation away from the building 1 metre horizontally. As can be seen from the heat transfer visualisations of Details 4 and 5 cold penetration is diverted away from the building.

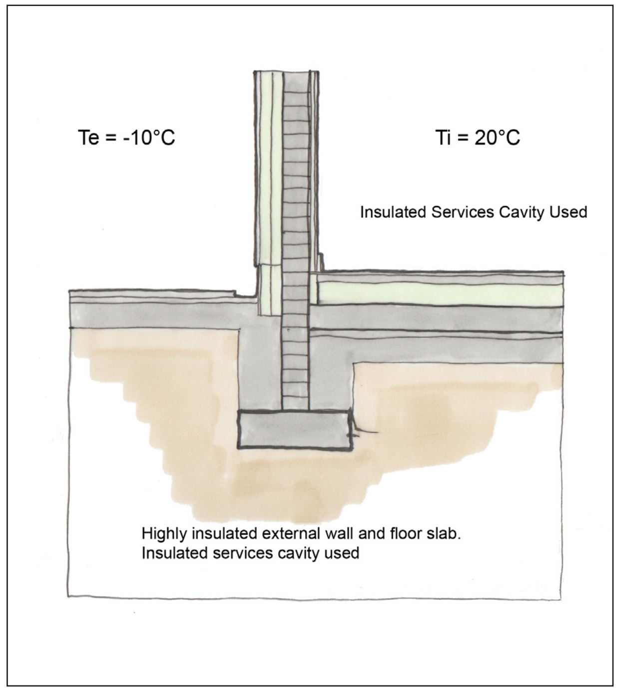
All simulations were carried out at a predicted worst case scenario (e.g. Winter 2010/2011) where internal temperatures were 20 degrees Celsius with an external temperature of -10 degrees Celsius. Frost penetration will carry deep into the ground but only to a certain depth where the heat storage capacity of the earth prevents further cold penetration.

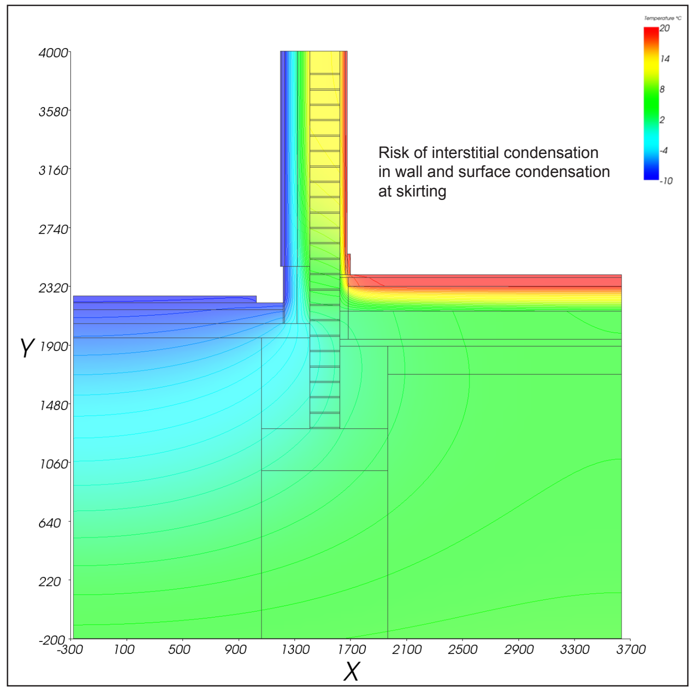
The results of the heat transfer modelling are summarised visually from pages 34 to 38. It is useful to examine the problem in two dimensions for a quick analysis, moving to a three dimensional analysis verifies the results to a higher standard.

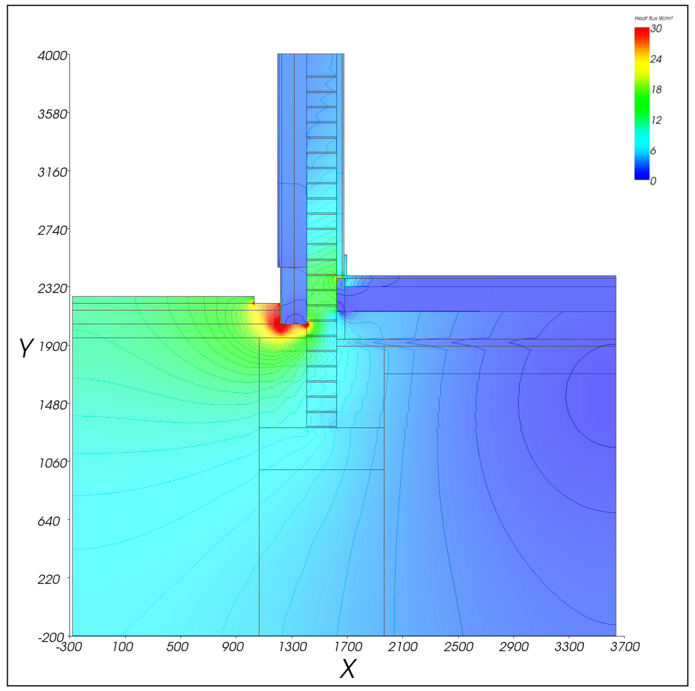
The results shown are the AnTherm simulations; however as a benchmark validation the details were also modelled in Therm 5.2 (two dimensional models only). Psi values were also calculated using Therm 5.2 and the results are tabulated in Appendix G.

Detail Sketch	Temperature Profile (°C)	Heat Flow Intensity (W/m²)	Energy Analysis

Detail 01







DETAIL 01

Psi Value:
0.169 W/mK

Wall Energy Loss:
47.03 W/K

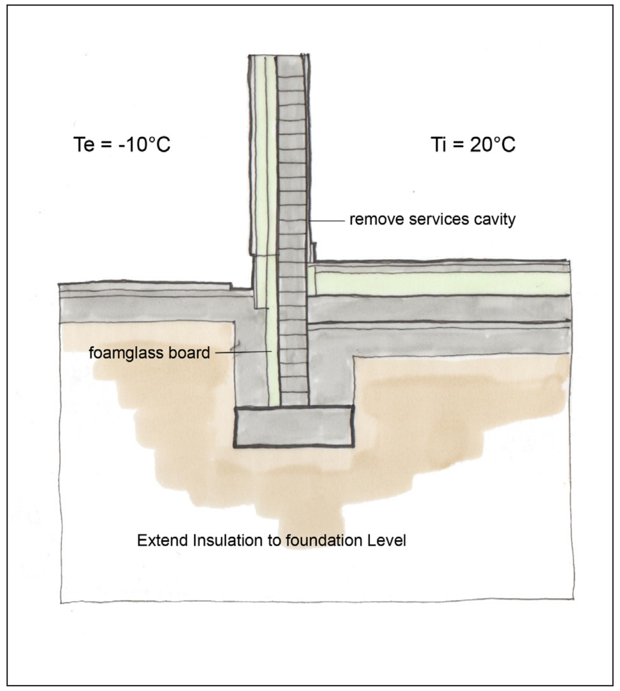
Floor Energy Loss:
9.09 W/K

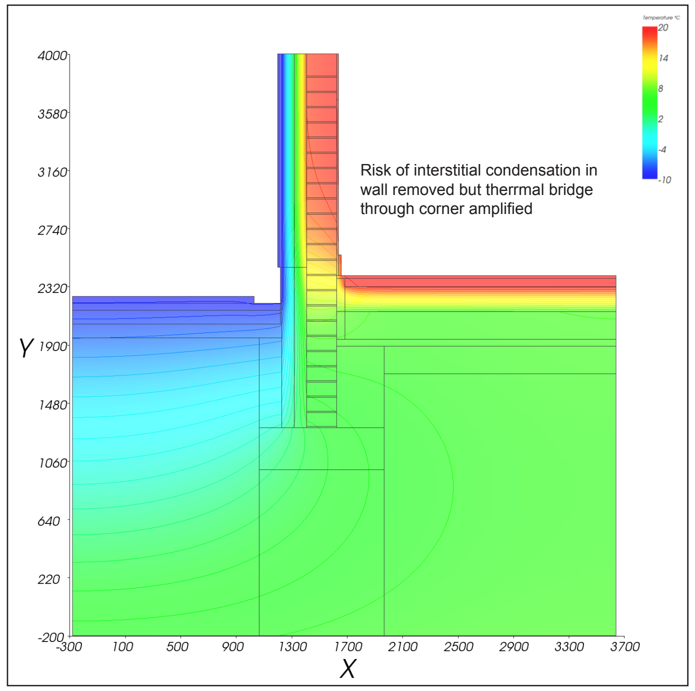
Thermal Bridge Energy Loss:
17.66 W/K

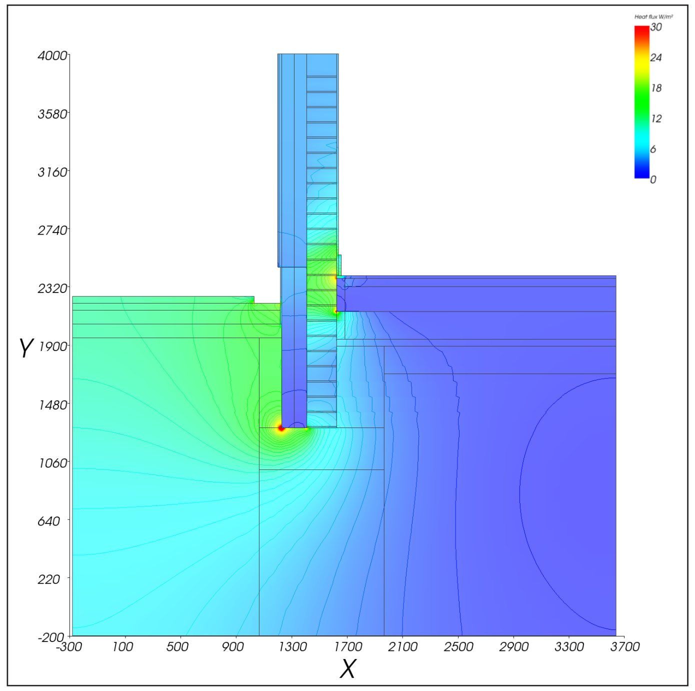
Non Compliant With TGD L

Detail 1 - Highly insulated wall and floor with insulated services cavity. The thermal analysis indicated that the linear heat loss through the corner would not meet building regulations. There is also a risk of condensation at the skirting area. If moisture was present in the wall there would be severe risk of interstitial condensation, the dew point is very close to the internal face of the wall. This is a detail often recommended by external insulation companies in Ireland.

