Self-build architectural systems should be based on locally sourced, carbon-free materials and be simple enough to be built by untrained or unskilled people, achieving a quality which eliminates any possible negative impacts on the health, life and comfort of users.

Wall construction technologies, building material properties, and their role in community development and the decarbonisation process.

Thesis Prepared

By

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Declaration of Authorship

22900-AB947 Masters Dissertation 2023/24

Declaration

"I confirm that this submission is my own work and has been composed by myself. It contains no unacknowledged text and has not been submitted in any previous context. All quotations have been distinguished by quotation marks and all sources of information, text, illustrations, tables, images etc have been acknowledged. I understand that any form of Academic Misconduct is strictly prohibited, including the use of essay mills, homework help sites, plagiarism, collusion, falsification, impersonation or any other action which might give me an unfair advantage. I accept that if, having signed this declaration, my work should be found at Examination to show evidence of academic dishonesty, the work will fail and I will be liable to face the University Senate Discipline Committee".

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ChatGTP et al: In case you made use throughout your production of AI tools, please describe how and for what purpose, with a small reflection on their benefits.

ChatGPT assisted me in structuring this dissertation and provided quick insights when potential new research directions emerged. It also helped me shorten overly long sentences - often a result of continuous brainstorming- into more concise, reader-friendly versions. This tool was particularly helpful as English is not my first language. However, all factual information included in this work was carefully cross-checked against reliable sources, as listed in the bibliography.

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Abstract

This dissertation investigates the differences between different types of walls, considering the amounts of embodied carbon delivered by each technology, as well as comparing the amount of operational energy needed.

It is discussing if the use of the definition of self-built in terms of timber frame wall is appropriate and suggest technology simple enough to be constructed by unskilled community members.

The findings highlight differences in longevity between timber frame construction and solid masonry, here considered as biofiber-based hempcrete. While timber frame is widely used in new-build housing, it has significant limitations such as short life span and vulnerability to moisture.

In contrast hempcrete offers at least 3 times longer lifespan due to its technological simplicity, solidity and reduced number of materials utilised in wall construction that can fail.

These studies contribute to the field of architecture by showing positive aspects of bio-based materials and their positive impact on occupants' health and the environment.

According to the Vitruvius's principle *"firmitas, utilitas et venustas"* - durability, convenience, and beauty it takes reader for a journey to explore the possibilities and threats connected to implementation of different wall technologies. It is not only showing deeply rooted connection to the architecture but it also makes us question whether the quality of today's dwellings can be called architecture when we know that so many of them are harmful to human beings.

Keywords

Self-build housing; Carbon Sequestration; Wall construction technologies; Embodied carbon; Sustainable architecture

Aims and Objectives

The aim of this paper is to utilise multiple Building Information Models (BIM) of an exemplar house, each employing a different way of delivery through selected wall technologies, to calculate and analyse differences in embodied carbon and other pollutants emitted into our environment. To ensure a fair comparison of technologies, it was decided to use the same U-values for walls, windows, doors, slabs, roofs, and foundations. Additionally, the internal footprint will remain constant to maintain the building's volume.

The conditions of the buildings presented in the previously prepared report will be considered (see Annex 1), and the potential for implementing new building materials and technologies will be discussed. The report will also assess the amount of embodied carbon and provide calculations that compare the energy demand and operational carbon emissions across various solutions.

Biofibre-based materials are becoming increasingly available in the British market, presenting new possibilities for roofs, walls, slabs, and render insulation. Biofibre-based products used in block formation sequester carbon, having already achieved carbon-negative material status. This means their production process releases oxygen while capturing carbon dioxide (CO2) from the atmosphere.

Location: Paisley, United Kingdom

Building simulation tools: Archicad 26-28

Research Questions

- Why is the performance of the building envelope so important?
- How does the building envelope connect with the ventilation and heating system?
- What are the benefits of building envelope studies?
- What issues are having an impact on houses' longevity?

Research Objectives

- Presentation of selected criteria
- Choice of wall technologies
- Preparation of a ‘parent’ building information model
- Choosing adequate Environmental Performance Declarations (EPD) for further environmental impact assessment
- Testing against energy performance
- Comparison and summary of the testing stage

Methodology

Evidence of the problem's existence is based on primary data (including photograph and reports) and secondary data. To document the harmful outcomes of new-build developments and highlight the necessity for an intervention, photographic evidence, statistics, and questions cited in this document were collected to establish the foundation for further development of this thesis. The methodology includes 3D modelling, a testing phase, and a comparison of the performance of existing and potential solutions.

