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The AECB Standard as Sustainable Solution for UK Cohousing Projects

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The aim of this thesis was to establish the suitability of the AECB Building Standard as a sustainable building standard for cohousing projects in the UK against the similar low energy building standard, Passive House. To do this, an AECB Building Standard assessment was carried out on a suitable new build cohousing project in Leeds, UK. Design guidance was given and calculations made regarding the efforts required to reach the AECB Building Standard and the suitability for its purpose. Furthermore, comparisons were drawn to the Passive House Standard, a standard that the AECB Building Standard is based on, to establish which is of greater benefit to the end user.

This final year project established that although the AECB Building Standard is an improvement on the existing building standards and regulations in the UK, the Passive House Standard is of greater benefit to the end user. The Passive House Standard was shown to deliver a product with a lower heating demand and more holistically thought out approach than that of the AECB Standard, with minimally increased capital costs.

With the increased cost of Passive House being only a small amount over that of the existing UK building standards, and the level of standard being greater than that of the AECB Standard regarding energy demand. it is clear that the AECB Standard is not a viable competitor to the Passive House Standard for UK cohousing projects.

Keywords	Sustainable Housing, Co-housing, AECB, Passive House

Contents

List of Abbreviations

Chaco	Chapeltown Cohousing. A cohousing project in Chapeltown, Leeds, United Kingdom.
Chi-value	Point Thermal Transmittance. A dimensionless measure of thermal energy at a point in Watt per Kelvin.
DHW	Domestic Hot Water. The hot water that is consumed at tapping points in buildings.
GHG	Greenhouse gases. Gases in the atmosphere that are capable of causing the 'greenhouse' effect, whereby thermal energy is trapped within the earth atmosphere, causing a global warming effect.
LEDA	Leeds Environmental Design Associates. A small engineering and architecture consultancy based in Leeds, UK. Operating across a multitude of sectors, LEDA have been regularly been recognized for their efforts to bring about a more sustainable built environment.
M&E	Mechanical and Electrical. An abbreviation used to refer to mechanical and electrical services within the construction industry.
MEV	Mechanical Extract Ventilation. Extract only ventilation that removes air from 'wet' and extract rooms, such as kitchens, bathrooms and utilities.
MHOS	Mutual Home Ownership Scheme. A financial model used to ensure affordability of a housing project for the entirety of its life. Developed by New Economics Foundation and CDS Co-Operatives.
MVHR	Mechanical Ventilation with Heat Recovery. A ventilation concept in which thermal energy is recycled from the exhaust air to the supply air to reduce the energy demands within a building.
PE	Primary Energy. The total energy used to deliver one unit of energy, accounting for energy used to generate, transport and transform one unit of energy to be consumed within a building.
PH	Passive House. A low energy building standard developed by Wolfgang Feist in Germany, maintained by the Passivhaus Institute.
PHI	Passivhaus Institute. A research institute, founded to research, develop, educate and accredit for passive house buildings.

PHPP	Passive House Planning Package. An assessment tool based on a Microsoft Excel Workbook that is used to measure the energy performance and compliance of passive house and other low energy buildings.
Psi-value	Linear Thermal Transmittance Coefficient. A 1d measure of thermal energy across a linear distance in Watts per metre Kelvin.
SAP	Standard Assessment Procedure. The building regulations compliance tool utilised in the UK to predict whether a building is suitable for construction.
TFA	Treated Floor Area. A useful floor space measurement used in the PHPP that is defined to allow a meaningful comparison between buildings and to measure a buildings energy expenditure.
U-value	Thermal Transmittance Coefficient. A 2d measure of thermal energy transmittance through an area in Watts per Square metre Kelvin.

1 Introduction

This thesis is an in-depth analysis at the practicalities of achieving the Association for Environment Conscious Building (AECB) Standard, formally known as the Silver Standard, for a community housing project in the North of England [1]. The thesis continues to draw a comparison to the Passive House (PH) Standard, on which the AECB Building Standard is based [2,3]. The case study is the Chapeltown Co-housing (Chaco) project in Leeds, United Kingdom.

Chaco is a new build cohousing project, conceived in 2010 to offer sustainable and affordable housing that reflects the local community. Residing on the boarders of Chapeltown and Harehills boroughs of Leeds, West Yorkshire, Chaco aims to represent the ethnically diverse areas, which for over 30 years, have held strong yet varied cultural identities. [4]. The areas suffer from widespread poverty and are among the most impoverished places in the UK [5,6]. Due to this, Chaco has been devised to reflect its community by means of a selective process and has a financial model that ensures affordability across its lifetime. [4.]

Alongside its community ethics, Chaco aims to achieve the AECB Building Standard, a low energy building standard for the UK that follows the PH methodology and uses the Passive House Planning Package (PHPP) for assessment [7.]

Differences between the PH and the AECB Building Standards are mainly focussed on the efficiency targets and certification procedures. The targets for the AECB Building Standard with regards to the energy demands, airtightness and certification are typically more achievable and require a less stringent certification process. The rationale for the AECB Building Standard being easier to achieve is focussed on the affordability of a project. [3.]

Chaco is a project of 29 plots of mixed residency domestic buildings. The project boasts a mixture of dwelling types including houses, apartments, and guest houses, alongside communal areas such as a common house, allotments, parking spaces and other shared infrastructure. [8.]

Chaco's financial model is based on the Mutual Home Ownership Scheme (MHOS), developed by New Economics Foundation and CDS Co-operatives, in which a member of the cohousing group contributes 35% of their income to the housing project in place of a mortgage repayment. The basic model for the MHOS is illustrated in figure 1 below.

The MHOS scheme ensures affordability by placing the project between social and market values, with the projects value being tied to the members' income. The project is financed by means of a typical mortgage agreement between the MHOS and the lender, with the construction and land acquisition costs being divided into equity shares, each with a value of £1, that are then allocated to households who pay 35% of their net income towards the repayment. [9.]

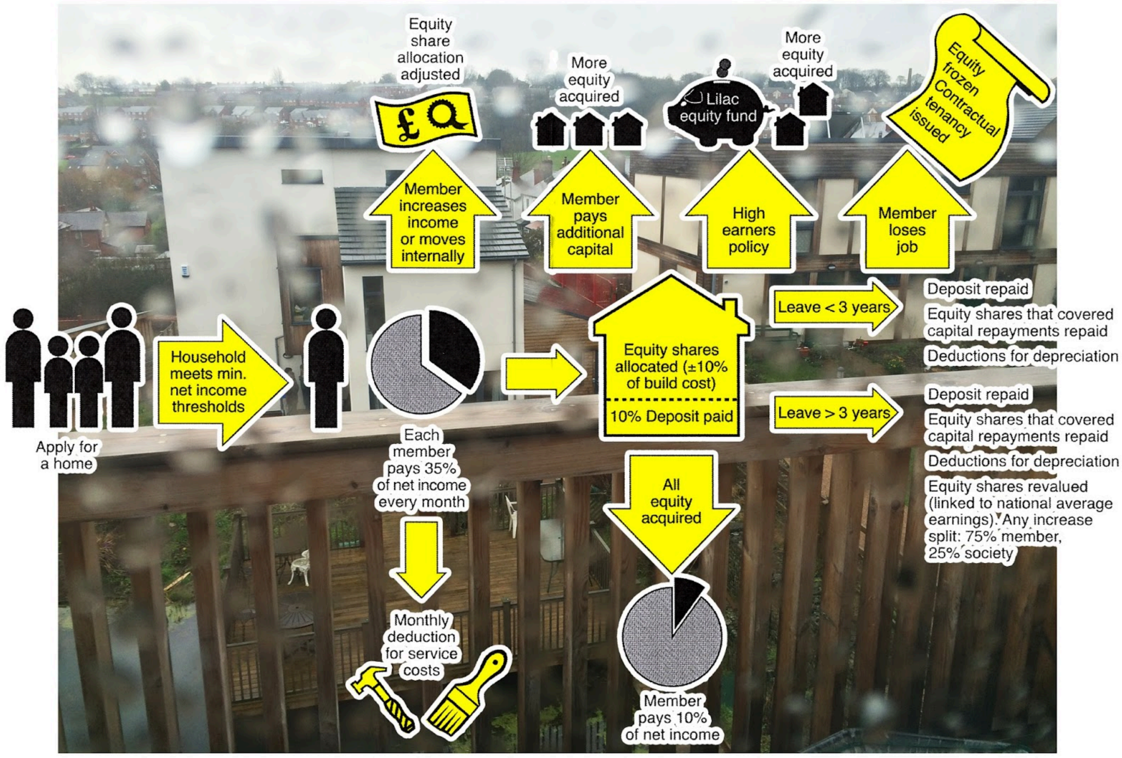

Figure 1. Lilac's Mutual Home Ownership Society [9].

Alongside Chaco's aim for affordability, the project has a strong focus on community, and aims to reflect its local demographic. This is controlled by means of an Allocations Policy that ensures a reflective membership, covering various ethnicities, ages, sexual orientation, disabilities and incomes. This policy denotes the minimum threshold of a particular demographic that will be reflected in the residents. [4,10.]

Table 1. AECB Building Standard and PH standard certification criteria [2,11].

Parameter	AECB Building Standard Target	Passive House Standard Target	Notes
Delivered Heating and Cooling kWh/(m²a)	≤ 40	≤15	As per PHPP *
Heating/Cooling Load W/m²	Not used	≤10	
Primary Energy (PE) Demand kWh/(m²a)	135 ****	As per PHPP *****	As per PHPP *
Airtightness (n50) h-1	≤ 1.5 (≤ 3)	≤0.6	With MVHR (with MEV) **
Thermal Bridges *** W/mK	Psi-$_{external}$ < 0.01		Calculated if over 0.01 W/mK
Summer overheating %	<10		Preferably <5

* Passive House Planning Package.
** MVHR may be required to meet heating demand
*** PH methodology is used.
****PE demand varies by country according to each nations PE ratio. As of PHPP 9.6 UK PE is 135 kWh/(m².a)
Note: The Primary Energy requirements have changed because PHI have updated PHPP

Chaco also aims for sustainability, with a focus on low operational energy expenditure within the housing project and shared facilities in order to reduce resource depletion [12]. Chaco aims to achieve this by committing to the AECB Building Standard, a certification procedure that assesses the operational energy expenditure of a building [7]. A building is certified as an AECB Building Standard project by providing evidence regarding the construction detailing, quality, materials, building services, airtightness and predicted energy demand of the building. Table 1 outlines the AECB Building Standard and PH criteria to be met by the modelling to achieve the standard. [2.]

2 AECB Building Standard

The AECB Building Standard is a result of a growing need to reduce the energy demands of buildings [13]. Originally known as the Silver Standard, with accompanying Gold and Bronze standards, it sat between the Gold Standard (PH) and the now defunct Bronze Standard, a more achievable low energy building design standard [14]. The AECB Building Standard is a way of measuring the success of a PH design and methodology, with more attainable targets, each of which is outlined in table 1. [3.]

The PH methodology is a building standard originally conceived by Wolfgang Feist and Bo Adamson in 1988 [15]. The standard uses a simplified model to evaluate the energy efficiency of a building on the basis of concepts of steady state physics [11]. The standard drew from previous methodologies such as airtightness, superinsulation and passive solar design to minimise energy requirements in buildings. [16.]

The AECB Building Standard is self-certified, making it possible for anyone to certify a project regardless of their professional background. The responsibility for ensuring that the project meets the standard lies with a named responsible party, whom submits evidence and a declaration that the project has met the necessary targets and criteria. [17,18.] In order to certify, evidence in the form of construction photographs and documentation of the project is submitted and the project is added to the Low Energy Building Database, a website used to document low energy buildings. [2,18.]