Detail 02







DETAIL 02

Psi Value:
0.230 W/mK

Wall Energy Loss:
47.03 W/K

Floor Energy Loss:
9.09 W/K

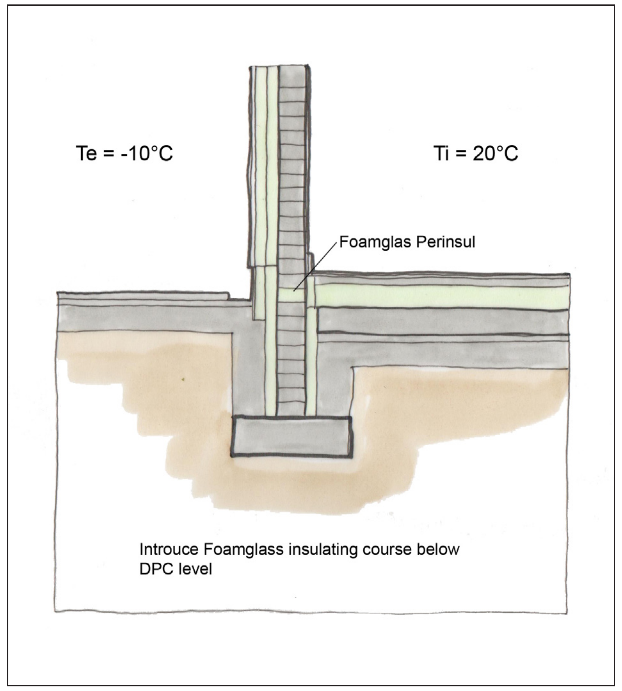
Thermal Bridge Energy Loss:
24.04 W/K

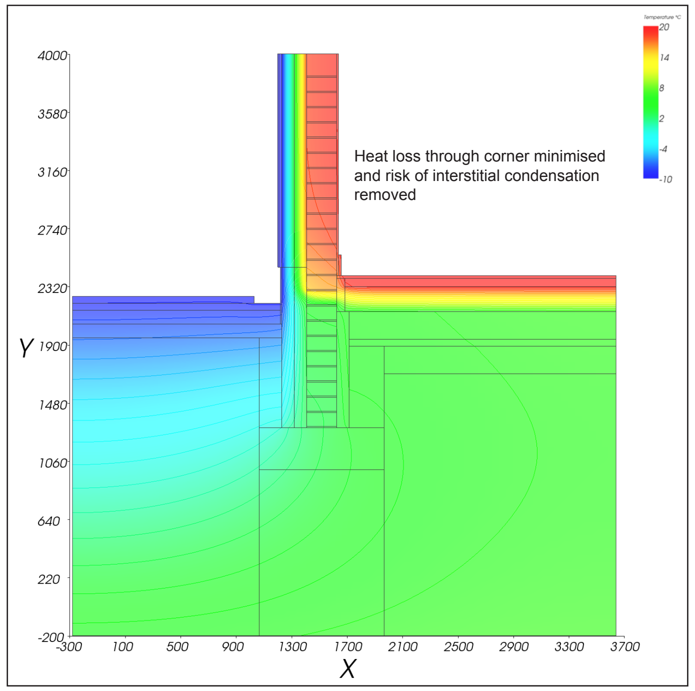
Non Compliant With TGD L

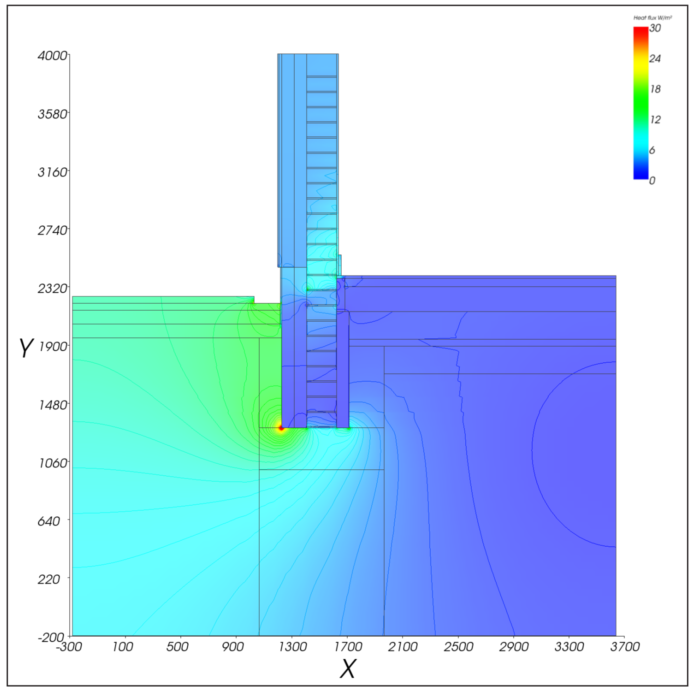
Detail 2 - The insulated service cavity is removed to move the dew point towards the external face of the wall. External insulation is continued below ground level to solve the problem of thermal bridging at the corner. The thermal bridge is still present and the detail performs worse than the previous setup. This is because the thermal envelope has a larger break due to the removal of the service cavity

Detail Sketch	Temperature Profile (°C)	Heat Flow Intensity (W/m²)	Energy Analysis

Detail 03







DETAIL 03

Psi Value:
0.085 W/mK

Wall Energy Loss:
47.03 W/K

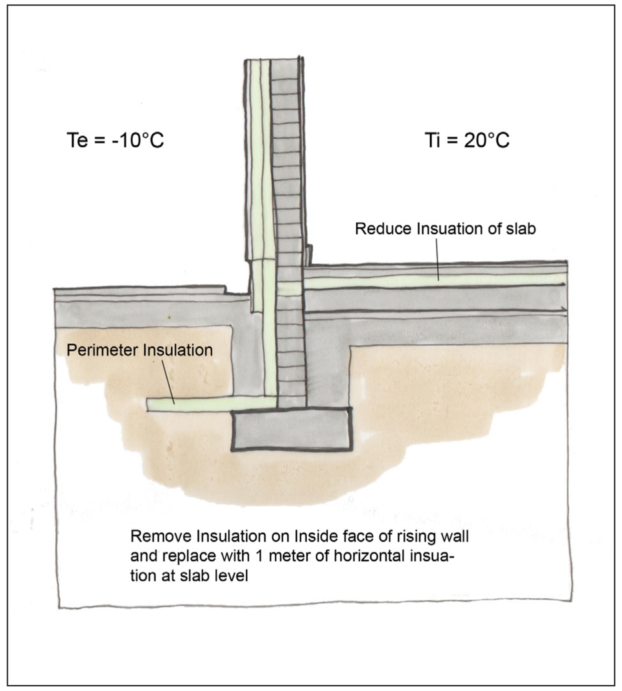
Floor Energy Loss:
9.09 W/K

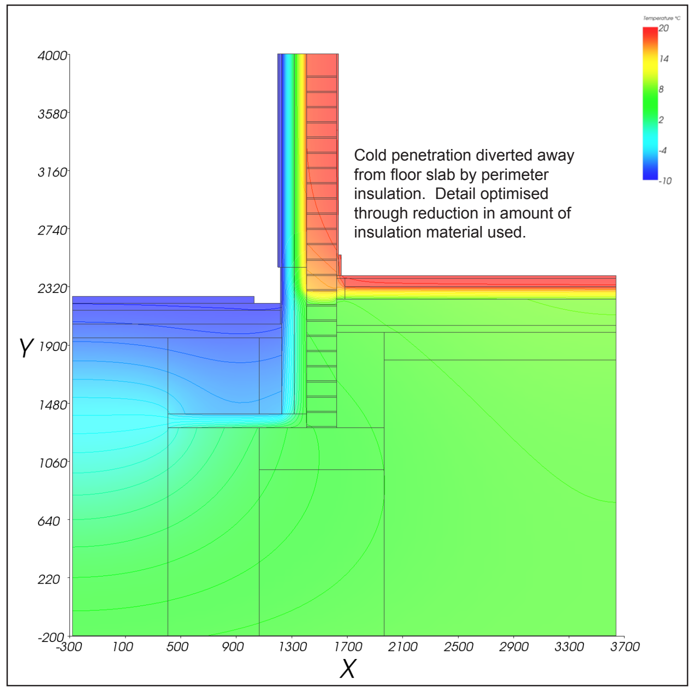
Thermal Bridge Energy Loss:
8.88 W/K

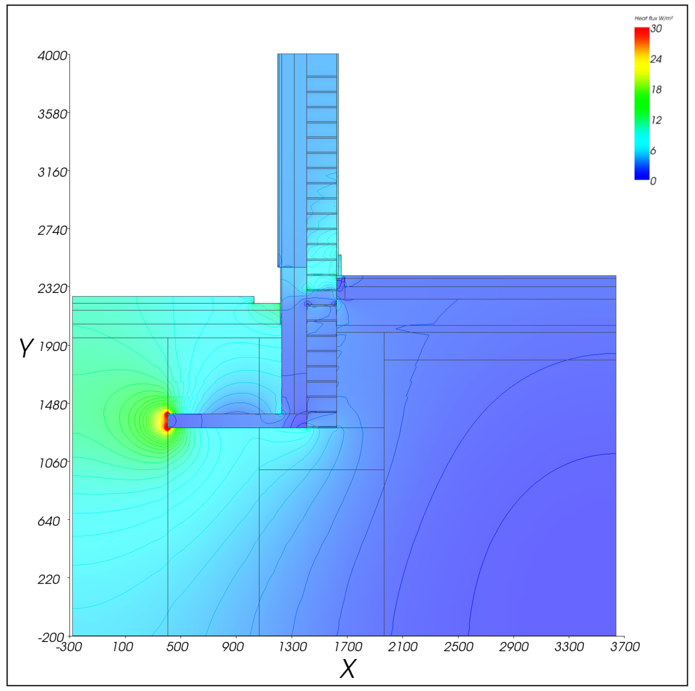
Compliant With TGD L

Detail 3 - The foundation insulation is continued on the opposite face of the rising wall and an insulating course of foamglass is introduced below DPC level. This has the effect of drastically reducing the thermal bridge. The energy performance exceeds the building regulations and could be considered sufficient in some situations. The thermal performance of this detail is at an acceptable level.

Detail 04







DETAIL 04

Psi Value:
0.067 W/mK

Wall Energy Loss:
47.03 W/K

Floor Energy Loss:
13.59 W/K

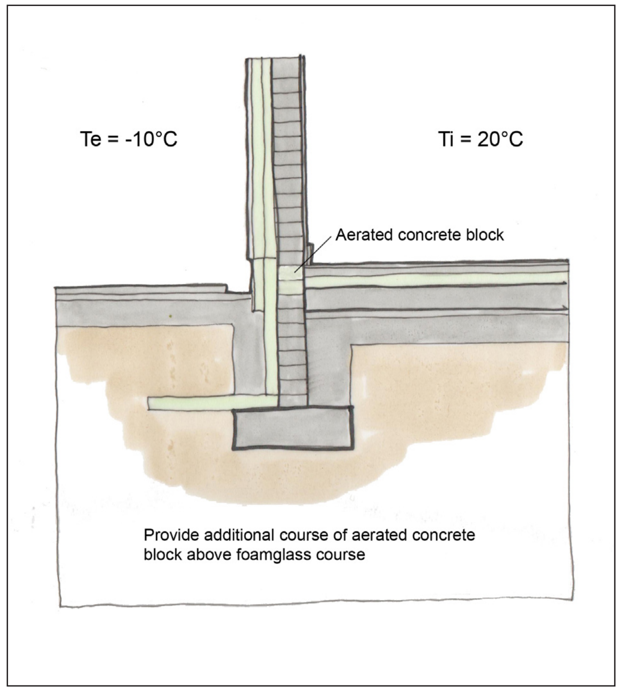
Thermal Bridge Energy Loss:
7.00 W/K

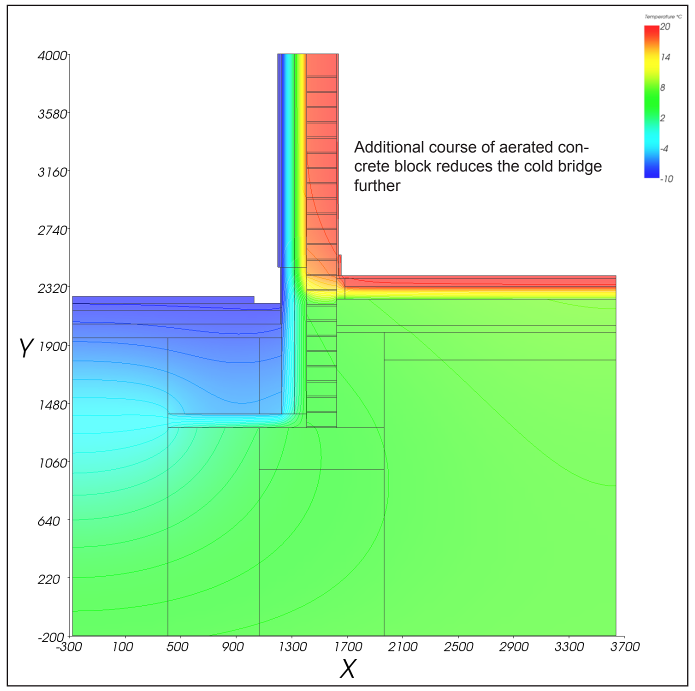
Compliant With TGD L

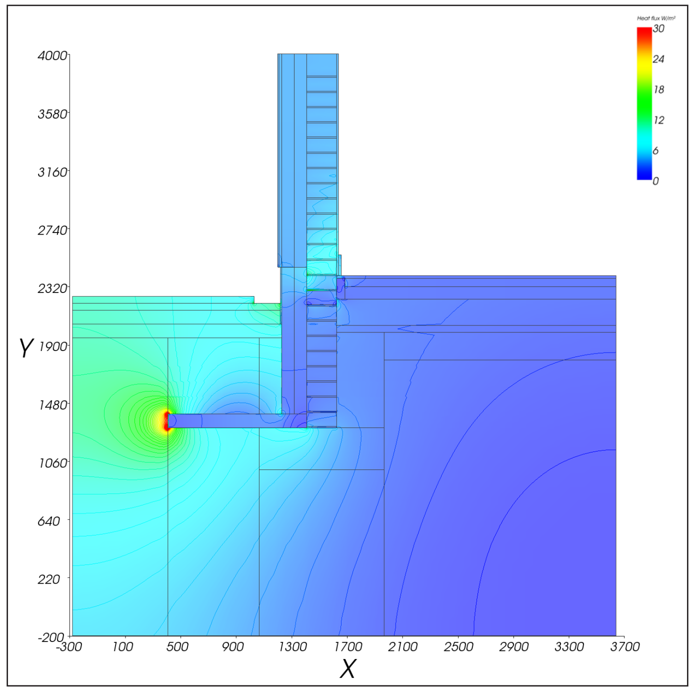
Detail 4 - By introducing a horizontal element of perimeter insulation the most severe effects of cold penetration are diverted away from the floor slab. As a result, the floor slab insulation can be reduced by a large amount and the linear thermal bridge is reduced by a further 21%. The heat loss through the thermal bridge is now smaller than the heat loss through the floor and wall.