At first, a selection of self-build technologies will be identified and analysed. As part of the research process, examples of different wall buildups will be examined for structural complexity, energy performance, embodied carbon, and lifespan. To achieve this, a series of models will be prepared and analysed using Archicad 26, a BIM software that provides critical information on material properties and enables performance simulations to investigate operational carbon footprints.

To ensure meaningful comparisons, a set of criteria grounded in multiple regulations, standards, and laws will be used. These include the international standard ISO 14025, which outlines principles for environmental declarations, as well as European Norm EN 15804 and relevant British Standards.

The choice of materials is guided by the availability of Environmental Product Declarations (EPDs), which provide sufficient data to calculate the overall embodied carbon footprint of the proposed designs.

Archicad software will also incorporate weather data collected between 2007 and 2021 from the Glasgow Airport weather station, located approximately 700 meters from the test site. This ensures more accurate inclusion of local climatic conditions (coordinates: 55.859002, -4.428782).

Gathered data will become a later testing ground for multiple performance simulations to recognise possibility of thermal bridging issues and preparation of energy performance evaluation report.

The gathered data will serve as the basis for performance simulations to identify potential thermal bridging issues and prepare an energy performance evaluation report. A simplified model of a detached house will be used to assess envelope performance, as the straightforward shape minimises potential heat losses from irregular designs.

An energy evaluation report will be prepared using Archicad, incorporating parameters such as wall area, wall thickness, U-value, air infiltration, and solar absorptance to test various solutions. The final bill of quantities, derived from the Archicad model and environmental declarations, will quantify the embodied carbon for each researched solution, enabling detailed comparisons.

Limitations

- Environmental Product Declarations (EPDs) are not yet mandatory, limiting the range of materials available for comparative simulation.
- The test site is located in Paisley, United Kingdom; therefore, the calculations may not be directly applicable to other locations in Scotland.

Simulation Model

A housing design from the 1970s was selected as the basis for the simulation model. Originally constructed as terraced housing with double blocks and an airgap between the masonry, the design can also function as a detached house. The simple layout minimises the impact of potential heat losses associated with more complex geometries.

Introduction

In 2019, the Royal Institute of British Architects (RIBA) published a report titled *RIBA Housing Policy Statement* (Royal Institute of British Architects, 2019). The report asserts that “every home we build today should last at least a century; most experts say two.” However, it also highlights concerns about the lack of character in many housing developments, predicting that these homes will age poorly, with an optimistic lifespan of no more than 60 years. Alarmingly, this estimate is further challenged in an article published in the RIBA Journal, titled *Lifespan*, which suggests that the real figure is closer to 30 years (Pearman, 2011). The policy statement also draws attention to uniform monotony in new suburban housing, with little meaningful change observed since the 1980s, as noted by commentators, housing experts, and the wider public.

A report from the Chartered Institute of Building provides additional insight into public opinion about “new builds.” Based on a survey of 2,000 people, the findings reveal that 55% of respondents believe “older properties are usually higher quality,” compared to only 21% who feel the same about new builds. When asked to describe new builds, 44% selected “overpriced,” 41% said they lacked character, 34% called them modern, 32% described them as poor in quality, and only 21% considered them efficient (The Chartered Institute of Building, 2023).

In response to these findings, a report was prepared by the author to examine a housing development constructed in Paisley in 2019. The report, titled *Exemplar 2019 Build – Small Snug Report* (see Appendix A), revealed numerous defects, including over 60% of window mastics being defective, loose, or absent. Other issues related to the wall structure, roof finish, and damp proofing were also identified, all of which could accelerate the building's deterioration and significantly reduce its lifespan.

This research initially relied on data from the Scottish House Condition Survey, given the limited information available about new buildings (Scottish Government, n.d.). Unfortunately, no comprehensive studies predict the condition of two-year-old buildings after 20, 40, or 60 years. The need to address the quality of the existing housing stock has been emphasised in prior studies (5A Design Studies), yet questions about the long-term durability of new builds persist, especially given the numerous observed defects that violate Building Regulations.

The focus of this research is on investigating wall technologies, a critical component of building design that separates internal living spaces from the external environment. Walls play a pivotal role in creating habitable, safe, and healthy microclimates for occupants. Errors in construction or design during the building process can drastically affect performance and lifespan, increasing operational costs and exacerbating issues like fuel poverty and health deficits, thereby worsening the housing crisis.

While retrofitting existing housing stock is a well-researched and necessary approach to improving occupant health and preserving architectural value, it raises important questions. For instance, how long will it take to retrofit all substandard homes to acceptable living standards? If this process takes 30 years, as suggested by architectural journals on life expectancy, a significant portion of today's new builds may require retrofitting by then, perpetuating a cycle of housing inadequacy and crisis.