The responsible party ensures that the project meets the energy targets by completion of a PHPP assessment, for which the “Verification” sheet is submitted as evidence. Finally, an airtightness certificate and other building documentation such as hand over manuals, are uploaded to the Low Energy Building Database along with details about the project and a signed declaration by the responsible party. [2,19.]

2.1 Targets to Achieve the AECB Building Standard

The targets that form the energy demands used in the AECB Building Standard reflect a cost effective and attainable low energy building standard for the UK [3]. There are five targets, broken up to ensure that the project is robust, comfortable and healthy to live in. However, given the assessment is a based on taking a holistic approach, each targets' result will typically have an impact on the others. [20.] The targets of the Delivered Heating and Cooling, Primary Energy, Airtightness and Overheating are discussed further below.

The first target of the AECB Building Standard is Delivered Heating and Cooling or Heating and Cooling Demand in PHPP. It is defined as the overall result of the heating energy efficiency of the fabric of a building such as its airtightness, insulation, windows and doors [21]. The target refers to the amount of heat energy required to maintain an average indoor air temperature of 20 °C, measured in kilo-Watt hours per square metre of treated floor area a year (kWh/m^2_{TFA}) [22]. It gives a general annual efficiency of the building envelope per square metre of usable floor space, defined as the treated floor area (TFA). The Delivered Heating and Cooling quantifies a metric that can be benchmarked and compared against similar methodologies for energy efficiency regardless of design, geometry or methodology. [23,24.]

The concept of Primary Energy (PE) is used to measure the total amount of expended energy to provide one unit of energy within a building. It relates not only to the efficiency of the energy consuming equipment within the building such as the heating unit and ventilation, but also to the type of fuel used to provide it. [25.] This is necessary to maintain comparability between different heating systems that use different fuel types; for example, a fireplace may require little energy within the building to generate heat, but the energy expended in extracting, producing and transporting the fuel must be accounted for, whereas a heat pump may require a small amount of energy in from the electrical grid to generate heat, the primary energy intensity of that grid is determined by a projects location.

Primary Energy Demand is the second target of the AECB Building Standard, and refers to energy required for a dwelling in kilo-Watt hours per square metre of treated floor area a year (kWh/m^2_{TFA}). The target accounts for the PE factors that are relevant for the location of the project as well as the type of energy that is used. [25.]

Airtightness, the third target of the AECB Building Standard, is a measure of how much of the air volume within a building is exchanged over the period of one hour. It is used to ensure that attention is paid to reducing heat loss via infiltration and, typically, reflects the build quality of a project. Airtightness is the only target that requires post construction testing and that is evaluated by pressurising and depressurising a building and measuring the air leakage. A reference pressure of 50 Pascal is used to allow comparison, but the test typically exceeds this pressure differential. Due to the fact that the results can be used as a way of quantifying the build quality of a project, they are often of particular interest in the construction of low energy buildings as they can be used as an early indicator of potential errors in design and to highlight potential issues in the building before it is too late or costly to fix them. [23,26.]

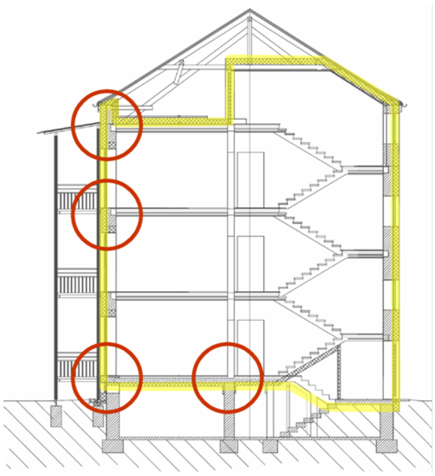

Figure 2. Thermal bridges and the thermal envelope of a building section [27].

Mitigation of thermal bridges is the fourth target of the AECB Building Standard. Due to the fact that heat loss will take the path of least resistance, ‘thermal bridges’ are of particular importance in low energy buildings. Thermal bridges are sections or points where an increase or decrease in heat loss is experienced due to a change in the homogeneity of an element, examples of which are highlighted in figure 2 above. [27.]

By insulating elements, without regard to thermally weak points like junctions and areas where there is a change in material and/or thicknesses, the heat flux across that point will be greater than with smaller amounts of insulation, where it would otherwise be dissipated anyway. [27.]

In the PH and AECB Building Standard, linear thermal bridge values that exceed 0.01 W/mK are considered. Linear thermal bridges are 2d thermal bridges that occur where there is a change in an elements sectional plane. If it is proven that a thermal bridge is below this threshold, they are considered negligible and can be ignored. This is referred to as ‘Thermal Bridge Free Design’. [28.]

Punctual thermal bridges also known as point thermal bridges, from elements such as wall ties and fixings must always be included as collectively, they can result in a significant amount of heat loss [29]. In the PH methodology, linear thermal bridges are taken into consideration by modelling a building’s heat loss planes externally, and thus, the overall heat loss is over-estimated. As a result of the over-estimation, it is common to find that linear thermal bridges are actually negative in value and when considered as part of the energy balance of the building means the heat loss is reduced when they are included. However, thermal bridges are just correction factors for a simplified heat loss model and only serve to make the model more accurate. [23,27,30.]

Thermal bridges are of particular importance due to their localised temperature differences. If they occur at points in which there is either little air flow or where the air is moist, they can lead to mould growth, damp and structural problems. Due to this, it is important that they are considered and mitigated beyond the needs for internal comfort. [27.]

The final target of the AECB Building Standard is the prevention of overheating, set at a threshold of 10% of the year at which internal air temperatures exceed 25 °C [31]. Preventing overheating is an important task in building design. However, there is a risk that overheating can be overlooked in the pursuit maximising solar gains and reducing heat loss.

In summer, solar gains can be unwanted, leading to uncomfortable indoor environments or the need for active cooling measures. Thus, solar gains need to be mitigated. Further attention should be given to the fact that climate change is likely to lead to a greater risk of overheating. [30,32.]

Therefore, it is wise to try to mitigate overheating as much as possible with passive measures such as well-placed shading elements, to assure the design is future proof. Ensuring a low risk of overheating, allows for a larger margin for indoor comfort in greater extremes of climate. [30,32.]

2.2 PHPP

The PHPP is an assessment tool developed by the Passivhaus Institute (PHI) to assess PH buildings. It is based on an Excel Workbook where a building design is modelled by inputting parameters to reflect its geometry, fabric, usage and equipment. [33.]

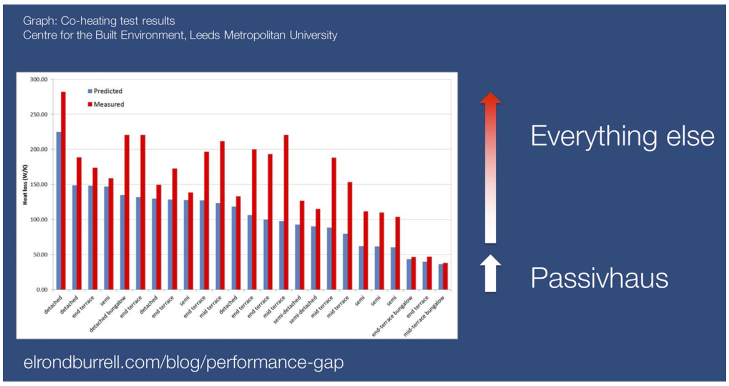

Figure 3. The performance gap between a typical building's expected performance and its recorded performance against that of a PH [34].

The model created in the workbook is then used to calculate the total heat loss of the building with various factors considered. The PHPP has proven to be a very robust and accurate measurement tool, with post occupancy evaluations (POE) of PH standard buildings showing a very small performance gap between the completed building and the modelled energy demand. This performance gap is highlighted in figure 3 above. [35.]

2.3 Evidence for Fulfilling AECB Building Standard

In order for a project to certify as an AECB Building Standard building, evidence must be produced to assure that it has been built as designed. The evidence consists of both construction documents and in-build photographs of key building junctions, the airtightness certificate showing the result in air changes per hour and the Validation sheet of the PHPP. [2.]

Appendix 1, produced by the AECB, outlines the evidence required. The provided evidence can also include optional building documentation such as building manuals and equipment documentation. [2.]

3 Heat Transfer

Heat energy is transferred by three pathways: convection, conduction and radiation. By modelling these transportation methods with a simplified building model in the PHPP, it is possible to accurately predict the energy required to maintain a healthy and comfortable indoor environment [36,37]. The PHPP assessment is calculated from data, input by the assessor, with regards to the elements of a building and its relationship with the relevant heat transfer pathway e.g. heat moves upwards due to stratification, thus a roof will lose more heat than a floor, all else being equal. [38.]

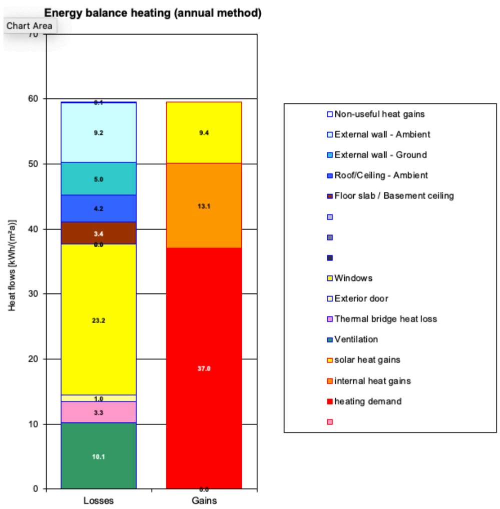

Figure 4. The energy balance from the PHPP for a house in the Chaco project.

The PHPP combines the output and heat pathway of each element to give a total energy demand per square metre of treated floor space based on the energy balance of a building. To reduce the risk of over-estimating the energy losses, gains in the form of solar radiation, internal heat gains from occupants and equipment are also included, and the energy shortfall is made up by the heating system. The energy balance of the PHPP is illustrated in figure 4, showing the heat gains and losses of a building, stacked against one another. [37.]

3.1 U-values, Psi-values and Chi-values

Heat flow by conduction is considered by the means of simplified heat flux through a building element using U-values, Psi-values or Chi-values, which are used to describe the rate of heat flow through a unit. The difference between the three depends on what type of heat flow is described. U-values are used to describe two-dimensional heat flows across a plane, for example from the inside to the outside through an external wall. Psi-values are used to describe the extra heat loss as a result of a change in an element such as its thickness or material. Psi-values are typically used at junctions between two building elements. Finally, Chi-values are used to describe the three-dimensional heat flow through a point such as a puncture in a material from a wall-tie or the point at which three elements meet, for example two external walls and the ground floor. [39.]

According to Dr. Luke Whale, thermal bridges encompassing both Psi-values and Chi-values are responsible for up to 30% of heat loss in a typical new build home in the UK. This is a phenomenon explained in thermal physics, by insulating a building to a greater degree, the heat loss is concentrated at the weak points, typically junctions and penetrations, due to heat taking the path of least resistance.

As a result, a building with higher levels of insulation but no consideration to thermal bridges will have higher heat losses at these junctions than that of an uninsulated building. Furthermore, thermal bridges are a risk of mould and thus poor indoor environment due to the temperature and possible indoor air humidity at these points. [40.]

3.2 Airtightness

Heat transfer by air movement or via a fluid is known as convection [36]. Convection is controlled by reducing infiltration and exfiltration in the building's walls, roof, windows, floors and doors [41]. This is achieved by careful detailing of the building design and construction. Typical methods of control include membranes that are sheet materials or painted on, taping of joints sheet materials and connection points between elements and the sealing of utilities and ducting penetrations using grommets, taping or plaster. [42.]