Detail Sketch	Temperature Profile (°C)	Heat Flow Intensity (W/m²)	Energy Analysis

Detail 05







DETAIL 05

Psi Value:
0.054 W/mK

Wall Energy Loss:
47.03 W/K

Floor Energy Loss:
13.59 W/K

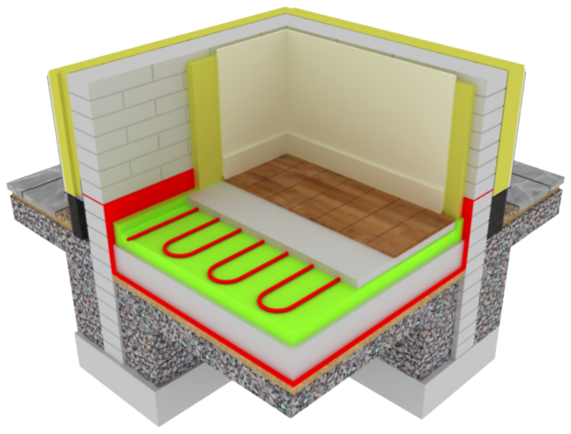
Thermal Bridge Energy Loss:
5.64 W/K

Compliant With TGD L

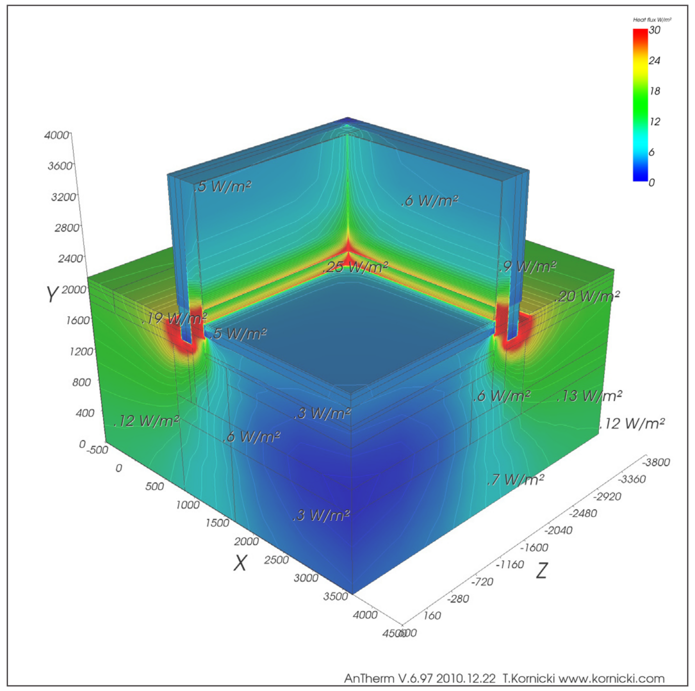
Detail 5 - The addition of a layer of autoclaved aerated concrete block (AAC) above the Foamglass course further reduces the thermal bridge. Detail two loses 425% more heat energy than the detail illustrated above. It was found that the positioning of insulating courses were at the most optimum in this situation. Any additional layers of insulating coursework produced negligible improvements. One layer of Quinnlite B7 above the Foamglass layer proved the equivalent of 8 courses below.

Detail Sketch	Heat Flow Intensity (W/m²)	Temperature Profile (°C)	Energy Analysis

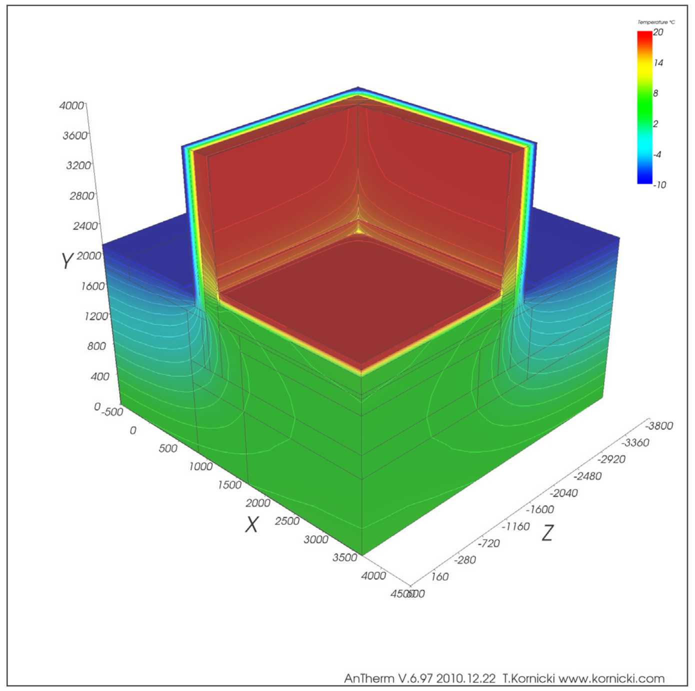
Detail 01



3D Render of model construction (ground ommit-ted for clarity



Heat Flux visualisation



Temperature distribution (Isotherms)

DETAIL 01

Psi Value:
0.169 W/mK

Wall Energy Loss:
47.03 W/K

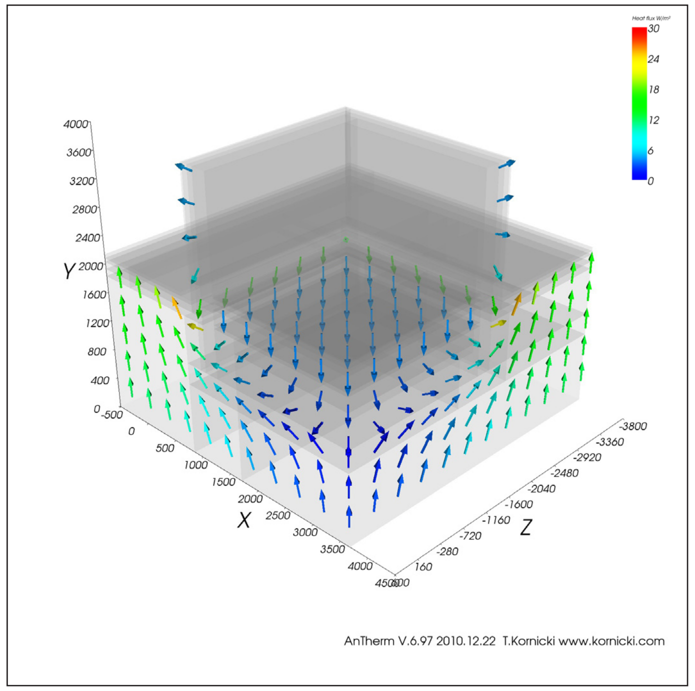
Floor Energy Loss:
9.09 W/K

Thermal Bridge Energy Loss:
17.66 W/K

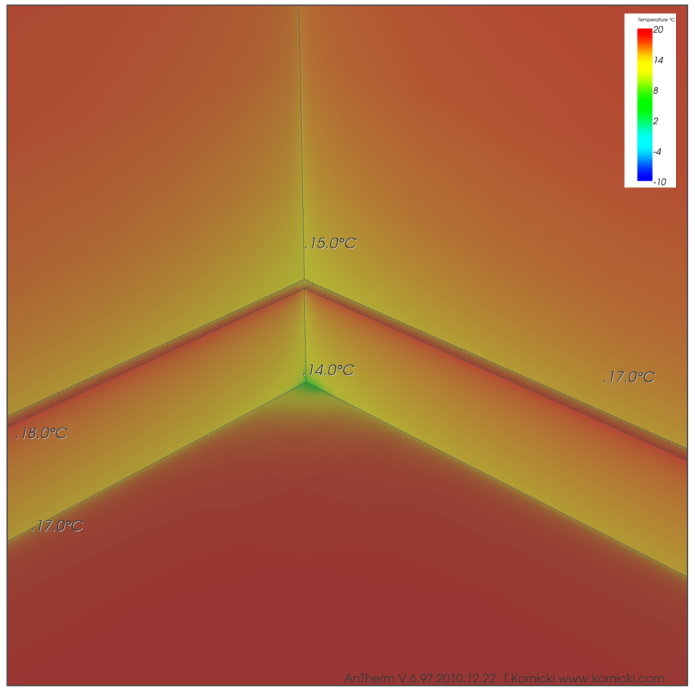
Non Compliant With TGD L

Detail 1 -

Highly insulated wall and floor with insulated services cavity. The thermal analysis indicated that the linear heat loss through the corner would not meet building regulations. There is also a risk of condensation at the skirting area. If moisture was present in the wall there would be a severe risk of interstitial condensation, the dew point is very close to the internal face of the wall. This is a detail often recommended by external insulation companies in Ireland.



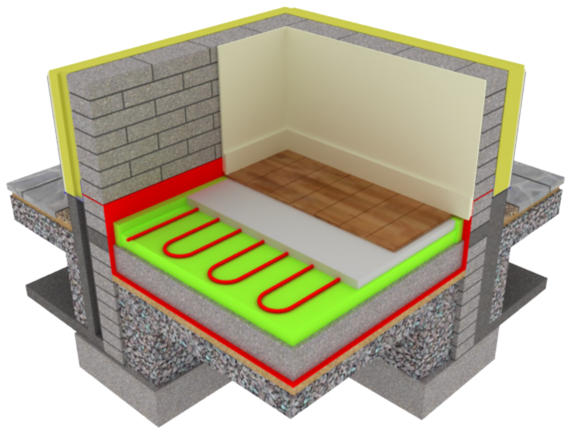
Heat Flux Vector Plot



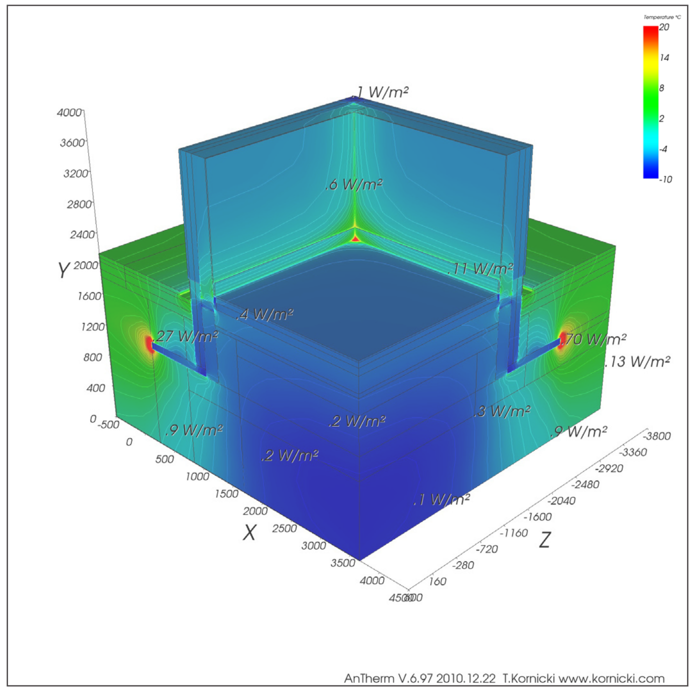
Close up of temperature (Isotherms) at internal corner of detail

Detail Sketch	Heat Flow Intensity (W/m²)	Temperature Profile (°C)	Energy Analysis