What is urgently needed is the strategic use of budgets to address the most hazardous and damaged housing accommodations. Solutions must be user-friendly, sustainable in terms of embodied carbon and energy consumption, and economically affordable. Only with such comprehensive and forward-thinking strategies can we begin to break free from this recurring cycle of the housing crisis.

Challenges

Scotland is striving to achieve its net-zero target, which necessitates significant changes in the construction industry. One notable development is the introduction of an amendment to building regulations, Part Z. Although not yet mandatory, this amendment outlines requirements for whole-life carbon emission assessments. The proposal represents one of the first legislative efforts to address the total carbon footprint associated with building delivery and maintenance (Part Z, 2024).

Prior to the introduction of Part Z, there was no legal definition or requirement for assessing embodied carbon. Building regulations historically focused exclusively on operational carbon emissions, with embodied carbon receiving no mention. This oversight meant that even Passive House designs were not subject to restrictions regarding the carbon footprint of materials used during construction.

Fortunately, awareness among architects is growing. Increasingly, architects are taking proactive steps to identify and minimise the environmental impact of buildings. This shift is especially timely, as regulations addressing embodied carbon are expected to become mandatory by 2026 (Cousins, 2021).

Chapter 1 – CONTEXTecture

1.1 Location

The data collected primarily represents areas within the United Kingdom, with a particular focus on Glasgow City and Paisley Town. Additionally, global statistics will be included throughout the document to provide a broader context and enable comparisons on an international scale.

1.2 Climate

The climate of the United Kingdom is characterised by its maritime nature, marked by moderate temperatures, frequent rainfall, high humidity, and strong winds, particularly in coastal regions. These conditions require architectural designs that balance functionality and resilience to ensure buildings can perform effectively over time. The climate data used for simulations in this research, aimed at assessing the performance of various wall buildups, is sourced from the *Repository of Building Simulation Climate Data* (Climate.OneBuilding, 2024). This dataset represents weather information collected in the Glasgow Airport area between 2007 and 2021.

1.3 Economy

The ongoing housing crisis in Scotland remains a significant and long-term challenge, profoundly affecting community health and well-being. A large portion of the existing housing stock is in urgent need of repair, with many properties no longer safe for their occupants.

To address this issue, substantial investments have been directed toward retrofitting existing homes and constructing new housing developments. However, prioritising quantity over quality has historically proven unsuccessful, often forcing residents into uniform, substandard living spaces. High demand in the housing market has seemingly led to more lenient attitudes among decision-makers and inspectors regarding the quality of domestic construction.

To substantiate concerns about the poor quality of new-build housing developments, evidence is presented in Chapter 1.5: State of New Build Housing Stock.

1.4 State of Existing Housing Stock

The condition of the housing stock significantly affects health and well-being, often in negative and harmful ways. Previous research, including *5A Design Studies*, highlights the widespread issue of poor housing quality. Data from the Scottish Housing Quality Survey (SHQS) Report confirms a severe shortage of high-quality housing stock. Between 2016 and 2018, 26% of Glasgow's dwellings were found to be in urgent need of repair—meaning immediate action was required to prevent further property damage, health risks, or safety hazards for occupants (The Scottish Government, n.d.).

British homes are among the worst in Europe in terms of wall insulation and heat retention. According to an *Euronews* article, housing in Great Britain performs the poorest across Europe, with the average home losing 3°C after five hours without heating when the internal temperature is 20°C and the external temperature is 0°C. The primary reason for this inefficiency is that 62% of the British housing stock was built before 1970, prior to the introduction of thermal standards.

In contrast, Germany, which has a similar proportion (59.3%) of pre-1970 housing, demonstrates far better performance. German homes lose, on average, only 1°C under the same conditions—three times less than their British counterparts (Yanatma, 2022).

1.5 State of New Build Housing Stock

A previously prepared report highlighted numerous issues that can significantly impact building performance and reduce its lifespan. One major concern is the building envelope, with over 50% of windows found to have missing or loose mastic. This defect directly affects the building's airtightness.

A shorter building lifespan increases its embodied carbon footprint per year, as the structure provides less time to offset its environmental impact. Additionally, affordability becomes an issue since the building will serve fewer years to justify its initial investment. Such defects can also pose health hazards if not properly addressed (see Appendix A). While the buildings examined were constructed in 2019 and may not fully align with the definition of "new build," they still provide valuable insights into the quality of recently built housing (site visits commenced on 11 May 2024).


Roof Finish


Cavity Vent


Cavity Vent


Cavity Vent


Roof Finish


Dissapearing dpc

Figure 1 Report

Just a 45-minute walk from this site lies another housing development, located near the Braehead Shopping Centre. This project, constructed by a different developer and likely a separate construction company, reveals further quality issues.