The testing of the airtightness is performed with an Air Pressure Test, in which a building is pressurised and depressurised at a range of pressures and an average at 50 Pascals is extrapolated. The 50 Pascal range is used to make it possible to compare results between buildings and to ensure a usable figure [43]. The PH standard requires a target of 0.6 air changes per hour, whereas an AECB Building Standard requires from 1.5 to 3 air changes per hour depending on the building's ventilation type. [2,23.] The vector of air changes per hour relates to the total amount of airflow through the building at the given pressure (50Pa) and is known as the n50. [44.]

In the UK, Building Regulations require the airtightness of a building to be measured in relation to the external envelope (q50) rather than the n50. The test is performed in a similar manner; however, the calculation gives the volume of air flow in cubic metres per unit of area every hour in square meters and hour. Furthermore, a q50 measurement can be made by either pressurising or depressurising a building, whereas for the n50 method used for PH and the AECB Building Standard, a building must be both pressurised and depressurised, with the end result being the average of both calculations. [26.]

These levels of airtightness can, however, can lead to poor indoor air quality, damp air, high levels of toxins and odour issues. To avoid this, it is common to use controlled ventilation in the form of Mechanical Ventilation with Heat Recovery (MVHR), or Mechanical Extract Ventilation (MEV). However, the latter is not typically advisable due to the lack of control and the imbalanced nature of extract only systems. [45.]

3.3 Ventilation

PH buildings usually have balanced ventilation, with the aim to reduce the energy required by the ventilation system as much as possible by reducing pressure loss in the duct runs and recovering energy by means of heat recovery. Reductions in pressure losses are possible to achieve by using round, rigid ducting with smooth inner walls and reducing the duct runs to keep the system efficient by reducing the required fan power for a given air flow. [46,47.]

For AECB Building Standard buildings, due to the less stringent airtightness and energy requirements, it is possible to install either MVHR or MEV, with the airtightness requirements of 1.5AC/h or 3AC/h (at 50 Pascals) respectively. [48.]

3.4 Windows

Windows are treated as special elements in the PHPP due to their transparent quality that allows solar gains in the form of radiant energy to provide an energy saving against the buildings heat losses. Typically, windows experience a much greater heat loss than a wall or roof as they are thin and typically have a much higher heat loss coefficient. Guidance for the installed U-values and other criterion for windows in different climates can be seen in table 2 below. The guidance outlines how the PHI to certify and classify windows for different climates. [49.]

Table 2. Selected boundary conditions for determining the hygiene and comfort criteria [49].

Region No.	Name	Boundary condition for hygiene criterion		Hygiene criterion		Ambient temperature for comfort criterion [°C]	Maximum heat transmission coefficient			
		θ_a	rHi	$\theta_{Si,min}$	f_{Rsi}		Orientation	[°]	$U_{W,inst.}$	U_W
1	Arctic	-34,00	0,40	9,20	0,80	-50	vertical	90	0,45	0,40
							inclined	45	0,50	0,50
							horizontal	0	0,60	0,60
2	Cold	-16,00	0,45	11,00	0,75	-28	vertical	90	0,65	0,60
							inclined	45	0,70	0,70
							horizontal	0	0,80	0,80
3	Cool-temperate	-5	0,50	13	0,70	-16	vertical	90	0,85	0,80
							inclined	45	1,00	1,00
							horizontal	0	1,30	1,30
4	Warm-temperate	3,00	0,55	14,00	0,65	-9	vertical	90	1,05	1,00
							inclined	45	1,10	1,10
							horizontal	0	1,20	1,20
5	Warm	10,00	0,70	15,50	0,55	-4	vertical	90	1,25	1,20
							inclined	45	1,30	1,30
							horizontal	0	1,40	1,40
6	Hot	not relevant		not defined		not relevant			1,25	1,20
7	Very hot	not relevant		not defined		not relevant			1,05	1,00

The installed window U-value is particularly important due to the fact that, typically, a manufacturer will state an overall window U-value, which does not account for the thermal bridging due to the installation. In calculating the heat loss through an installed window, four types of heat loss must be accounted for. These are, the U-values of the frame and glazing and the Psi-values of the glazing edge and installation thermal bridge. The calculation for a window in PHPP detailed in below. [50.]

$$\mathrm{Uw.inst} = \frac{\mathrm{Ug} * \mathrm{Ag} + \mathrm{Uf} * \mathrm{Af} + \Psi\mathrm{g} * \mathrm{Lg} + \Psi\mathrm{w} * \mathrm{Lw}}{\mathrm{Aw}}$$

Where;
Uw.inst - U-value for the installed window - (W/m^{2}K)
Ug – U-value for the glazing - (W/m^{2}K)
Ag – Area of the glazing - (m^2)
Uf - U-value of the frame elements - (W/m^{2}K)
Af – Area of the frame elements - (m^2)
Ψg – Thermal bridge of the glazing edge - (W/mK)
Lg – Length of the perimeter of the glazing - (m)
Ψw – Thermal bridge of the window installation - (W/mK)
Lw - Length perimeter of the whole window installation - (m)
Aw – Area of the window - (m^2)

The importance of the window U-value calculation is that compared to typical building standard in the UK, the window U-value includes the installation thermal bridge, ensuring a more robust calculation. Typically, a UK SAP assessment, the tool used to assess the building regulations compliance in the UK, disregards this value in the window U-value and leaves it be considered as a separate thermal bridge, if it is considered at all.

The installation thermal bridge can make a big difference to buildings where there is a large number of glazed elements. It is recommended that a window should be installed in the insulation layer, to minimise the heat flow. In a cavity wall this means installing the window or other element in the cavity between the inner and outer masonry layers. [50,51.]

Alongside the installation thermal bridge, it is important to take into consideration the glazing edge spacer also known as a bond as this element, historically, was made from aluminium, which is highly conductive. This has now been banned across Europe and, typically, plastic, steel or glass spacers with a much lower conductance are used. Apart from heat loss, the spacer is of particular importance due to the high risk of condensation and, thus, mould occurrence at window edges due to increased water activity. [52.]

4 Achieving the Standard in Practice

As the energy consultant at Leeds Environmental Design Associates (LEDA), the company that performed the AECB Building Standard assessments, I was required to complete the PHPP assessments for each plot. The information used for the assessments was accumulated from West & Matchell the architects, The Starfish Group the main contractor and any other subcontractor or supplier with relevant information for the PHPP assessment of the Chaco project.

In practice, any low energy construction project requires careful planning, discussion, iterative design and input from the entire design team. For the Chaco project, LEDA had been contracted to perform the PHPP calculations, site visits, energy consultation and design advice to achieve the AECB Building Standard on behalf of the main contractor. The main contractor had been the successful bidder for the design and build contract and required design guidance to ensure that the AECB Building Standard was met. Given the nature of construction, and requirements beyond thermal comfort such as structural stability, acoustic quality, fire safety, living standards and regulatory matters, it is important that the discussions take place at an early stage in the design with parties from all disciplines.

Unfortunately, LEDA were appointed relatively late on in the design process. Therefore, a full detail package of drawings had been produced and initial ground works had begun prior to the involvement of LEDA. Thus, efficient working practices and dialogue between the design team was important to review the construction details and ensure that they were fit for purpose.

If the construction details were not sufficient in their original form, a solution that would satisfy all parties would be required. The solution would need to be quantified regarding its effects on the PHPP assessment for the AECB Building Standard certification and approved before being accepted.

4.1 Thermal Insulation

In LEDAs initial iterations of the and decisions made in the early stages of the project by the main contractor, it was apparent that the above U-values would not be sufficient for every plot on the Chaco project to achieve the AECB Building Standard. Without improving the specifications elsewhere, or carrying out a more detailed and costly evaluation of designs such as thermal bridge evaluation, the entire project would not pass the AECB Standard as proposed. In order to address this, the contractor opted to improve the U-values of the plots that were failing, notably, the roof U-values across the project and the external walls of plot 26. This plot received improved external wall insulation by means of an insulated plasterboard to the inside of the wall. The product specified was the Kingspan K118 Insulated Plasterboard, which uses a high performing phenolic insulation on the outer face of the plasterboard. The insulated plasterboard was specified as a 32.5 mm including 12.5 mm plasterboard thickness.

The original specification for the U-values as determined by the thermal conductivity and thickness of the material are outlined in table 3.

Table 3. Original U-values for Chaco given in the Contractors Proposals.

Element	U-value (W/m²K)
External Walls	0.18
Roof	0.15
Floor	0.11
Balcony Floor/Roof Deck	0.15
Windows	0.90
Doors	1.00
Rooflight	0.90

Across all of the plots, it was recognised that improvements were required for the roof insulation. The improvements were made possible, alongside a major design change, in which the roof was changed from a cold roof, in which the insulation was at ceiling level and the roof space was considered external to the thermal envelope, to a warm roof where the insulation layer was moved up to the roof rafters. Changing the design of the roof allowed the use of an improved insulation strategy using the Kingspan K7 roof board, underpinned with the Kingspan K118 Insulated Plasterboard at a 62.5mm thickness. The revised detail can be seen in figure 5 below. [53,54.]

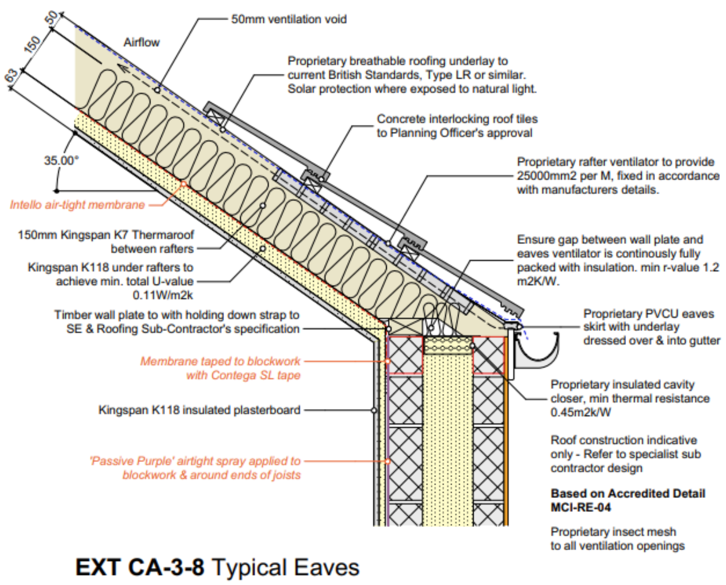

Figure 5. Detail for Chaco by West & Matchell Architects, showing typical roof to external wall detail with markups in orange by LEDA.

4.2 Airtightness

As a result of the delayed involvement of LEDA in the project, it was necessary to review the proposed design and make the necessary amendments as quickly as possible. An initial design team meeting was arranged in which the construction details would be reviewed and agreed in which I attended in my capacity as the energy consultant for LEDA. The outcome of the meeting raised several concerns about the structural limitations of the building, fire safety requirements, airtightness issues and buildability. Details discussed, and points raised included

- The inclusion of service voids to reduce the number of penetrations through the airtightness layer.
- The specification of specific airtightness material.
- The revision of airtightness penetrations due to fire safety measures.
- The specification of tape and grommets to be used at junctions and penetrations.
- An improved buildability of the details for on-site implementation.

Further revision of the details was required following the design team meeting to address any issues or points that may have been missed during the meeting. The revised details required further revision to highlight any unforeseen issues from a thermal perspective following feedback from the design team meeting. A common method of detail revision includes performing ‘the pen test’, a method of ensuring the continuity of a material or specified layer, such as insulation, or airtightness. The ‘test’ is performed by drawing a line around a section of the building at the airtightness or insulation layer, with an aim of not removing the pen or pencil from the paper. An example of this can be seen in figure 6 below, in which the airtightness of a party wall detail is being checked. In the detail, the airtightness is specified as the parge coating using a wet sand mix applied to masonry to the inner face of the blockwork. This parge coat continues into the cavity in which the PCC concrete plank sits and down to the floor below. It is also noted on the drawing that the PCC plank has hollow channels running through that must be sealed at their ends to avoid air leakage through them. [55.]