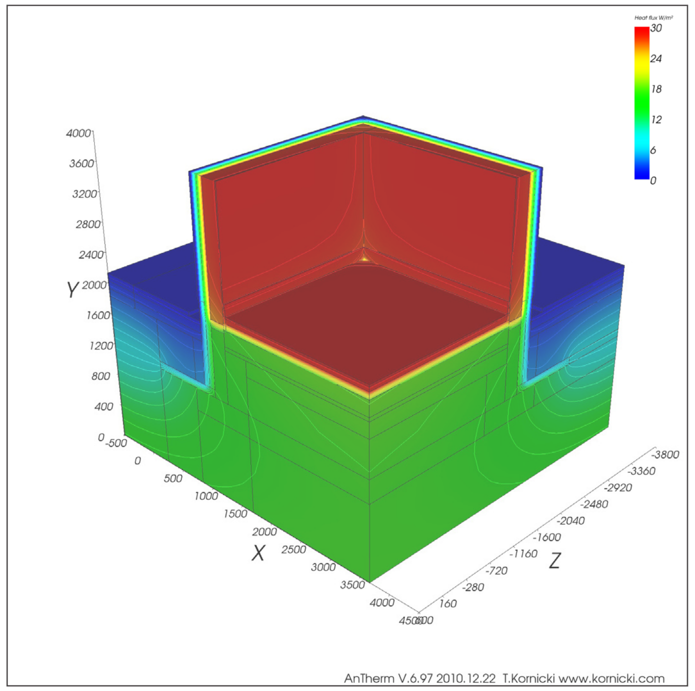
Detail 04



3D Render of model construction (ground ommitted for clarity



Heat Flux visualisation



Temperature distribution (Isotherms)

DETAIL 04

Psi Value:
0.067 W/mK

Wall Energy Loss:
47.03 W/K

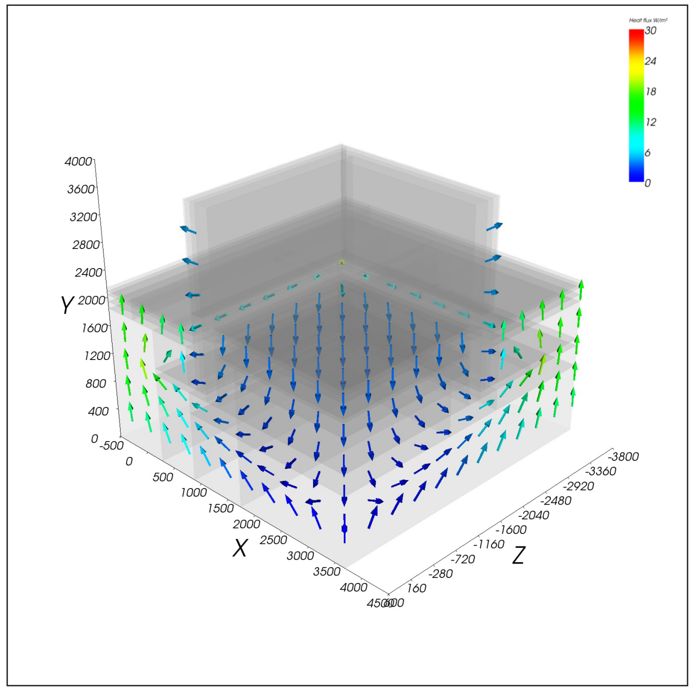
Floor Energy Loss:
13.59 W/K

Thermal Bridge Energy Loss:
7.00 W/K

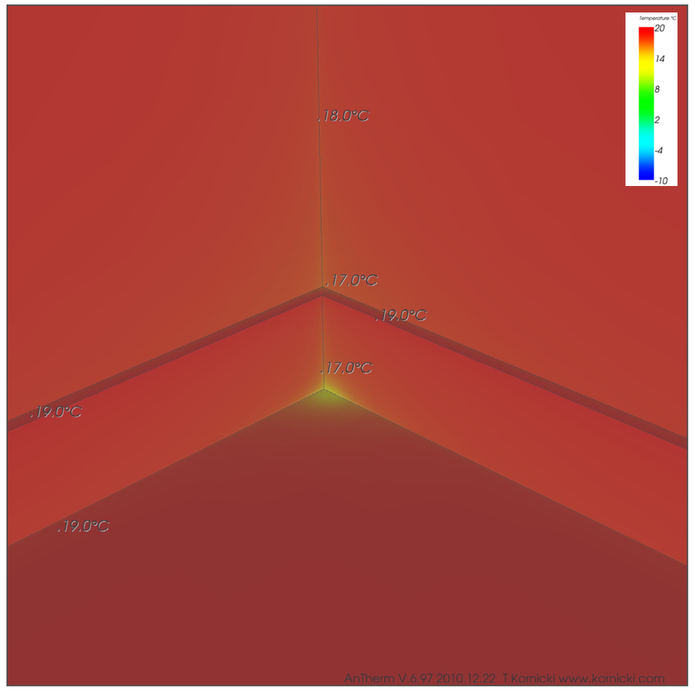
Compliant With TGD L

Detail 4 -

By extending the external insulation to footing level, introducing a perimeter insulation course in the rising wall and introducing a horizontal element of perimeter insulation the most severe effects of cold penetration are diverted away from the floor slab. As a result, the floor slab insulation can be reduced and the linear thermal bridge is reduced to 29% of the heat lost through Detail 02.



Heat Flux Vector Plot



Close up of temperature (Isotherms) at internal corner of detail

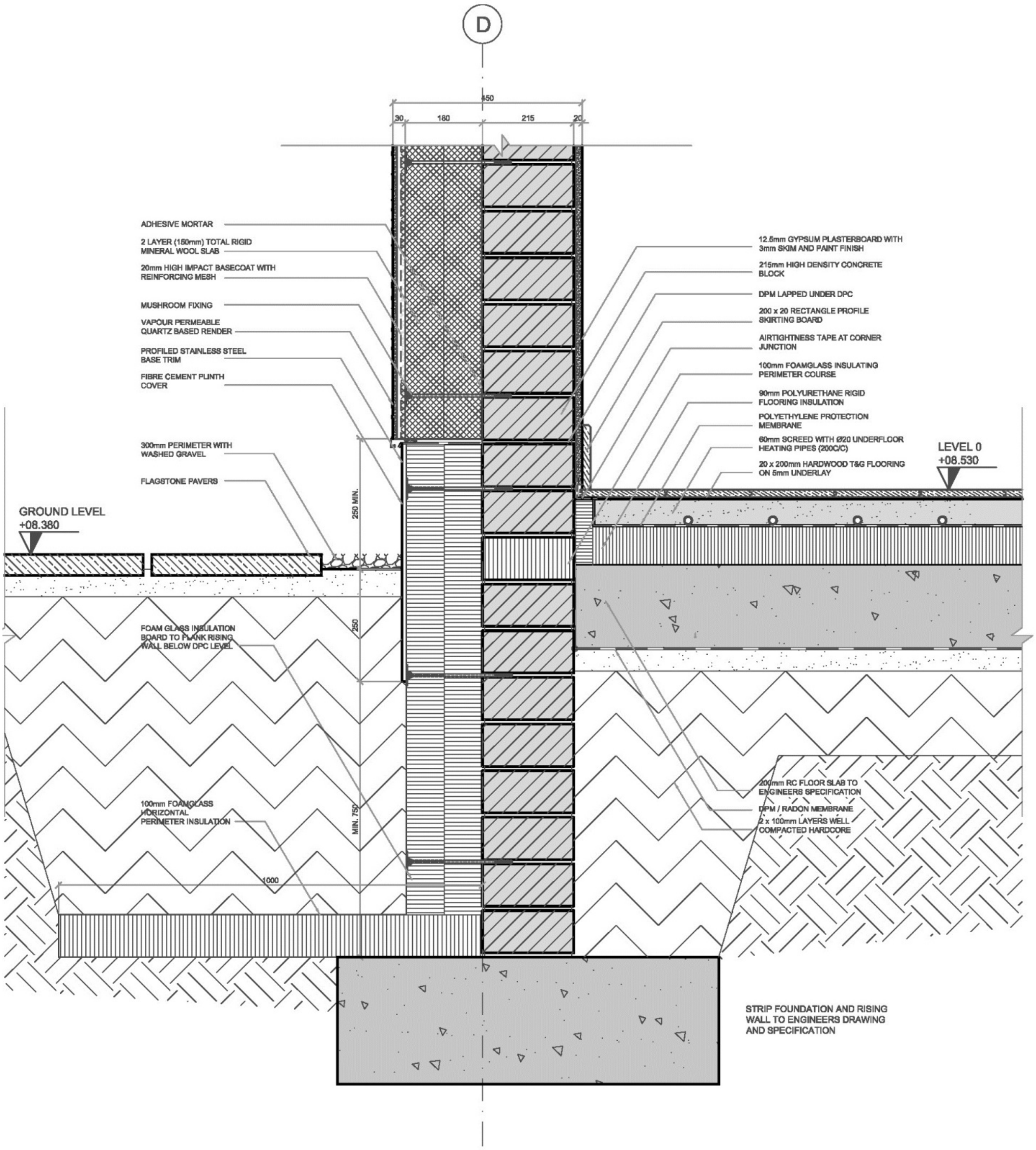
4.10 Guidelines to reduce thermal bridges (In General):

The following is a summary of methods the author found useful in designing good construction details;

- Provide an unbroken thermal envelope to a complete building
- Where it is not possible to provide an unbroken envelope; lapping, extending or increasing insulation may offset the problems associated with the thermal bridge
- Separate materials of high conductivity using insulation materials
- Choose materials of low conductance from the initial design stage
- Decrease the surface area in contact with a highly conductive material
- Understand and apply the scientific principles of heat transfer when designing construction details
- Analyse and test a detail using heat transfer software before the detail is finalised

4.11 The Final Detail

The image below shows a typical ground floor detail developed for the Verschoyle Court project. The detail shown has a Psi Value of 0.067 W/mK, this detail exceeds the current building regulations for linear heat loss through a ground floor junction by 58%.



TYPICAL GROUND DETAIL
SCALE 1:15

5.0 Conclusions

This dissertation has examined two separate but related areas of heat transfer in buildings;

- The quantification and analysis of linear thermal bridging through the use of Psi values, and
- The use of thermal visualisations as a design tool in creating novel construction details

These two areas complement each other and should be used together in creating construction details for modern energy efficient buildings.

Using heat transfer software to model thermal movement in building details will help develop a better understanding of thermal bridging and the reasons why it occurs. If an Architectural Technologist can visualise heat transfer through a structure this can be used as an aid to his designing of better construction details.

A building with excellent U-Value figures will not necessarily perform as expected unless considerable attention has been paid to continuity within the building envelope and minimising heat loss through the thermal barrier.

To design the best possible construction details, minimise fabric heat loss and optimise thermal comfort for the end-user, all construction details should be analysed before they are approved for construction. For a modest investment the purchase of quality heat transfer software could provide a very good return for a technical design team. Building details could be analysed and prototyped for considerably less cost than building physical models and/or repairing the cost of poorly designed details.

Three dimensional thermal modelling also has its drawbacks. It is time consuming to produce even a simple detail and the construction of such a model requires a far greater level of expertise in the area. The cost of three dimensional heat transfer software may be prohibitive for smaller architectural practices. Although two dimensional heat modelling should be used in every office, three dimensional heat modelling may be better suited to consultants and experts until the cost falls to a more affordable level.

There is a new role for the Architectural Technologist as a consultant in the design and thermal testing of building details, it is no longer sufficient to perform simple U-Value calculations. A higher degree of technical expertise and scientific understanding is required to perform correct analyses.

Although this project concentrated on new-build details, the methodology used has very practical possibilities for use in renovation and refurbishment situations. This type of work will be become increasingly more important over the coming years as Ireland seeks to improve the thermal efficiency of its existing housing stock.

Good design is not about simply meeting building regulations or legislative requirements. Good design should be about creating novel solutions that work and improve comfort for the end user. Not only can thermal analysis be used for this purpose it can also be used to value-engineer solutions, thus saving money and optimising the use of valuable physical resources.

6.0 Further Research Areas

Due to limitations of time, scope of the project and available resources there remains unanswered questions in this area of study.

- There is a need for a comprehensive set of guidelines for the use of heat transfer software in the Irish construction industry, particularly for Architects and Architectural Technologists. Existing guidelines can be vague and/or contradictory.
- There is a need for education in the use of this software at undergraduate level. If Architectural Technologists are to be the experts and leaders of Architectural building technology they must be knowledgeable in this important area of building physics.
- Integration of existing 2D and 3D models with the various heat transfer packages is limited. It would be extremely useful to have compatibility between building models such as Google SketchUp or Autodesk Revit and heat transfer software.