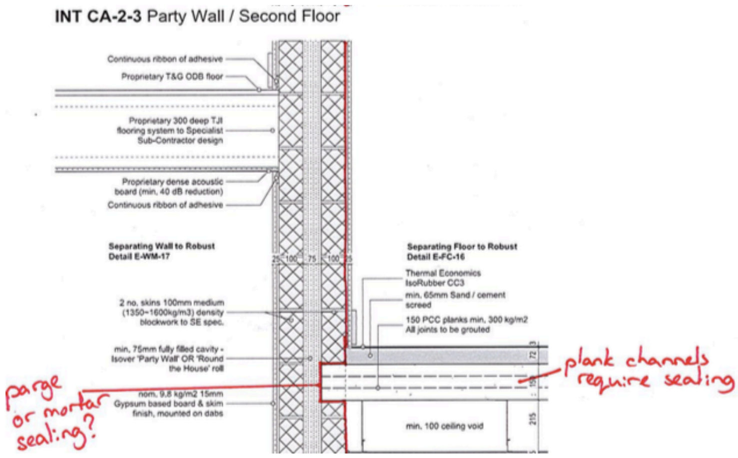

Figure 6. Example of pen test on detail for a party wall to internal floor by West & Matchell Architects, with markups in red pen by LEDA.

The project specification dictates an airtightness of 1.5 air changes for the pressure test, which is the limit for an AECB Building Standard building with MVHR [3]. This is very low for standard construction in the UK, but quite high in energy efficient buildings. The lack of airtightness in the UK is mainly dictated by two factors, firstly, in most modern buildings in the UK, there is no need to specify or utilise an airtight barrier, and secondly, the workmanship is usually unconcerned by this due to the limit for the pressure test, measured as air permeability, in the building regulations being relatively high (5 m^3/m^2h). As a result, the main contractor had some reservations in committing to achieve anything lower than the 1.5 air change target, but following a more complete evaluation of the PHPP, it was notable that without a more ambitious approach to the airtightness, it was uncertain that the project would meet the AECB Building Standard without improving the thermal performance of the fabric to unviable levels. [56.]

In order to provide further reassurance that the airtightness strategy using parge coating, taping junctions appropriately and continuity of airtightness methods would provide the desired result, LEDA arranged for the contractor to send several of their staff from a range of levels to attend some formal airtightness training from a PH specialist in the UK. Furthermore, to ensure any problems were caught before it would be too costly or invasive to address them, it was agreed that there would be at least one extra airtightness test performed at 'first fix', the point in construction where the main fabric of the building would be completed, but at which access to the inner fabric was still possible.

The above measures and assurance about similar strategies having been used in PH projects with airtightness levels below 0.6 air changes an hour in the air permeability test ensured confidence in the build quality. To achieve the required airtightness following the previous measures it is necessary to continue detailing airtightness measures and provide good levels of on-site supervision to ensure the building is built as designed. The agreed strategy provided the contractor with the confidence to agree to a lower airtightness of below 1 air change an hour for the air permeability test. The change in specification from 1.5 to 1 air changes an hour for the air permeability test would allow a more ambitious figure for the airtightness target in the PHPP. Furthermore, the reduction in airtightness would avoid further unnecessary insulation improvements that could impact the overheating target.

4.3 Shading and Orientation

A large part of PH design revolves around maximising solar radiation for a given site to benefit from free heat whilst at the same time preventing overheating, defined by PH as the percentage of time over the course of a year where internal temperatures exceed 25 °C. For Chaco, the design had been largely agreed upon and approved by the planning authorities prior to any involvement from LEDA or even the AECB Building Standard being specified. This limited the efficacy of the design advice regarding maximising solar radiation through orientations and optimising glazed surfaces. As the planning permission for the buildings featured a large proportion of glazing to both the north and south shown in figure 7, it was not possible to further optimise the designs by reducing the northerly glazed areas. [30.]

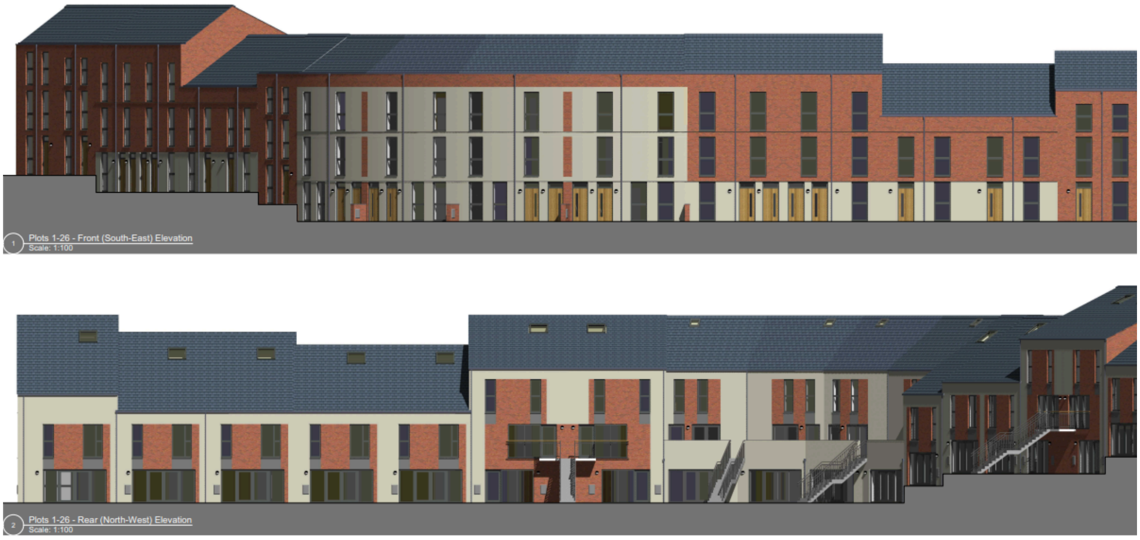

Figure 7. South East and North West Elevations for Chaco by West & Matchell Architects used for calculations for the PHPP assessment by LEDA.

A typical recommendation to optimise a design for energy efficiency would be to reduce the amount of full height windows. Alongside this, implementing shading devices to the southern elevation to reduce the chances of overheating, whilst still maximising the amount of solar radiation when the sun is lower in the sky during winter time can benefit the energy balance further. [57.] Due to the large glazed surface areas, and relatively poor thermal performance of the windows in the Chaco design, the risk of overheating was low. However, the implications for the design decisions meant that achieving the AECB Building Standard's heating demand and primary energy demand targets would be more difficult and further energy savings would need to be found elsewhere.

Figure 8. Dixons Academy Leeds Site Plans [58].

To ensure that the PHPP assessment of the Chaco project was suitable for the immediate future, it was important to consider changes in the vicinity and planned developments that may impact the Chaco site. One major development was a large school academy to the north and east of the Chaco site, shown in figure 8. This could have been a significant shading factor on the Chaco site due to the northerly sector of the school site being uphill and to the north of the Chaco development, labelled as "proposed housing development" on the site plan in figure 8. However, due to the major source of radiant energy coming from the south, the impact was established to be minimal, with the greatest effects resulting from the eastern section of the academy, which had some significant effect on the solar gains for the end terrace plots numbers 26-20. [58.]

4.4 Climate

In modelling a PH in PHPP, a relevant climate dataset needs to be selected to reflect the regions annual weather conditions such as the average ambient temperatures and solar radiation. The typical climate dataset used for a project in the Leeds region is Waddington, which is located in the East Pennines, Region 12 in the BRE Climate Data Sets seen in figure 9. [59.]

1. Central London
2. Thames Valley
3. South East England
4. South England
5. South West England
6. Severn
7. Midlands
8. West Pennines
9. NW England/ SW Scotland
10. Borders
11. North East England
12. East Pennines
13. East Anglia
14. Wales
15. West Scotland
16. East Scotland
17. North East Scotland
18. Highlands
19. Western Isles
20. Orkney
21. Shetland
22. Northern Ireland

Figure 9. BRE Regional Climate Data Sets for the UK [28].

However, in examining the map, it was noted that the Chaco project location of Leeds, was on the boundary of the region and that the climate data for Waddington may not accurately represent that of Leeds. To ensure suitability, climate data for Leeds was collated from the NASA climate database recommended by the PHI and entered into the PHPP. This highlighted that the weather conditions in Waddington were not like those of Leeds, which made the standard more achievable.

Table 4. Excerpt from PHPP Overview Spreadsheet for plot 1 house type E2, showing different results for two climate data sets, Waddington and Leeds.

Chaco PHPP Checker		Criteria	Unit	Waddington	Leeds
Delivered Heat and cooling	≤	40	kWh/(m2a)	32	39
Primary Energy demand	≤	134	Wh/(m2a)	108	117
Summer overheating	<	10	%	0.0	1.4

To ensure a robust and reliable result from the PHPP, it was agreed that the unfavourable climate dataset for Leeds would be used to accurately model the conditions despite it making it harder to achieve the standard. The outcomes for plot 1 using each dataset is detailed in table 4 above to highlight the difference in results when using the different datasets. Further comparison can be seen be above in table 4, showing the difference between the recorded NASA data for Waddington and Leeds.

It is important to note that the average ambient temperature differs by roughly 0.5 °C with the southern radiation differing by 20 kWh/m^2 for January between the two climate datasets. The difference in ambient temperature and radiation between the climate datasets is likely to be the reason for the difference in space heating, primary energy demand and overheating for the plot. [60.]

Table 5. Excerpt of PHPP assessment of the climate data sheet for Waddington and Leeds compiled by LEDA.

	Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
	Waddington	Latitude °	53.167	Longitude °	-0.517	Altitude [m]	68	Name of location	Waddington
° C	Exterior temperature	4.3	5	6.6	8.5	11.5	14.6	16.3	16.9
kWh/(m²month)	Radiation North	6.0	11.0	20.0	30.0	41.0	49.0	46.0	35.0
kWh/(m²month)	Radiation East	13.0	22.0	41.0	63.0	83.0	84.0	87.0	74.0
kWh/(m²month)	Radiation South	41.0	52.0	73.0	79.0	85.0	77.0	84.0	88.0
kWh/(m²month)	Radiation West	15.0	25.0	45.0	63.0	79.0	81.0	84.0	75.0
kWh/(m²month)	Horizontal radiation	19.0	33.0	65.0	101.0	135.0	136.0	142.0	121.0
° C	Dew point temperature	2.1	1.8	3.1	4.1	6.9	9.8	11.4	12.3
° C	Sky temperature	-5.0	-5.1	-3.7	-2.6	0.7	4.0	6.1	7.1
	Leeds	Latitude °	53.8	Longitude °	-1.5	Altitude [m]	140	Name of location	Leeds
° C	Exterior temperature	3.8	4	5.6	7.4	10.9	14.2	16.7	14.1
kWh/(m²month)	Radiation North	7.0	12.0	23.0	33.0	44.0	46.0	46.0	38.0
kWh/(m²month)	Radiation East	10.0	19.0	38.0	58.0	77.0	74.0	76.0	68.0
kWh/(m²month)	Radiation South	21.0	39.0	66.0	82.0	91.0	81.0	86.0	89.0
kWh/(m²month)	Radiation West	10.0	19.0	38.0	59.0	77.0	74.0	76.0	68.0
kWh/(m²month)	Horizontal radiation	17.0	32.0	66.0	103.0	139.0	138.0	140.0	120.0
° C	Dew point temperature	1.5	1.1	1.8	2.5	4.7	7.2	9.4	9.7
° C	Sky temperature	-7.1	-7.4	-5.4	-3.5	0.4	4.7	7.1	6.6

In comparing the two data sets in table 5, it is assumed that the PHPP results in table 4 are a result of the increased radiation and temperatures recorded for Waddington, resulting in a smaller heat demand and primary energy demand for the plot. With regards to the overheating, the increased risk from 0% in Waddington to 1.4% in Leeds may arise from the southerly radiation in the hotter months of July and August. [61.]