7.0 Important Legislation & Standards

1. Irish Building regulations TGD L – Appendix D
2. I.S. EN ISO 10211-1: 1996 Thermal bridges in building construction – heat flows and surface temperatures. Part 1 general calculation methods.
3. I.S. EN ISO 10211-2: 2001 Thermal bridges in building construction – heat flows and surface temperatures. Part 2 linear thermal bridges.
4. BRE Information Paper 1/06 Assessing the effects of thermal bridging at junctions and around openings
5. BR497 - Conventions for Calculating Linear thermal transmittance and Temperature Factor
6. ISO 14683 - Thermal bridges in building construction - Linear thermal transmittance - Simplified methods and default values
7. BS EN ISO 6946: Thermal performance of buildings and building components – Thermal resistance and thermal transmittance – Calculation method
8. BS EN ISO 13370: Thermal performance of buildings – Heat transfer via the ground – Calculation methods
9. ISO 13786 - Thermal performance of building components - Dynamic thermal characteristics - Calculation method

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Table of Figures

Appendix A - Abbreviations / Definitions

Adiabatic	A boundary condition in which heat transfer does not take place (e.g., at a section cut)
BIM	Building Information Modelling
Boundary condition	A parameter used in heat transfer analysis usually defining the extents of a detail as modelled (e.g. internal, external, adiabatic)
CFD	Computational Fluid Dynamics
DEAP	Domestic Energy Assessment Procedure
FEA	Finite Element Analysis
Finite Method	The mathematical method used to solve the complex calculations in Finite Element Analysis software
Heat Flux	Also known as heat flow density is a measurement of energy flow per unit of area per unit of time. It's unit is W/m^2.
Isotherm	A type of contour line or surface on a map that connects or indicates points of equal temperature.
PHI	Passive House Institute
PHPP	Passive House Planning Package
Psi Value	See 'Ψ' Value
Steady-State	Steady-state is a term used in heat transfer calculations that describes a system in static equilibrium. This can also be used to describe situations of constant unchanging heat flow.
Transient	Transient flow as opposed to steady-state describes a system that is in a process of change. E.g. a system of changing heat flow or temperature increase/decrease.
R Value	The R Value of an object is a measure of that objects thermal resistance measured in m^2K/W
U-Value	A measure of a planar elements thermal transmittance, measured in W/m^2K. It is used to describe the thermal transmittance of a built up construction for example an insulated cavity wall.
Y Factor	The Y Factor of a building is the sum of all linear thermal bridges multiplied by their length and divided by the total exposed area. It's unit is W/m^2K.

Ψ Value	Also known as the 'psi' value is a measure of linear thermal transmittance or 'thermal bridging'. It is the thermal transmittance of a junction between two planar elements. It's unit is W/mK.

Appendix B – Weather Data

All temperature data derived from Met Eireann data for the 20-year period 1987 to 2006.

All data standardized to an elevation of 50 metres above sea level and to year 2007, by means of the following adjustments:

- Temperature lapse rate with elevation: 154 m/°C
- Current global warming rate in Ireland: assumed to be 0.2°C per decade.

Table 2 Temperature Data for Ireland

Station	Jan	Feb	Mar	Apr	May	Jun
Belmullet	6.6	6.8	7.8	9.1	11.4	13.3
Birr	5.4	5.7	7.2	8.6	11.2	13.7
Casement	5.4	5.9	7.0	8.4	11.0	13.6
Clones	4.9	5.1	6.7	8.3	11.1	13.6
Cork Airport	5.9	6.0	7.2	8.4	11.1	13.5
Dublin Airport	5.6	5.7	7.0	8.4	11.0	13.6
Kilkenny	5.3	5.7	7.3	8.7	11.5	13.9
Malin Head	6.1	6.1	7.1	8.3	10.6	12.7
Mullingar	4.8	5.1	6.7	8.2	10.9	13.3
Rosslare	6.9	6.8	7.8	9.0	11.4	13.8
Shannon Airport	6.3	6.7	8.1	9.6	12.4	14.7

Station	Aug	Sep	Oct	Nov	Dec	Year
Belmullet	15.2	13.8	11.1	8.7	7.0	10.5
Birr	15.5	13.3	10.2	7.4	5.7	10.0
Casement	15.5	13.3	10.4	7.4	5.8	10.0
Clones	15.2	13.0	9.9	7.0	5.1	9.7
Cork Airport	15.4	13.4	10.5	8.0	6.5	10.1
Dublin Airport	15.5	13.4	10.5	7.6	6.0	10.0
Kilkenny	15.9	13.5	10.4	7.4	5.8	10.1
Malin Head	14.9	13.4	10.8	8.4	6.7	10.0
Mullingar	15.1	12.9	9.8	6.8	5.2	9.5
Rosslare	15.9	14.4	11.8	9.1	7.6	10.9
Shannon Airport	16.4	14.4	11.3	8.6	6.8	11.0

Note: Temperature Data taken from (King, 2007)

Table 3 Relative Humidity & Rainfall data for Dublin

Month	Relative Humidity	Average Rainfall (mm)
January	88	67
February	86	55
March	82	51
April	76	45
May	75	60
June	76	57
July	78	70
August	80	74
September	83	72
October	85	70
November	88	67
December	88	74

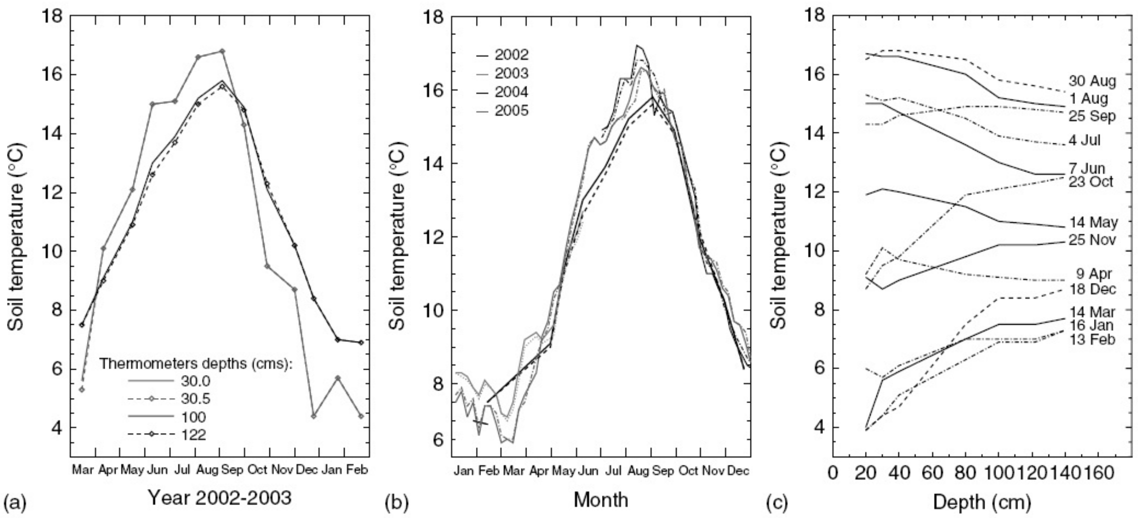


Figure 18 Soil Data for Ireland (Garcia-Suarez, Butler, & Morrow, 2002)

Appendix C – Thermal Properties of Common Building Materials

Material	Density (Kg/m^3)	Thermal Conductivity (W/mK)
Clay Brickwork (outer leaf)	1,700	0.77
Clay Brickwork (inner leaf)	1,700	0.56
Concrete block (heavyweight)	2,000	1.33
Concrete block (medium weight)	1,400	0.57
Concrete block (autoclaved aerated)	600	0.18
Concrete block (autoclaved aerated)	350	0.08
Cast concrete, high density	2,400	2.00
Cast concrete, medium density	1,800	1.15
Aerated concrete slab	500	0.16
Concrete screed	1,200	0.41
Reinforced concrete (1% steel)	2,300	2.30
Reinforced concrete (2% steel)	2,400	2.50
Wall ties, stainless steel	7,900	17.0
Wall ties, galvanised steel	7,800	50.0
Mortar (protected)	1,750	0.88
Mortar (exposed)	1,750	0.94
External rendering (cement sand)	1,300	0.57
Plaster (gypsum lightweight)	600	0.18
Plaster (gypsum)	1,200	0.43
Plasterboard	900	0.25
Natural Slate	2,500	2.20
Concrete tiles	2,100	1.50
Clay tiles	2,000	1.00
Fibre cement slates	1,800	0.45
Ceramic tiles	2,300	1.30
Plastic tiles	1,000	0.20
Asphalt	2,100	0.70
Felt bitumen layers	1,100	0.23
Timber, softwood	500	0.13
Timber, hardwood	700	0.18
Wood wool slab	500	0.10
Wood-based panels (plywood, chipboard, etc.)	500	0.13
Expanded polystyrene (EPS) slab (HD)	25	0.035
Expanded polystyrene (EPS) slab (SD)	15	0.038
Extruded polystyrene	30	0.029
Mineral fibre / wool quilt	12	0.045
Mineral fibre / wool batt	25	0.035
Phenolic foam	30	0.025
Polyurethane board (unfaced)	30	0.021
Foam Glass		0.045
Rubber		0.17
Carpet		0.06
Linoleum		0.17
Float Glass		1.00
Aluminium		160.0

Material	Density (Kg/m^3)	Thermal Conductivity (W/mK)
Steel		50.0
Stainless Steel		17.0
Solid Plastic		0.17
Natural Stone		1.50
Sand-Lime Masonry		1.00
Chipboard		0.18
Oriented Strand Board (OSB)		0.13
Wood Fibreboard, Medium Density Fibreboard		0.07
Silt / Clay		1.50
Peat		0.40
Dry Sand / Gravel		1.50
Wet Sand / Gravel, Moist Clay		2.00
Saturated Clay		3.00
Rock		3.50

Note: Data Modified from Irish Building Regulations TGD L (2007)& Passive House Planning Package 2007 Handbook

Appendix D – Regulation Requirements for Heat Transfer Modelling

The guidance in TGD L is primarily derived from BRE Information Paper 1/06, BRE Report 497 and EN ISO 10211. TGD L recommends these documents as further guidance when modelling proposed design solutions. The standards as set out in BRE 497 must be adhered to in order to achieve accurate Psi value calculations.

Thermal conductivities of elements in the numerical model should be as in BRE BR443.

Any numerical modelling software used should be validated to the examples shown in BR497 and EN ISO 10211.

The extents of flanking elements of a heat transfer model should extend to three times the thickness of the building element or one meter, whichever is the greater.

For the ground floor detail; the floor plan is considered to be a square with a length and breadth of 8m. The model should cover a quarter of this room; therefore the length of floor modelled is 4m. In this situation, when calculating the U-Value of the floor, the P/A value is taken as 0.25.