4.5 Thermal Bridges

Thermal bridges play a major role in the heat loss of highly insulated and airtight buildings because heat is lost through weaknesses in the fabric rather than being lost through the elements themselves. Due to this, it is necessary to consider and mitigate thermal bridges as much as possible for a robust energy model. Calculating thermal bridges can prove time consuming and costly for smaller projects, but in large projects where a detail is repeated many times, quantifying the amount of heat loss through a junction can result in large savings both financially and energetically. The savings are achieved by reducing the amount of necessary insulation or other energy saving measure that is being implemented. [28.]

Despite the potential for financial savings, discussions with the developer led to a conservative approach regarding thermal bridge analysis in the Chaco project. The reluctance to quantify the thermal bridges unless other options had been exhausted meant greater optimisation of the design was not possible. However, certain key junctions required assessment due to the scheduling of works and planned construction time scales. The junctions included the External Wall to Ground Floor and the Sliding Door threshold, both shown in figure 10.

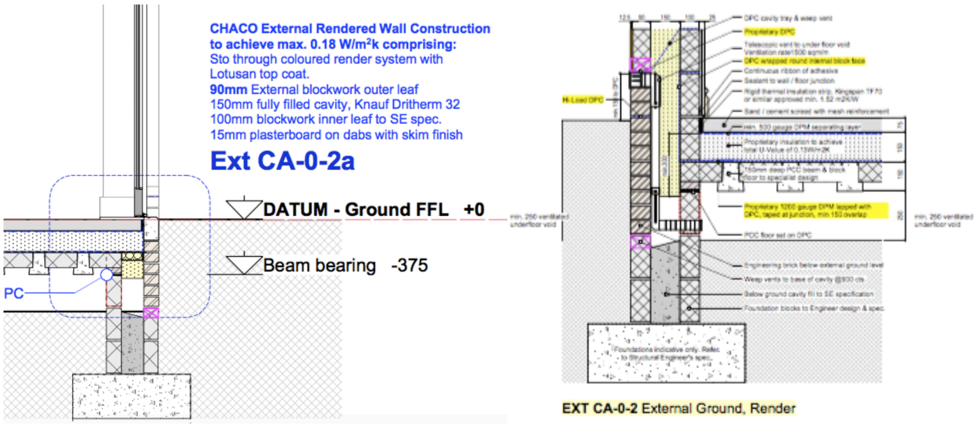

Figure 10. Sliding Door Threshold Junction and External Wall/Floor Junction, respectively.

In both cases shown in figure 11, a thermal bridge analysis was performed in which the heat loss was calculated for each of the two adjoining elements in separate calculations. To assess the thermal bridging effects at the junction, the detail was modelled, and the total heat flow through it was calculated. By subtracting the heat loss through the two separate elements from that of the junction, with respect to each element's modelled length, it is possible to ascertain the thermal bridge or 'Psi-value'. [62.]

For all unquantified thermal bridges, a default Psi-value of 0.1 W/mK was attributed to ensure that the heat loss was accounted for. This was important to ensure that the results from the PHPP were conservative, overestimating the heat loss rather than underestimating it.

4.5.1 Ground Floor to External Wall

Common recommendations for cavity wall construction would be to reduce thermal bridging by using a low thermal conductivity block such as Aircrete at the inner leaf blockwork to the floor slab [40]. Aircrete is a low thermal conductivity masonry material, formed into blocks, beams and other structural elements, commonly used in cavity wall constructions to reduce thermal bridging at junctions [63]. Given the low thermal conductivity, Aircrete can be considered part of the insulation layer and can be used in a thermal bridge free detail [64]. However, due to concerns regarding the logistics of having different types of blockwork on site, the main contractor for the Chaco project preferred not to change this detail, and the calculated Psi-value of 0.09 W/mK was used in the PHPP analysis completed by LEDA.

U - value calculation for data row			Wall			
	Check surface resistances correct				y	
	Checl total length correct				y	
			Modelling U Value (W/m2K)			0.191
U - value calculation for data row			Floor Cassette			
	Check surface resistance correct (zero under)				y	
	Checl total length correct				y	
			Floor Cassette Modelling U Value (W/m2K)			0.141
VENTED Ground Floor Calculation using ISO 13770, check values below						
	ventilation opening	0.0115		windspeed	5	
	wind shielding	0.05		ground k	2.0	W/m2K
	areas m2	4	m2	perim m	1	m
	wall thick	0	m	Rgins	0	
	Void ht above ground	0.625	m	Uwall	2	
	dg	0.42		B'	8	
	Ug	0.64		Vcpro	2.0864	
		FLOOR VOID Temperature (20/0) C				1.74
		FLOOR Modelling U Value (W/m2K)				0.129
Psi calculation			length	U-value/L2D	heat flow	psi value
			mm	W/m2K	W/mK	W/mK
L2D					0.657	
Wall	Length time U value:		1125	0.191	0.215	
Floor	Length time U value:		1860	0.129	0.239	
					0.202	
		psi Internal			0.20	W/mK
Psi calculation			length	U-value/L2D	heat flow	psi value
			mm	W/m2K	W/mK	W/mK
L2D					0.657	
Wall	Length time U value:		1449.3	0.191	0.277	
Floor	Length time U value:		2238.2	0.129	0.288	
					0.092	
		psi External			0.09	W/mK

U - value calculation for data row			Wall			
	Check surface resistances correct				y	
	Checl total length correct				y	
			Modelling U Value (W/m2K)			0.188
U - value calculation for data row			Floor Cassette			
	Check surface resistance correct (zero under)				y	
	Checl total length correct				y	
			Floor Cassette Modelling U Value (W/m2K)			0.141
VENTED Ground Floor Calculation using ISO 13770, check values below						
	ventilation opening	0.0115		windspeed	5	
	wind shielding	0.05		ground k	2.0	W/m2K
	areas m2	4	m2	perim m	21.793	m
	wall thick	0	m	Rgins	0	
	Void ht above ground	0.625	m	Uwall	2	
	dg	0.42		B'	0.36709035	
	Ug	3.36		Vcpro	45.4686	
		FLOOR VOID Temperature (20/0) C				0.13
		FLOOR Modelling U Value (W/m2K)				0.140
Psi calculation			length	U-value/L2D	heat flow	psi value
			mm	W/m2K	W/mK	W/mK
L2D					0.594	
Wall	Length time U value:		1125	0.188	0.211	
Floor	Length time U value:		1860	0.140	0.261	
					0.122	
		psi Internal			0.12	W/mK
Psi calculation			length	U-value/L2D	heat flow	psi value
			mm	W/m2K	W/mK	W/mK
L2D					0.594	
Wall	Length time U value:		1449.3	0.188	0.272	
Floor	Length time U value:		2238.1	0.140	0.314	
					0.008	
		psi External			0.01	W/mK

Figure 11. Thermal bridge calculations for the Ground Floor to External Wall detail completed by LEDA.

The thermal bridge analysis for the junction of the ground floor to external wall is detailed in figure 11, with the typical junction on the left and improved junction featuring low thermal conductivity blockwork on the right. Figures 12 and 13 show the detailed junctions and the isothermal heat flux through them as modelled in Therm, a two-dimensional conduction heat-transfer analysis tool that can be used to calculate thermal bridging .Therm, based on the finite-element method, was developed by Lawrence Berkeley Lab. [65.]

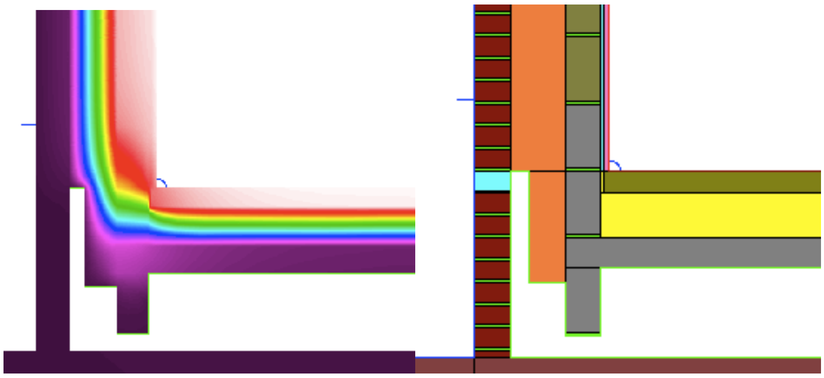

Figure 12. Left: heat flux of junction with improved Aircrete blockwork modelled in Therm. Right: junction with improved Aircrete blockwork modelled in Therm.

Figure 12 shows, on the right, the improved junction where an Aircrete block has been used on the bottom three courses of the inner leaf blockwork for the external wall to ground floor junction. The isotherm on the left shows the temperature gradient across the junction.

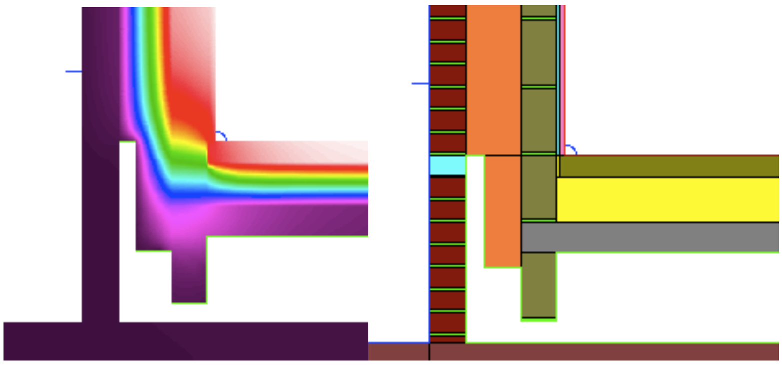

Figure 13. Left: heat flux of original junction modelled in Therm. Right: original junction modelled in Therm.

In figure 13 above, the same detail is shown with the regular blockwork used throughout the detail. Comparing the junctions visually, the isothermal lines can be seen to have changed their gradient, with the improved junction having moved the cold spot outwards slightly. Although the change is visually slight, when examining figure 11, the heat loss reduction of 88% from the original detail is apparent.

4.5.2 Sliding Door Threshold

The sliding door threshold in the Chaco project plots was also of particular importance due to its construction timescales. Door thresholds are often complicated when regarding the thermal performance of buildings due to their opening mechanism and structural requirements [66]. To address the thermal bridge created at the threshold, a highly insulative, yet compression resistant material is needed. [67.]

For the purposes of Chaco, the calculations completed by LEDA showed the use of a thermal break beneath the thresholds would significantly reduce the heat flow at this point. The revised design by West & Matchell Architects positioned the threshold on top of a layer of Compacfoam, a compression resistant, insulating material to improve the thermal bridge at this point. Compacfoam is made from recycled glass, that is melted and mixed with a blowing agent such as limestone or carbon that releases a gas at high temperature. It is costly but very effective, and widely used in PH projects due to its lightweight characteristics and thermal and structural performance. [68.]

The use of Compacfoam as a thermal break went some way to reducing the thermal bridge at the threshold. However, against the recommendations by LEDA, for aesthetic purposes, the architect chose to use a finished piece of timber maintained below the door from the inside to the outside. It was noted that due to the use of the timber below the threshold, and its grain orientation, heat flow would be higher than if the grain had been perpendicular to the direction of heat flow. [69.]

The use of Compacfoam would not reduce the thermal bridging effects completely. Due to design decisions, the contractor was unwilling to change this and it had to be accounted for in LEDAs PHPP assessment. To mitigate the effects, discussions between LEDA and the architect resulted in the thickness of the timber being limited as much as possible whilst maintaining its necessary strength to withstand regular foot fall and aesthetic appeal. The revised detail from West & Matchell Architects can be seen in figure 14 with the airtightness and thermal break measures in orange.

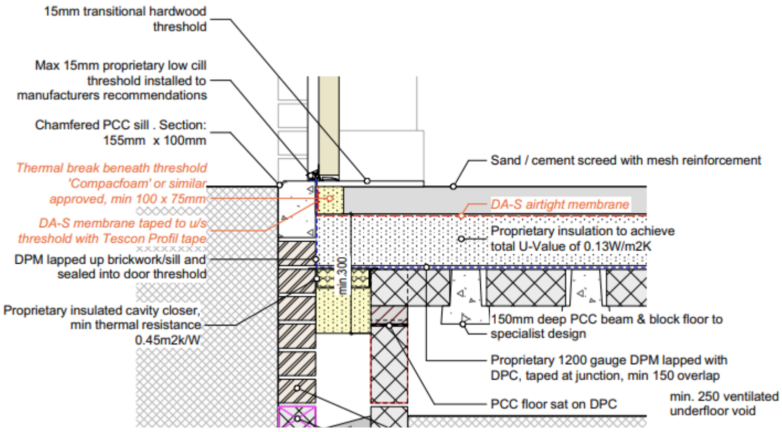

Figure 14. Detail by West & Matchell Architects with LEDAs comments and suggestions in orange.

The thermal bridging effects for the junction in figure 14 remained unquantified because of decisions by the contractor, so as with other unquantified thermal bridges, a Psi-value of 0.1 W/mK was attributed. This ensured an overestimation of heat loss rather than an underestimation to avoid a poor performance upon construction completion.

4.5.3 Lintels

Like door thresholds, lintels are often overlooked in heat loss assessments. However, in buildings with a large number of openings, they can account for a relatively high percentage of energy demand. Due to the large number of lintels and that they are usually made from highly conductive materials such as steel, significant savings can be made by addressing them properly. The lintels of the Chaco project had originally been specified as steel and concrete lintels depending on the necessary strength required for the opening's span. [70.]

Hi-therm Lintels

In order to reduce the energy losses through the lintels, Keystone Hi-therm+ lintels were initially specified. The lintels, shown on the left of figure 15, are specialist, thermally broken lintels that have an inner and outer galvanised steel lintel connected by a low conductivity polymer and expanded polystyrene insulation in between. The use of Hi-therm+ lintels meant that a Psi-value of 0.064 W/mK could be used, which the manufacturer quotes as being up to 5 times more efficient than a typical steel lintel. [70.]

Figure 15. Keystone Hi-therm+ lintel to the left and the Catnic Thermally Broken Cavity Wall Lintel in the centre and right [71,72].

However, following a more complete assessment, it was noted that greater energy savings were required for the Chaco project. As a result, the Catnic Thermally Broken Cavity Wall Lintels, shown on the centre and right of figure 15, were specified for the project. These brought the thermal bridging Psi-value for the lintels down to a maximum of 0.05 W/mK, allowing further energy savings. The specified lintels are completely thermally broken, with an inner and outer steel lintel and a high strength insulation material in between. [71,72.]

Other lintels

In some plots of the Chaco project, where the loads from the openings were too great, the structural engineers had specified concrete and steel lintels. Due to the high Psi-value of standard concrete and steel lintels, it was important to mitigate this where possible. To mitigate the heat loss at the lintels a thermally broken lintel could be used or if the case that a thermally broken lintel was not possible, the void space around the lintel should be filled with insulation to reduce the risk of heat loss and condensation within the wall. [70.]

For concrete and steel lintels, a Psi-value of 0.5 W/mK was used in the calculations to account for the high heat loss at these points especially through highly conductive materials such as steel. The Psi-value of 0.5 W/mK is typically given as a default in the SAP database, used for building compliance calculations in the UK. This ensured that the Chaco project would be on the safe side regarding heat loss. [71.]

4.6 Ventilation

Ventilation units explored early on in the Chaco project as options included the Brookvent Aircycle 1.2. However, due to the lack of certification from the PHI and the lack of experience with the unit, it was suggested that a more familiar unit would be better suited. For a PH or AECB Building Standard project, it is possible to use non-PHI certified units, however, it is important that they are suitable for airtight buildings when regarding their frost protection strategy. Furthermore, it is important to note that, non-PHI certified units are subject to a 12% reduction in the manufacturer's efficiency figures. [73.]

Prior to the AECB being set as the energy target, a performance specification had been produced by LEDA. In the document, the MVHR unit recommended for the Chaco project was the Envirovent Energy Sava (ESava) 200 and 300 units depending on the plot size, of which the ESava 300 was PHI certified.

Due to the lack of certification according to the PHPP rules, the ESava 200 units were subject to the 12% penalty in its efficiency in the PHPP calculations. The penalty is applied to account for any discrepancies in the quoted manufacturers' data that can tend to be overly optimistic.

Table 6. Example calculation of MVHR efficiencies for PHI and SAP.

Temperatures and flows from manufacurer's test report (typically BRE or BSRIA or similar)		
Kitchen plus n rooms	1	
Tin	24.85°C	
Tout	5.02°C	
Texh	7.40°C	
Tsup	23.00°C	
Airflow	15l/s	
	54m³/h	(Airflow*3600)/1000
Electrical power	11.78W	
TSUP efficiency (SAP)	90.67%	(TSup-TOut)/(TIn-TOut)
TEXH efficiency (PHI)	94.67%	(TIn-TExh+(2*Electrical Power)/(Airflow(m^3.h)*0.33))/(TIn-TOut)
SFP	0.79W/(l/s)	Electrical power/Airflow(l/s)
	0.44Wh/m3	(2*Electrical power)/Airflow(m^3.h)

In specifying the ESava 200, an additional to calculate the unit's efficiency in line with the PHI certification procedure was carried out, using the test data supplied by the manufacturer. The calculation method discounts energy gains from, firstly, the heat from the fan and, secondly, external temperatures, and calculates the efficiency of the heat exchanging unit itself.

The manufacturers test data was requested from Envirovent, and despite the data being considered as classified, they provided the raw test data, such as temperatures and air flow speeds for which they had calculated the efficiency of the unit. Having access to the raw test data from the manufacturer allowed the recalculation of the unit's efficiency using the PHI method described previously. An example of the calculation can be seen above in table 6. [46,74,75.]

Typically, MVHR units have a frost protection that prevents moisture from causing damage within the unit by freezing at low external temperatures. For air-tight buildings, on the other hand, a common of frost protection is to install a pre-heater battery, that preheats the incoming air when ambient temperatures are below a set threshold around 0 °C. This tends to be the most commonly used method of frost protection for PH and other highly airtight buildings. A schematic for the operating principle of an MVHR unit is shown in figure 16 below. [76.]

In the design and specifying of MVHR units for the AECB Building Standard, it was highlighted that the ESava 200 unit has a frost protection strategy that did not operate a preheater battery. To prevent the moisture ingress, the ESava 200 unit, at a set threshold, reduces operational ventilation. For airtight buildings, this can result in poor indoor air quality, indoor environment problems and increased energy requirements from the heating system.

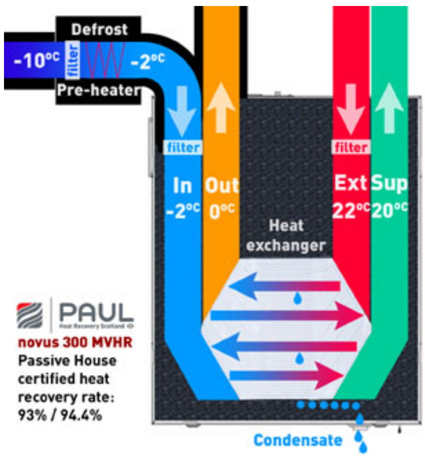

Figure 16. Operating principle of an MVHR unit illustrated by the Paul Novus 300 [76].

This was agreed as unsuitable for the Chaco project due to the target airtightness levels, and so the manufacturer strongly advised that the contractor should use a more suitable PHI certified ventilation unit that is appropriate given the building methodology.

This resulted in the specification of the ESava 300 and Slimline 150 units for the plots 2-25, and for the plots 1 and 26-29 that have a higher heating demand, the Paul Novus 300 unit was specified, given its greater efficiency. [74,76.]

4.7 Window and door requirements and installation factors

According to the original tender documentation supplied to LEDA by the main contractor, the windows had been specified as triple glazed units with insulated spacers to achieve an overall U-value of 0.9 W/m^2K. However, due to planning permission restrictions on the acoustic qualities of the roadside windows, the main contractor had stated they had been unable to source triple glazed windows that satisfied the acoustic requirements. As a result, the window manufacturer suggested high efficiency double-glazed units with a higher U-value. [77.]

As stated by Burrell, a notable PH Designer and architect,

> The recommended installation detail includes wall insulation covering some of the window frames to further mitigate or eliminate heat transmission through the frames and the window reveals. [78.]

Due to the detailing and design decisions made by the architects as part of the construction, the windows were to be installed in the outer leaf of the masonry build-up. This is typically less than optimal and results in a higher heat loss at the window edge, and thus, a greater window U-value in its installed state. As the contractor was unwilling to quantify the thermal bridging as a result of this, a conservative value of 0.088 W/mK was used as suggested in the PHPP for a masonry, non-insulated installation. [79.]

The PHPP spreadsheet contains a database of various PHI certified components, including building assemblies, window and door glazing, window and door frames, MVHR units, compact unit heating systems and waste water heat recovery systems. To ensure the robustness of the PHPP assessment of the Chaco project with the use of non-PHI certified windows, appropriate data from the window manufacturer was required for manual input. [80.]

The manufacturer's data accounted for the U-values of the glazing and frames, the g-value or the amount of solar radiation that is let in though the glazing, the thermal bridges of the glazing edge spacer and the thicknesses of each frame element.

Each frame element entered within the PHPP requires its own thicknesses and thermal bridge values due to the different geometries and materials at different parts of the frame. The main contractor had sourced windows from two suppliers, one for the frame elements and the other for the glazing. Appendix 2 includes an extract from the window frame manufacturer The Veka UK Group. The data regarding the frame thicknesses and thermal bridge effects for PHPP for the window frame elements was requested by LEDA from The Veka UK Group and input into the PHPP assessment.

4.8 Heating System

Efficiency, internal heat gains and primary energy usage are all calculated using data input in the PHPP, regarding the heating system and design [80]. In the UK, it is common for houses to use combination condensing boilers, which are gas boilers that extract waste heat via condensation. [81,82.]

Space heat distribution			E2
Length of distribution	L_H	m	58.7
Nominal width of pipe		mm	15
Insulation thickness		mm	25
Insulation reflective coating?		-	
Thermal conductivity of insulation		W/(mK)	0.040
Insulation quality of mountings, pip		-	1-None
Temp. of the room thro	ϑ_X	°C	
Design forward flow te	ϑ_V	°C	60.0
Design system heating	$P_{heating}$	kW	1.0
Forward flow temperature control ('x' if appropriate)			x
			completed 1, 2, 6 and 7
DHW useful heat			
DHW demand for showers, per per		litre/person/d	16.0
DHW demand others, per person a		litre/person/d	9.0
DHW distribution			E2
Temp. of room through	ϑ_X	°C	
Design forward flow te	ϑ_{dist}	°C	60.0
Daily circulation period	td_{Circ}	h/d	18.0
DHW individual pipes			
Exterior pipe diameter	d_{U_Pipe}	m	0.015
Accumulated length pe	L_U	m	39.703
Amount of tapping poi	$n_{tapping\ point}$	-	8.00
Tap openings per person per day		-	6
Utilisation days per year		d	365

Figure 17. DHW and Space heating distribution sheet for plot 1.