Table 4 Surface Thermal Resistances corresponding with EN ISO 6946 (Feist, 2007)

	Upward	Horizontal	Downward
R_{si} [m^2K/W] Thermal Resistance of the Interior Surface	0.10	0.13	0.17
R_{se} [m^2K/W] Thermal Resistance of the Exterior Surface		0.04	
R_{se} [m^2K/W] Thermal Resistance of the Below Ground Exterior Surface		0	

Appendix E – Selected Thermal Bridge Calculations to BRE BR497

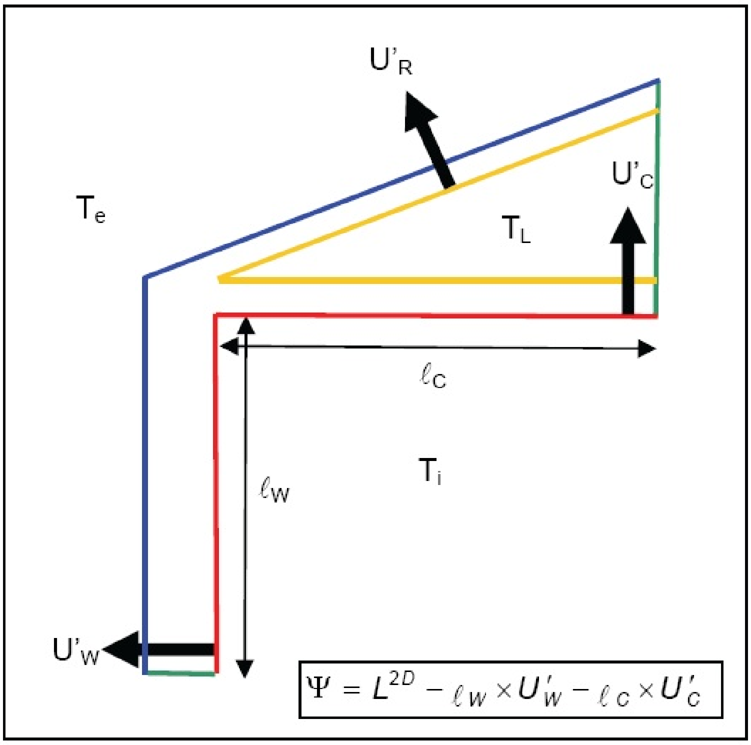


Figure 19 Roof Eaves

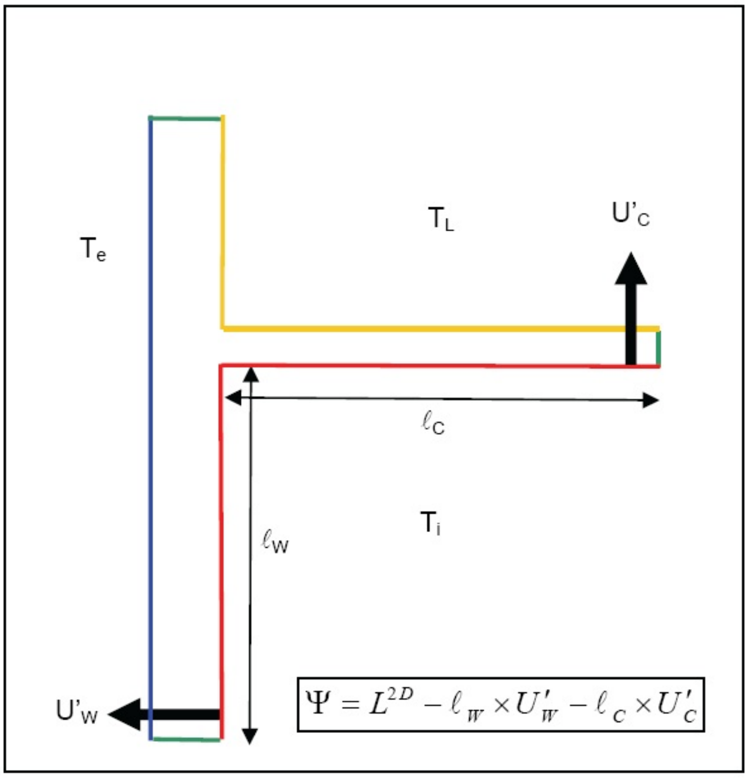


Figure 20 Roof Gable

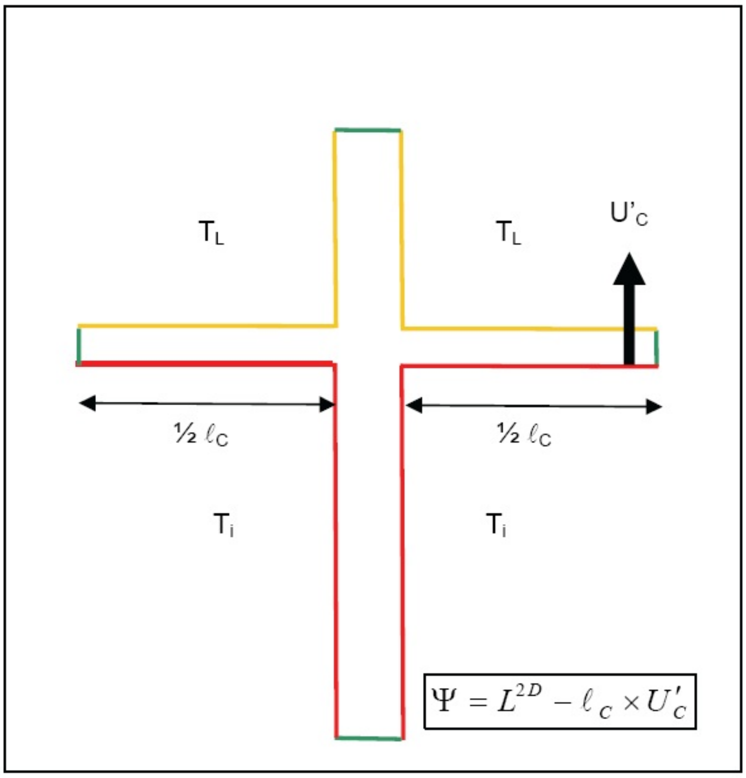


Figure 21 Roof Party Wall

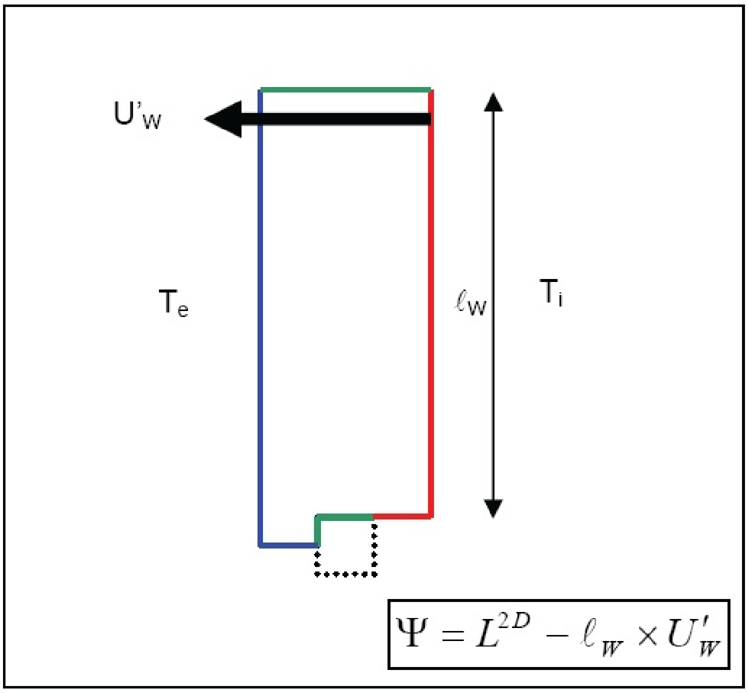


Figure 22 Lintel

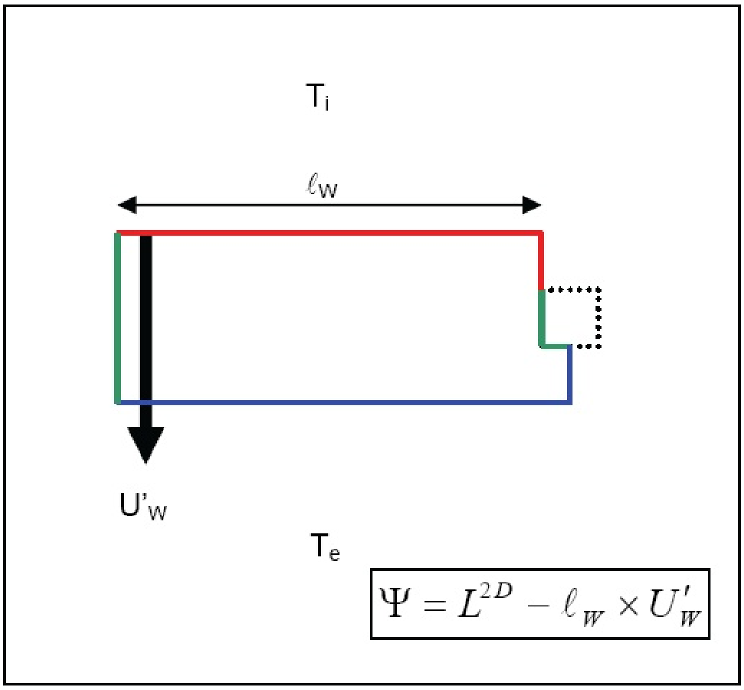


Figure 23 Jamb

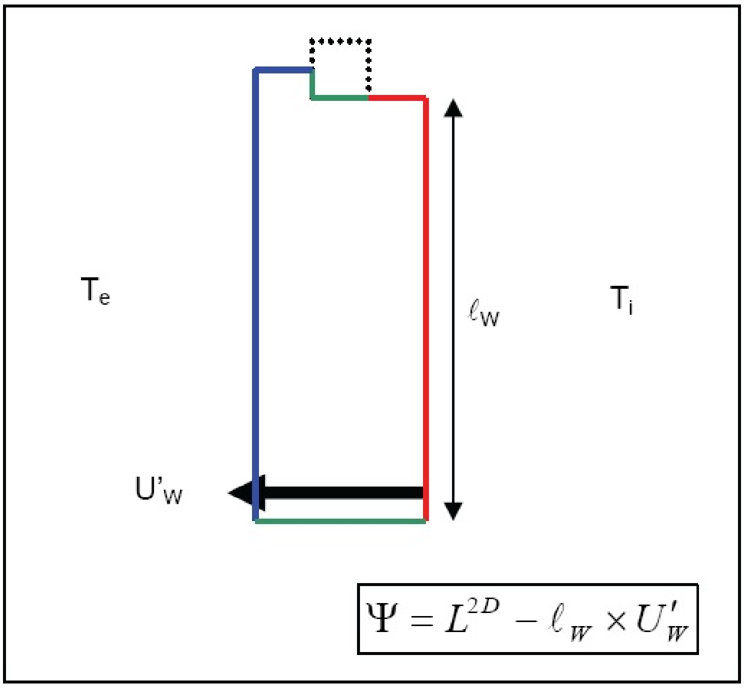


Figure 24 Sill

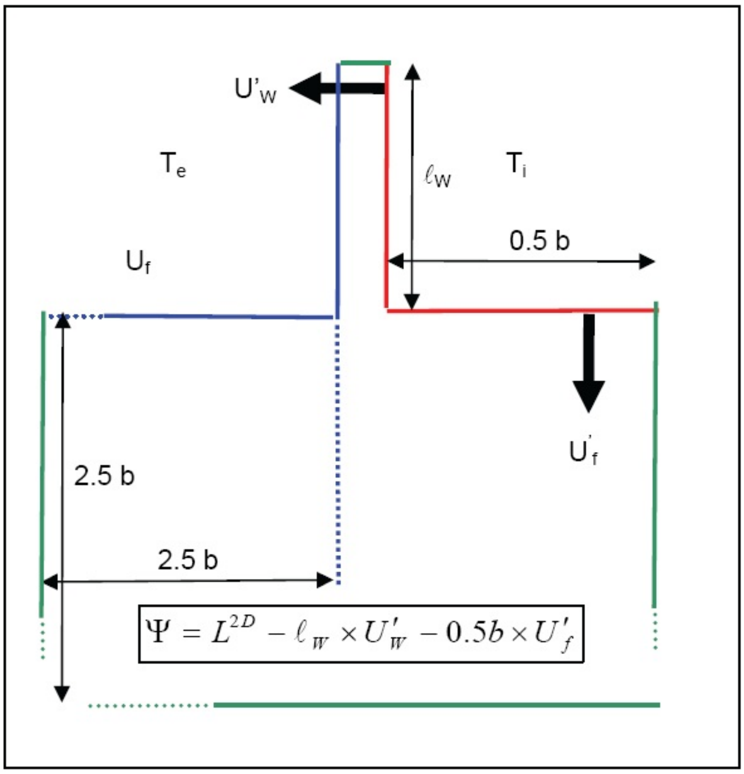


Figure 25 Solid Ground Floor

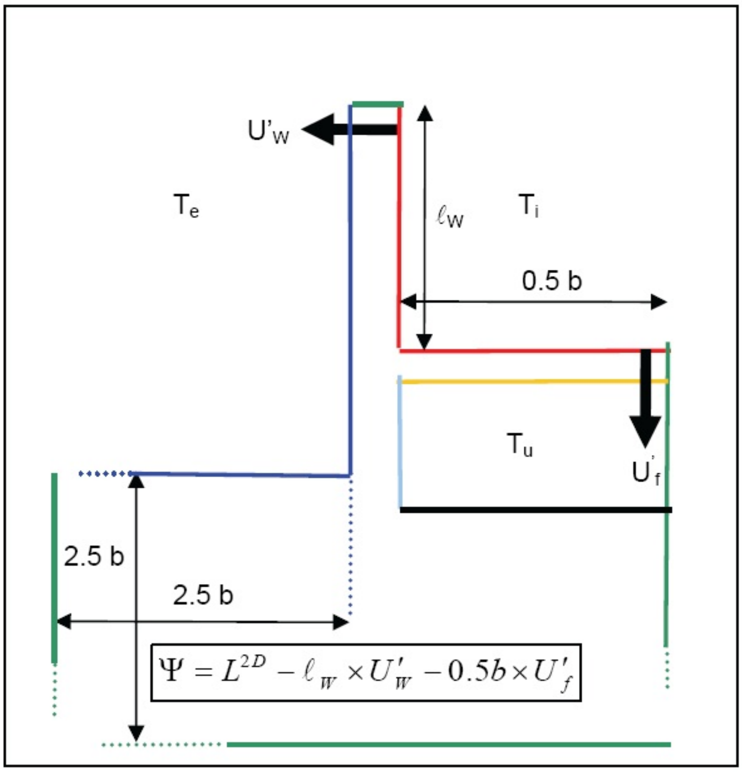


Figure 26 Suspended Ground Floor

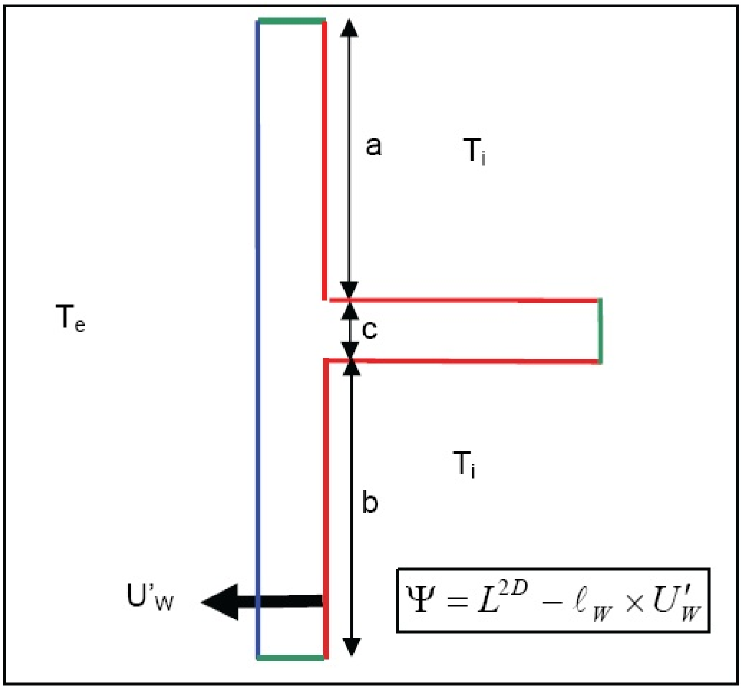


Figure 27 Intermediate Floor

Appendix F – Ground Thermal Bridge Calculation Method to EN ISO 10211:2007

10.4 Determination of the linear thermal transmittance for wall/floor junctions

10.4.1 Numerical calculations using a two-dimensional geometrical model can be used to determine values of linear thermal transmittance for wall/floor junctions.

Model the full detail, including half the floor width or 4 m (whichever is the smaller), and a section of the wall to height h_W, and calculate L_{2D} as the heat flow rate per temperature difference and per perimeter length. h_W shall be the minimum distance from the junction to a cut-off plane in accordance with the criteria in 5.2.3 and h_f shall be the height of the top of the floor slab above ground level (see Figure 15). The dimensions of the model outside the building and below ground extend to 2,5 times the floor width or 20 m (whichever is the smaller). See also 5.2.4.

If the calculation is done using a 4 m floor width (i.e. $B' = 8$ m), the result can be used for any floor of greater size ($B' > 8$ m).

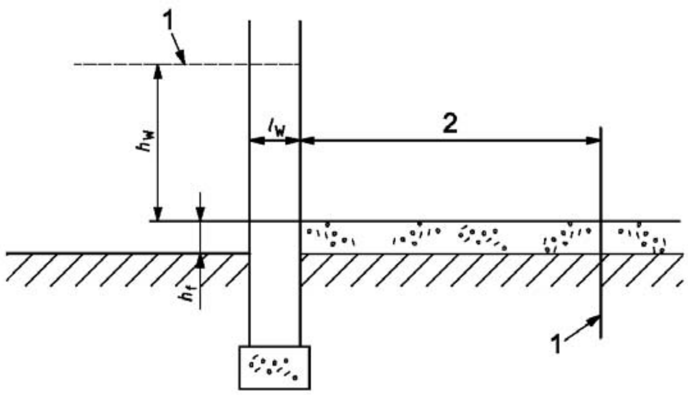
10.4.2 Option A Then calculate the thermal transmittance of the floor, U_g, using the simplified procedure in ISO 13370, using the same value for B' and including any all-over insulation of the floor slab. Calculate Ψ_g from Equation (19) using internal dimensions, and from Equation (20) using external dimensions:

$$\Psi_g = L_{2D} - h_W U_W - 0{,}5 \times B' U_g \qquad (19)$$

$$\Psi_g = L_{2D} - (h_W + h_f) U_W - 0{,}5 \times (B' + w) U_g \qquad (20)$$

where U_W is the thermal transmittance of the wall above ground, as modelled in the numerical calculation.

NOTE Option A is especially suitable if the simplified procedure in ISO 13370 will be used for calculating the heat transfer via the ground for any floor size.



Key

1 adiabatic boundary

2 $0{,}5 \times B'$ or 4 m

h_f height of the top of the floor slab above ground level

h_W minimum distance from junction to cut-off plane (see 5.2.3)

l_W fixed distance

NOTE The dimensions of the model extend to $2{,}5 \times B'$ or 20 m outside the building and below ground.

Figure 15 — Model for calculation of linear thermal transmittance of wall/floor junction

Appendix G – Thermal Bridge Calculations

Thermal Bridge Calculations to EN ISO 10211:2007

INTERNAL MEASUREMENTS (UK & IRELAND)					
	DETAIL 1	**DETAIL 2**	**DETAIL 3**	**DETAIL 4**	**DETAIL 5**
Total U Factor (W/m^2K)	0.1359	0.1545	0.1285	0.1565	0.1542
Length (mm)	5540	5580	5580	5580	5580
Wall U Factor (W/m^2K)	0.1501	0.1811	0.1811	0.1811	0.1811
Length (mm)	1540	1540	1540	1540	1540
Floor U Factor (W/m^2K)	0.087	0.087	0.087	0.13	0.13
Length (mm)	4055	4055	4055	4055	4055
L_{2D} (W/mK)	0.7529	0.8621	0.7170	0.8733	0.8604
Wall U' (W/mK)	0.2312	0.2789	0.2789	0.2789	0.2789
Floor U' (W/mK)	0.3528	0.3528	0.3528	0.5272	0.5272
Psi Value (W/mK)	**0.169**	**0.230**	**0.085**	**0.067**	**0.054**

Appendix H – Images & Drawings of Verschoyle Court Project

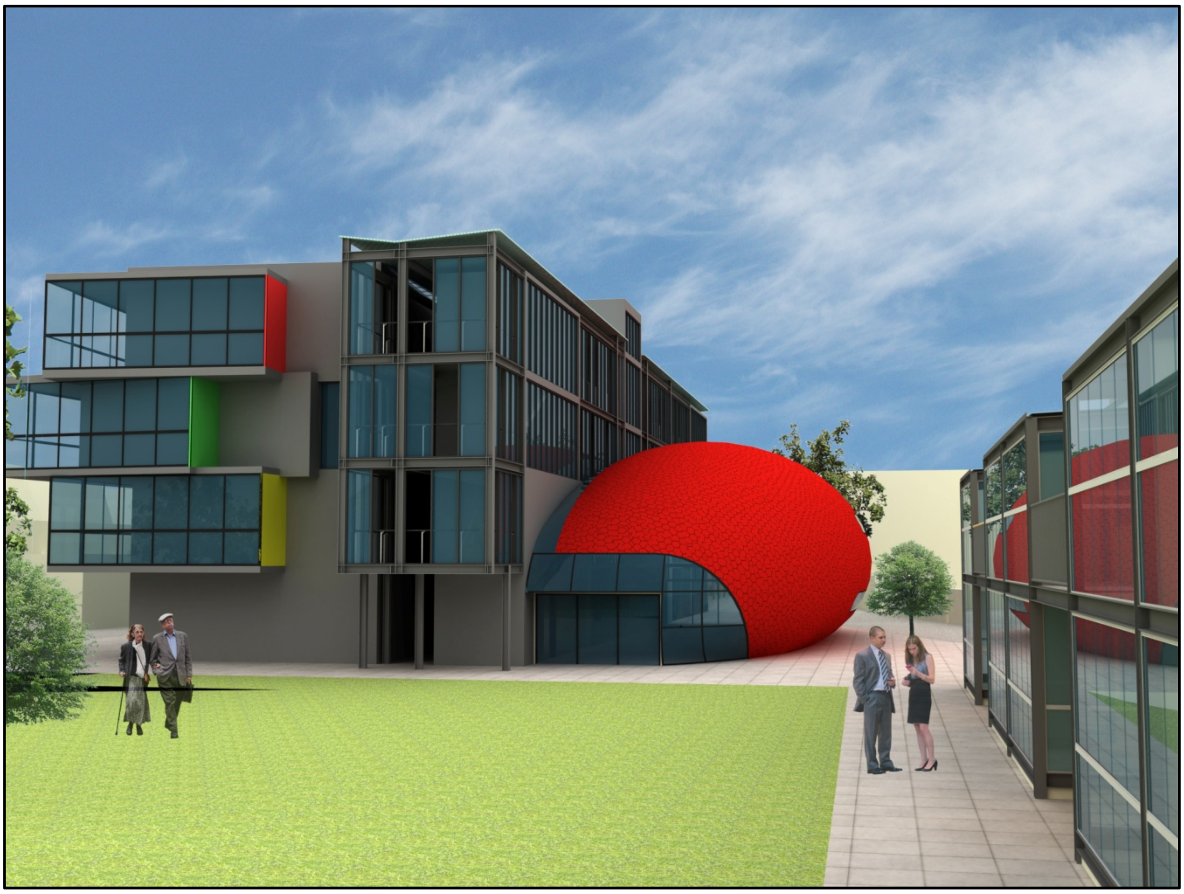


Figure 28 Visualisation of the proposed new build apartment block and community hall at Verschoyle Court, Dublin 2. Bernard Gilna of Gilna Architecture provided the architectural concept for the scheme. (Visualisations by the author)