The proposed heating system for the Chaco project was a combination boiler, with the larger plots including a hot water cylinder for domestic hot water use. To account for the energy expenditure of the heating system, pipe runs from the proposed mechanical and electrical designs were used to estimate the expected length of heating pipes for both space heating and domestic hot water distribution. The input for plot 1 can be seen above in figure 17. [80.]

Boiler efficiencies, net and gross

In order to use the efficiency values of the combination boiler system received from the manufacturers energy efficiency calculations, appropriate data is required. Typically, the values given by the manufacturers in the UK are given as stipulated by the Seasonal Efficiency of Domestic Boilers in the UK (SEDBUK). Although this is a meaningful value to the efficiency of a boiler that cannot actually give out more than 100% as per the Net values, assuming all heat is recovered by means of condensation of the water vapour from the burning process, it is not applicable in the PHPP assessments. Furthermore, the SEDBUK value assumes that a boiler operates with some amount of heat recovery from condensation which is usually disregarded completely in manufacturers stated efficiencies. [83.]

PHPP, on the other hand, uses net values, which require the conversion or manufacturer data [84]. The net efficiency value can be calculated, by dividing the stated gross efficiency by the given fuel factor for the given fuel type such as natural gas, liquefied petroleum gas or oil. [83.]

4.9 Design team meeting revisions

Design team meetings are important in discussing, and agreeing on changes in an efficient manner with input from all the necessary disciplines. They offer focused design to take place, covering important aspects that are out of the scope of individual disciplines. [85.]

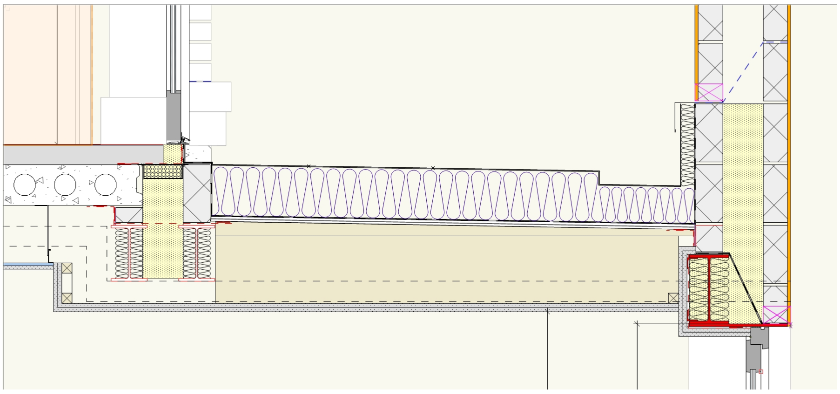

Figure 18. Section by West & Matchell Architects highlighting changes made to the balcony/roof deck.

As a result of design team meetings, significant changes can be made to small aspects of a design [85]. The meeting process can be slow but allows a refining of the design to ensure it met the needs of the Chaco project. Ideally, the design is optimised from the offset of the Chaco project ensuring that these necessary changes are reduced to a minimum.

A key point often raised during the design team meetings in which LEDA attended for the Chaco project was from the main contractor, regarding the buildability of a proposal or suggestion. Buildability can often be overlooked, but the way in which a construction is actually conceived is important in ensuring it is actually built as it was designed. One such point was raised regarding the section detail above in figure 18, where concerns were raised as to how the roof deck could be realised and the sequence required to do so.

If it is not possible to build a proposal, the risk is that a shortcut or alternative route may be taken on site that may hinder the design structurally, thermally or in some other way. A key point when detailing or reviewing a detail is to ensure it is possible to assemble, in a sequence that is realistic given the environment it is performed in, and with the materials being used.

The structural engineer has one of the most important roles within the design team, and it is necessary that any proposal satisfies the requirements of the structural engineers. This can prove to be a difficult task from an energy consultants' perspective, as often the structural requirements are at odds with what would perform best thermally. However, if the structural engineer's requirements are not adhered to, the safety and stability of a project may be put at risk. When working with a structural engineer, it is best to have the requirements for the design prior to making any suggestions in order to understand what is possible and where, and to follow these requirements with mitigation strategies if the situation is not optimal. [86.]

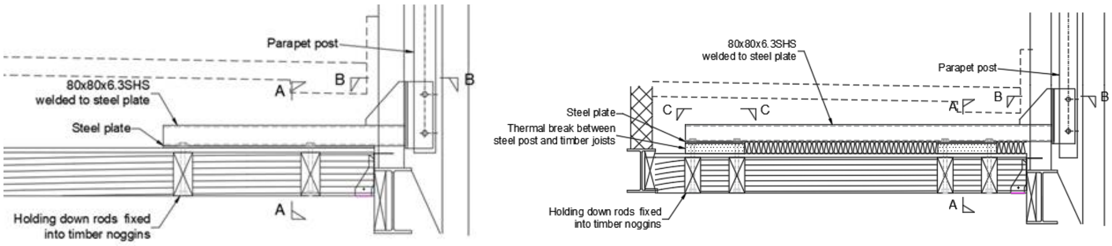

Figure 19. Structural engineers' original design for wind posts to parapet walls on the left and the revised design on the right showing a structural thermal break.

The above figure 19 shows a revised detail on the right, where the welded steel plate used to prop up the parapet walls against wind loads is a significant thermal bridge through the insulation layer. The thermal break is a high-density polyurethane that can withstand compressive and shear loads and allows the wind post to transfer loading through to the structure, whilst maintaining the insulative quality and reducing bridging.

It is important for mechanical and electrical engineers that they are included in discussions regarding the importance of the continuity of insulation and airtight layers. This is due to the fact that a mechanical or electrical engineer will need to create ways through the layers to allow for electrical cable runs, plumbing, ducting and other penetrations.

By including the mechanical and electrical engineers in early discussions regarding the airtightness and insulative layers, they can be made aware of the importance of the layers' continuity, and provide valuable suggestions in order to manage penetrations appropriately. It is also very important that the heating and ventilation is done efficiently, to ensure the energy use in the building is kept to a minimum and designed as modelled.

It is a common problem in projects that focus on the profit levels that specifying high-end elements, materials and/or equipment can be problematic, especially when working in a Design and Build contract, in which the main contractor is focussing on profits rather than energy use. This can result in under specified elements being used instead of something that may benefit the habitants of a project following its completion. [87.]

Furthermore, the concern on profit margins above other aspects can result in less than optimal designs being proposed and not properly designed. With the Chaco project, rather than quantifying thermal bridges, a higher specification material has been used in the form of insulated plasterboard which has resulted in greater expense. This would perhaps not have been necessary if the thermal bridges had been quantified and included in the energy balance.

5 Summary

In order to bring the design of the Chaco project to the AECB Building Standard, LEDA had to make several suggestions to revise the design. Table 7 outlines the key changes made throughout the design process from the original design. Had the assessment taken place at an earlier stage, many of these changes may not have been needed, or they may have been greatly reduced.

Table 7. Changes made following the process of developing Chaco to the AECB Building Standard.

Element/Specification	Original	AECB Building Standard
Airtightness (at 50 Pa)	1.5 air changes per hour	1 air change per hour
Airtightness strategy	none	Use of airtightness membranes, tapes and boarding to reduce air leakage and training to site staff to ensure quality.
Airtightness tests	1 test upon completion	At least 1 additional early stage test to ensure quality and highlight issues
Penetration strategy	none	Grommets used at all thermal envelope penetrations
MVHR units	Envirovent Energi Sava 200 and 300 units	Envirovent Energi Sava 300 and Paul Novus 300 units
Wall U-value	0.186 W/m^{2}K	0.183 W/m^{2}K
Wall U-value for plot 26	0.186 W/m^{2}K	0.152 W/m^{2}K
Roof Light U-value	N/A	0.51 W/m^{2}K uninstalled
Roof U-value	0.180 W/m^{2}K	0.114 W/m^{2}K
Lintels	Hi-Therm +	Catnic Thermally Broken
Details	N/A	Optimised details by means of reducing conductive material use and using thermal breaks in structural situations

Every change was the result of discussions, revisions and calculation, each of which carries its own cost. These costs would have also been mitigated with effective planning and implementation at an early stage

6 Conclusion

6.1 Comments, Concerns, Hindsight and Feedback

An important factor in achieving the AECB Building Standard is the stage in which a suitable strategy is implemented. By introducing the relevant professionals and designers in the early stages of a project, it is possible to produce a building proposal that is optimised for energy efficiency from the outset. As a result, the detailed design stages at a later stage in a project will be of a reduced importance to minimise the energy losses as the bulk of the work has already been carried out by using an optimised design.

Problems as a result of late involvement of an AECB Building Standard assessor in the Chaco project include oversized windows, poor form factor such as large surface areas to internal volumes and unoptimised solar gains. With early intervention on the design, the Chaco construction as a whole would have required fewer revisions and there would have been a reduced need for focus on the finer details regarding the thermal performance of elements and materials.

To understand the effects of early intervention, table 8 highlights the results of reducing some window heights in the Chaco project by 900 mm. This represents changing the window sill height from the floor for a full height window, as used in many windows for Chaco, to a sill height of 900 mm. As can be seen, the design using an optimised sill height would allow energy savings of 1 kWh/m^2a for the heating demand. This would allow for financial savings elsewhere, such as using less high performing materials or using a more achievable airtightness target in the project.

Further optimisation of the design of the Chaco project could have been achieved by placing the windows within the insulation layer of the wall rather than in the external leaf. Unfortunately, the design had already been given planning permission based on the "As Designed" proposal, which led to higher specification materials and better detailing requirement for the materials and services than necessary.

Table 8. Example of effects of changes in window height by 900 mm.

Result	Plot 1 – E2 – As designed	Plot 1 – E2 – Height optimised	Plot 1 – E2 – Height and positioning optimised
Heating demand	38 kWh/m^2a	37 kWh/m^2a	35 kWh/m^2a
Heat load	15 W/m^2	14 W/m^2	14 W/m^2
Primary energy demand	115 kWh/m^2a	114 kWh/m^2a	112 kWh/m^2a
Primary energy renewable	110 kWh/m^2a	108 kWh/m^2a	105 kWh/m^2a

Further implications from early design decisions include optimising the solar gains by the placement of the buildings on site. For Chaco, the main shading effect is a result of the industrial units to the south of the project, which sit around 5m in height.

By moving the Chaco project further back to reduce the impact of these buildings, further energy savings could have been made. Table 9 shows the impacts of this, in addition to the previous height and positioning optimisations in for the windows.

Table 9. Further optimisations on site position to reduce over shadowing.

Result	Plot 1 – E2 – Window height and positioning optimised and shading reduced
Heating demand	33 kWh/m^2a
Heat load	14 W/m^2
Primary energy demand	110 kWh/m^2a
Primary energy renewable	101 kWh/m^2a

Further analysis of the impacts of shading on a building can be seen in figure 20, highlighting the effects of an object casting shade upon a project, taken from a report produced by Warm Ltd for York Housing. [88]

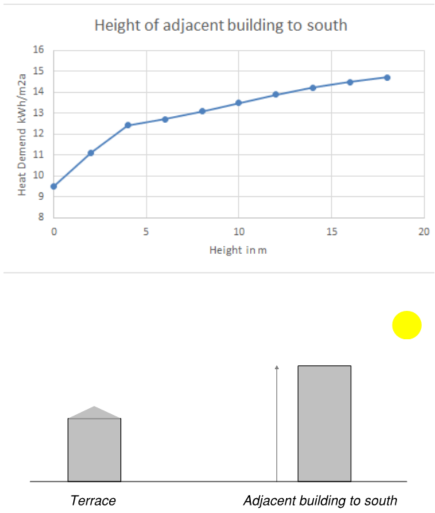

Figure 20. Over shading effects of a southerly object [88].

The heat loss form factor of a project affects the energy efficiency in a major way. Typically, the more cuboid a building is, the more efficient it will be. The form factor is the ratio between the heat loss area or thermal envelope and the treated floor area of a building. Typically, the more compact and simpler a building shape, the lower and hence, better its energy efficiency will be provided everything else stays the same. This is an important early stage development tool that can be used to optimise a building's design when it comes to energy efficiency. [89.]

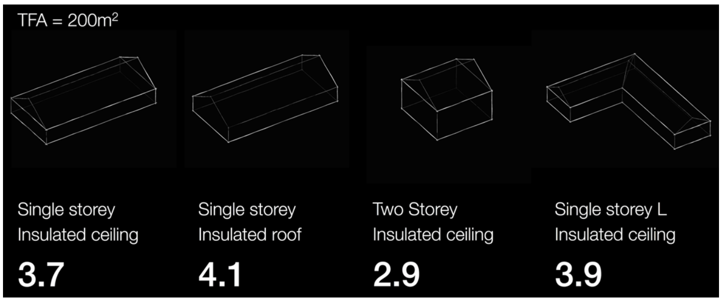

Figure 21. Heat loss form factor for a building with a TFA of 200 m^2 [89].

In figure 21, the heat loss form factor can be seen for a variety of different designs. The heat loss form factor can also be used to ascertain an average U-value of the building fabric required to meet a particular heat loss standard as seen in figure 22 [89].

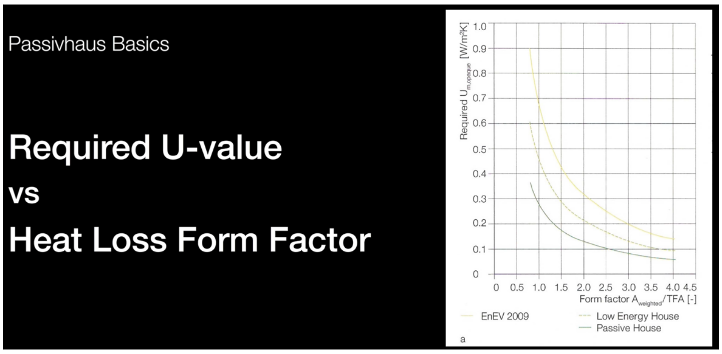

Figure 22. Heat loss form factor to U-value [89].

A preferential change outside of the control and scope of the final year project regarded the installation of gas boilers in the Chaco project. Gas combination condensing boilers are commonly used in the UK due to their efficiency, familiarity and affordability. However, given the current climate situation, it is becoming more advisable to specify more efficient heating systems, which can be made more affordable to install due to the economies of scale in larger projects. [90.]

Early in the developments for the Chaco project, LEDA produced an options appraisal of different heating systems that, at the time, resulted in an efficient gas combination condensing boiler being specified for the tendering document. However, given the move away from gas as a fuel source, and the growing supply chain for heat pumps in the UK, it would have been preferable to use a cleaner source of heat energy within the dwellings. [91.]

The PH standard is a holistic standard with goals set in a way that can have a direct impact on the home user. The impacts include avoiding potential risk of mould growth and simplification of the building systems. [92.]

Unfortunately, the AECB Building Standard uses targets that are more concerned with cost than the holistic nature of construction and occupation of a building [3]. This results in the initial approach being less ambitious than necessary to achieve high standard in construction. This can lead to cost cutting which could reduce some areas of the PHPP assessment in quality, or ignore or overlook them due to the less stringent targets being set. [93.]

For a PH, it is not an option to use double glazing or sub-par elements as they will cause a failure in the PHPP due to their inefficiency leading to health risks or other implications [94]. Each element impacts on another, and the PHPP does a good job of accounting for that, but with a relaxed target, the specification of elements can also be reduced, which, in turn can cause for example cold spots and mould growth. The PH standard has been designed to account for the risk of mould growth and other problems, and so, these issues are avoided by achieving the standard. [95,96.]

However, with the AECB Building Standard, the targets are relaxed without any justification as to why. This can result in imbalances, such as high specification U-values, but poor detailing or glazing, or inappropriate MVHR units being specified. Furthermore, the certification procedure of an AECB Building Standard project is open to exploitation or error due to the self-certification process. Limited evidence is submitted, and the submissions follow no verification of any kind. The party involved in the certifying does not need to be qualified, or an independent third party, and there is no necessary independency of any kind. [19.]

Although there are no studies or research published on the expected capital uplift of an AECB Building Standard building, there is a significant amount of research on the PH standard. In 2019, the Passive House Trust in the UK produced a report stating that the initial capital cost for a PH at a larger scale for social housing is around 9% higher than the cost of a regular social housing, with scope to reduce the difference to 4% with a wider adoption of the standard. [97.]

Given the above, it is safe to assume that the adoption of the AECB Building Standard should result in lower capital increases over a mainstream construction standard. The important factors in ensuring the initial capital costs are reduced as much as possible are

- Passivhaus or the AECB Building Standard must be in the initial brief
- An experienced PH designer or consultant should be employed
- The design should be kept simple
- Ventilation design is important
- Where necessary, overheating and its control should be considered and mitigated
- Airtightness is key
- The team are motivated and understanding
- It is more than just design
- Designers and contractors work collaboratively
- A certifier is appointed early, which is required for a PH, and can help with the AECB Building Standard

An important aspect in the comparison of the PH standard and the AECB Building Standard with a typical construction is that both the AECB Building Standard and the PH standard have some level of quality assurance, with the PH standard offering further benefits such as a time-tested health and indoor air quality improvements. [98,99.]

6.2 Evaluation

In evaluating the implementation of the AECB Building Standard for the Chaco project the following aspects must been considered.

- The AECB Building Standard assessment for the Chaco project overestimated the heat loss due to a lack of clarity on particular details.
- It is likely that the Chaco project has been subject to increased costs following the late contracting of the AECB Building Standard assessors, which would not have been the case had they been appointed earlier in the design.
- The Chaco project missed energy saving opportunities due to the planning approved design having no input from the AECB Building Standard assessors.
- The Chaco project suffered due to circumstances out of anyone's control due to the Coronavirus pandemic. However, there would most likely have been greater progress prior to the pandemic if early implementation of the previously discussed points had occurred.

On the whole, the Chaco project has proven successful, with the exception of the caveats listed. Had the Chaco project been implemented with a greater understanding of the AECB Building Standard, and with input from a PH designer or AECB assessor early on, many of the issues experienced could have been mitigated and a better performing design could have been in place when submitting to the planning authority. At this point, it would have been advantageous to explore options of having a more ambitious standard such as PH, and an alternative heating system such as communal heat pumps.

The Chaco project has experienced an increased capital cost due to poor planning and lack of involvement of the necessary design team at the early stages of design.

To address the shortcomings due to the design team and planning deficiencies, the tender documentation should have emphasised their necessity. Furthermore, the initial design should have been approved in general by an AECB assessor prior to it being submitted for Planning approval.

Generally, extrapolating information from case studies by the Passive House Trust in the UK, it can be assumed that achieving the AECB Building Standard should not incur any significant increase in capital costs, provided an experienced design team are in place [35].

6.3 Final Notes

The AECB Building Standard can be seen as a generally positive thing for buildings in the UK, it is generally affordable and notably better performing than the current building standards. However, it seems that the initial capital costs for the PH at larger scales could also be realised with the AECB Building Standard with little to no uplift. The AECB Building Standard does feature some improvements over the mainstream UK building stock such as;

- Improved energy performance and, thus, consumption costs
- Better documentation of the build process
- Improved level of culpability
- A tendency for improved air quality. [3,98.]

However, the AECB Building Standard still leaves a few areas of uncertainty that could be addressed by implementation of the PH standard [100]. As a result, this thesis recommends that when considering a low energy standard to comply with at an early stage for large scale construction, the PH standard is more attractive as a standard to achieve. [3.]

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AECB Supporting evidence requirements for the AECB Building Standard

Supporting evidence requirements

	Drawing & photographic record	Drawings.PDF A4 format	Photographsjpeg format.
1	All elevations of completed building	One elevation per page. Scale bar to be included.	one photo. for each elevation
2	Floor to wall junction – continuity of insulation visible	✔	✔
3	Floor to wall junction – airtightness measures visible		✔
4	Intermediate floor to wall junction – airtightness measures visible	✔	✔
5	Roof to wall junction – continuity of insulation visible	✔	✔
6	Roof to wall junction – airtightness measures visible		✔
7	Typical window in wall detail – jamb with wall insulation measures visible	✔	✔
8	Typical window in wall detail – jamb with airtightness measures visible		✔
9	Typical treatment of services penetration in fabric – with airtightness measures in place	✔	✔
10	Typical MEV or MVHR installation showing ducts & duct insulation		✔
11	Hotwater storage and pipework – showing tank and pipe insulation		✔
12	Windows/doors – showing opening light with seals and glazing spacer bars		✔
Other			
13	Air pressure test certificate (pressurisation and depressurisation results)	✔	
14	PHPP verification sheet as pdf	✔	
15	Copy of building users manual	✔ optional	

VEKA Group UK Energy Certificate for window frame elements

Energy Certificate Provided By VEKA UK Group

The VEKA UK Group

PRODUCT DESCRIPTION — 7 January 2020

Brand : **VEKA** System : **M70** Product : **Tilt & Turn**

FRAME SPECIFICATION

Frame :	67 mm	101309	Centre Chamber :	113422 (67f Box Section)
Mullion :	68 mm	102297 or 102298	Centre Chamber :	113412 (68m Box Section)
Sash :	82 mm	103364	Centre Chamber :	113413 (82s L Section)

Width : **1230 mm** Height : **1480 mm** Window Area : **1.8204 m²** To EN 14351

Enhancements : **None** Glazing : **Double Glazing (28mm)**

Frame Uf : **1.306 W/m²K** Sash & Frame Uf : **1.402 W/m²K**

Mullion & Sash Uf : **1.471 W/m²K** Mullion & Sashes Uf : **1.459 W/m²K**

GLAZING SPECIFICATION

Outer Pane : **mm** Middle Pane : **N.A.** Inner Pane : **mm** Gas :

First Gas Cavity : **mm** Second Gas Cavity : **mm** Unit Thickness : **mm**

Glass : &

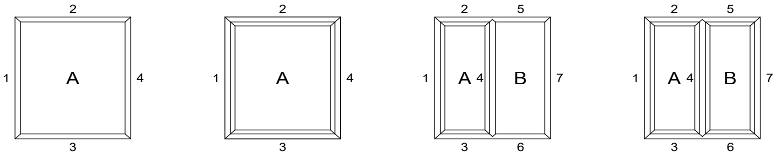
SPACER BAR SPECIFICATION — Glazing U_g : **W/m²K**

Spacer Bar : Secondary Sealant :

Secondary Sealant Depth : **mm** Spacer Bar Ψ value : **W/(m·K)**

U-VALUE CALCULATION

Fabricated from genuine VEKA components : ☐ Georgian bars to EN 14351 : **None**



Fixed Light	Single Opener	Opener & Fixed (Regulation Window)	Double Opener
W/m²K	W/m²K	W/m²K	W/m²K

bsi. Thermal Performance Verification 0086

BFRC

Door Panels

Upper Infill Panel : ☐
Lower Infill Panel : ☐
Full Infill Panel : ☐
Panel U-value : W/m²K

Calculate Energy Rating : ☐

Energy Index : - kWh/(m²·yr)
Energy Rating : -

Glass g value :
Product g value :

Revision 19 - 2 U-values : Notified by BSI (0086) Energy Ratings : Independently verified by BFRC VEKA Technical Office February 2019