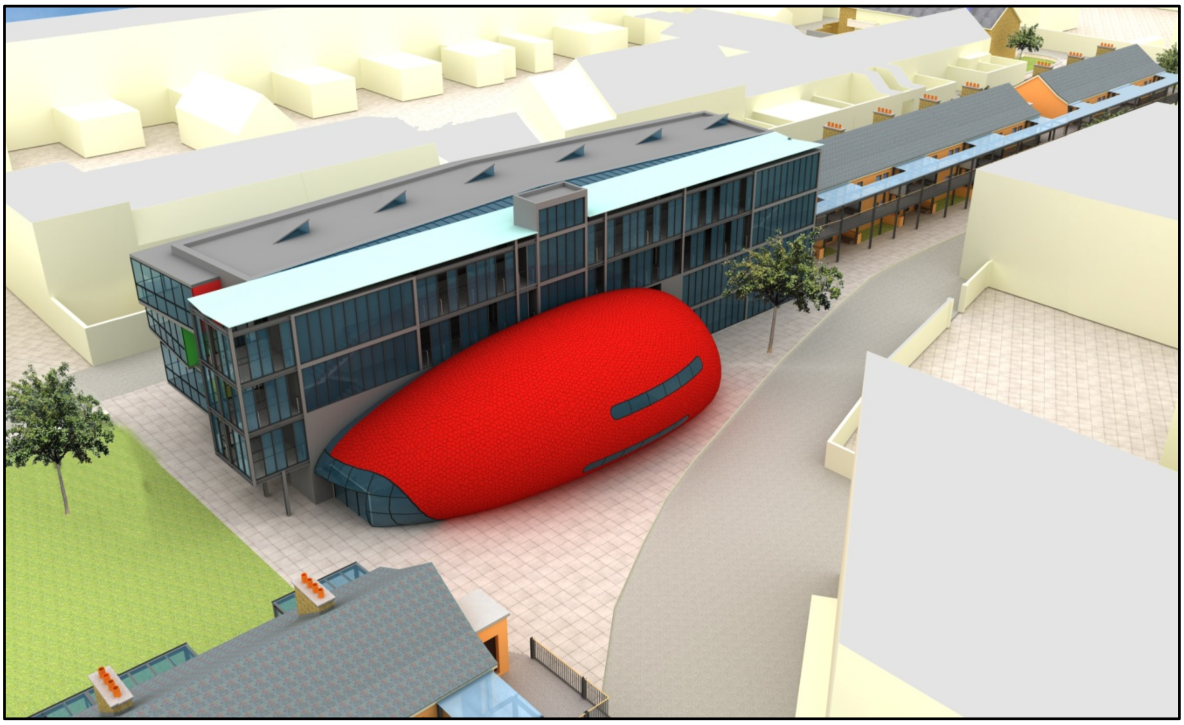
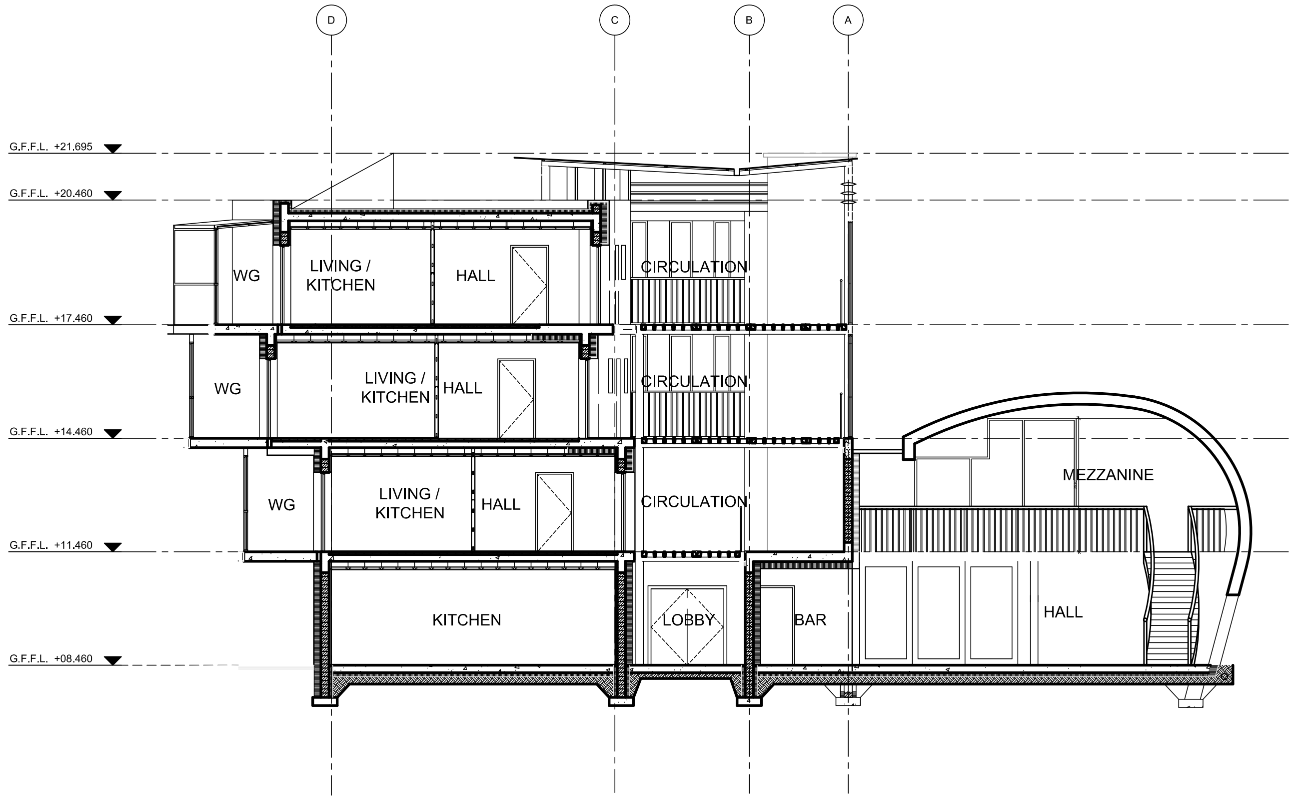


Figure 29 Birds eye view of the proposed new build element at Verschoyle Court

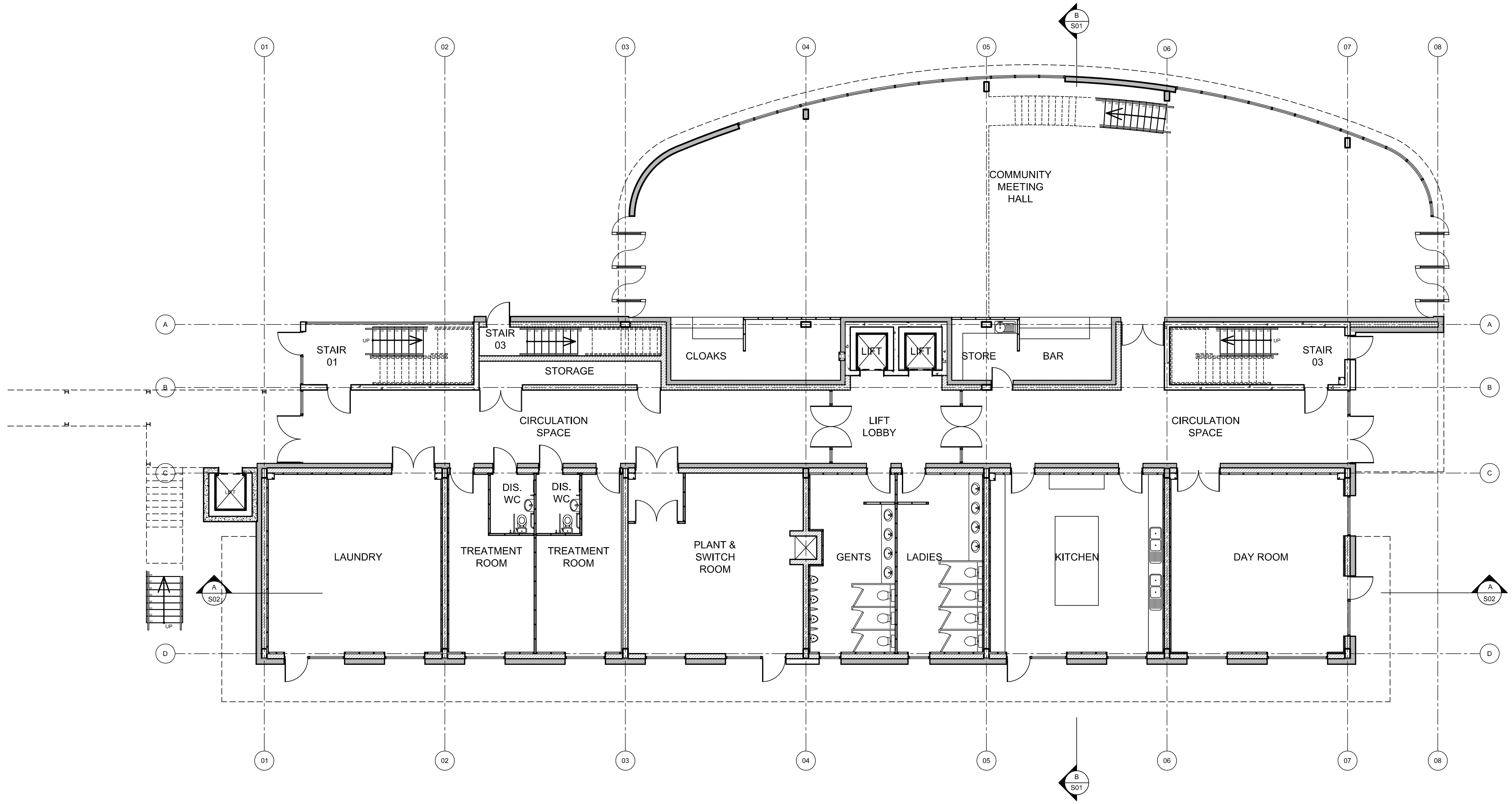
Figure 30 North facing façade of the proposed refurbishment at Verschoyle Court

Figure 31 South facing façade of the proposed refurbishment at Verschoyle Court



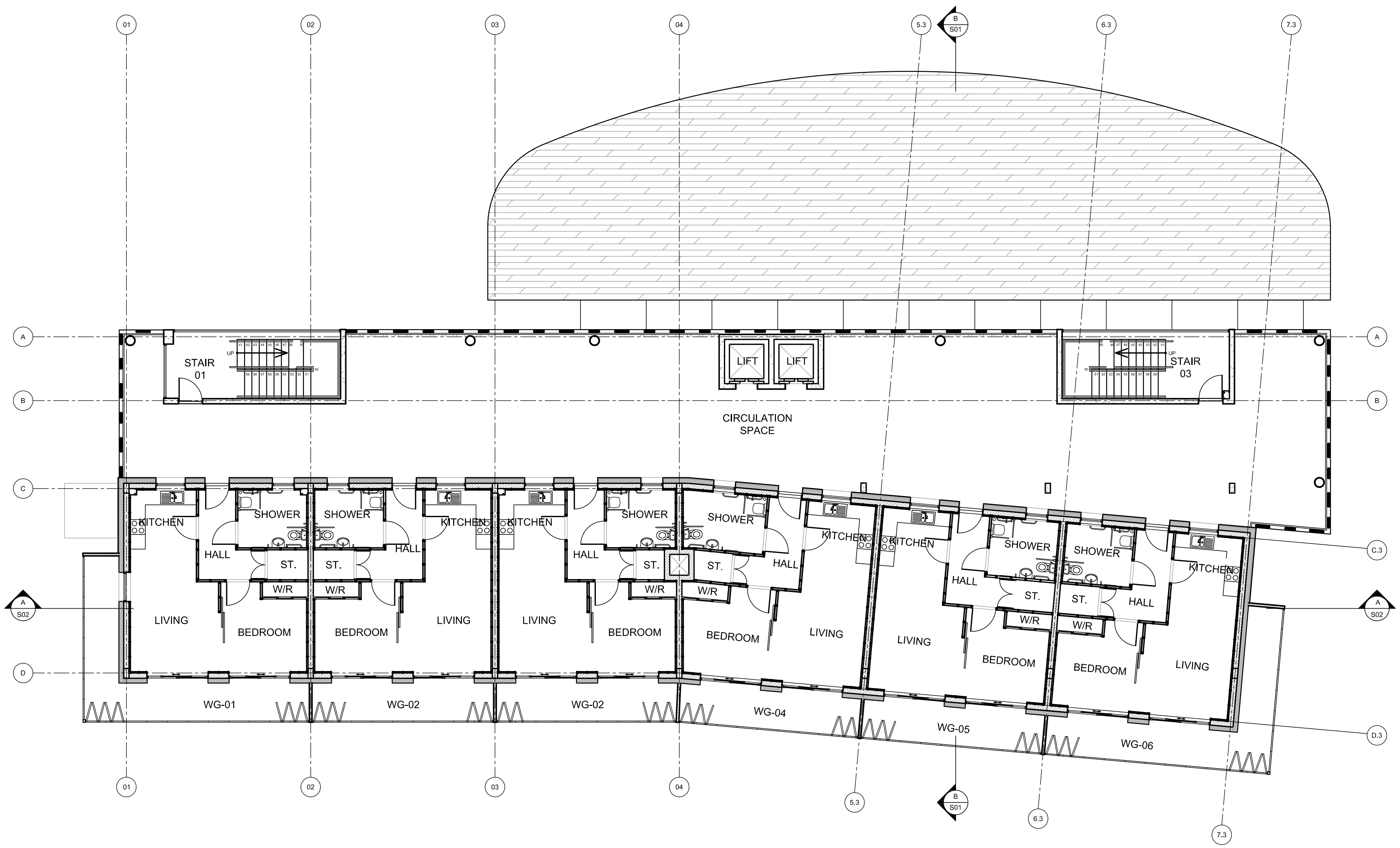
SECTION B - B (NEW BUILD)

SCALE 1:200



GROUND FLOOR PLAN (NEW BUILD)

SCALE 1:200



TYPICAL UPPER LEVEL PLAN (NEW BUILD)

SCALE 1:200