Figure 2 Site Investigation

Figure 3 Uneven Windows-Lentil spacings

In this example, significant gaps were observed between window frames and lintels. Most mastics on the market are designed to fill gaps of 8–15mm; exceeding this width can compromise the material's integrity, causing it to loosen or fall out. Such oversights in material properties mirror the issues in the earlier example, where over half of the sealant applications required repair within five years.

1.6 Summary

Figure 3 Brickwork not lined up

Figure 2 Brickwork not lined up

Examining the current state of delivered housing and considering public opinion on its quality reveals that people's concerns are well-founded. This is further supported by the examples provided earlier. When coupled with the fact that pre-1919 housing accounts for nearly a quarter (23%) of

Glasgow’s available housing stock, it raises the question of whether existing solutions are sufficient to address today’s housing challenges.

Chapter 2 – PERFORM & SUSTAINtecture

2.1 Introduction

Sustainability can also be understood as environmental affordability - the ability to use resources from our ecosystems in ways that allow us to "pay it back," striking a vital balance between human needs and the planet's health. Today, humanity is in significant debt to nature, and the consequences are evident across the globe. Climate change is urging us to act immediately. However, acting immediately does not mean acting in panic or impulsively. We must respond in a coordinated manner, using our collective knowledge and experience to identify the causes and implement solutions to address this crisis.

In architecture, sustainability is often associated with good insulation and the choice of an energy-efficient heating source. Unfortunately, the concept of sustainability extends far beyond these aspects. When considering the sustainability of materials, we often overlook the importance of the lifespan of the final product. Even a house with a reduced carbon footprint may not be sustainable if its lifespan is significantly shortened—something that could happen if inappropriate or faulty solutions are used. On the other hand, the positive impact that well-designed housing can have on the health and well-being of its occupants should not be underestimated. Healthy homes contribute to the individuals who work to address the environmental challenges we face.

A positive shift toward investigating embodied carbon footprints is being brought about by the Net Zero Public Sector Building Standards (Oxford Net Zero, n.d.; Scottish Futures Trust et al., 2021). While these standards are currently voluntary, they are the first to address the regulation of embodied carbon.

The Part Z regulation will be implemented in two phases: the first by 2026, introducing mandatory measurement and reporting of whole-life carbon emissions for projects exceeding 1000m^2 or those creating more than ten dwellings. The second phase, to be introduced by 2028, will establish legal limits on upfront embodied carbon emissions (Part Z, n.d.).

Ultimately, many critical decisions will need to be made by architects, who are responsible for preparing the specifications and proposals for appropriate construction technologies. These early decisions form the foundation for all subsequent work by other specialists.

2.2 Performance Criteria

2.2.1 Introduction

To determine the most optimal technologies for wall construction, the selected technologies will be assessed against multiple criteria. Sustainability is a widely discussed topic across various industries today. Given that the building sector is one of the leading contributors to environmental pollution, it is essential to identify criteria that can influence a building's overall eco-friendliness. These performance indicators play a crucial role in enhancing the sustainability of a building.

2.2.2 Thermal Mass

Thermal mass is highly valued in climates where there is a significant difference between day and night temperatures, as it helps mitigate rapid heat loss (Kendrick et al., 2012). It stores heat energy gained during the day through solar gains and releases it at night, ensuring a gradual and stable temperature change (GreenSpec, 2022). In contrast, thermal mass can also help maintain cooler indoor temperatures during summer heatwaves by absorbing and delaying the effect of external heat. This helps reduce the energy needed for both heating and cooling, improving the overall energy efficiency of a building (Ratio Seven, 2024).

2.2.3 Thermal Transmittance- U-value

The thermal transmittance – U-value is one of the most critical performance parameters. It is expressed in Watts per square meter per Kelvin [W/m2K] and is strictly regulated by the building regulations. To calculate it, the thickness of materials utilised in wall structures needs to be divided by their conductivity (k-value) to achieve the resistance (R-value [K m²/W]) for each layer of different material, if one divided by the sum of resistances with constants of the Ros-Outside surface (0.04 K m²/W) and Ris Inside surface (0.13 K m²/W) resulting in Thermal Transmittance – U-value [W/m2K] (Designing Buildings, 2023; Lymath, 2015).

Resistance of material - R_m

$$\mathbf{R_m = d/k\text{-value}\ [K\ m^2/W]}$$

Thermal Transmitance - Uvalue

$$\mathbf{R_{is}+R_1+R_2+R_3+R\ldots+R_{os}\ [W/m^2K]}$$

Choice of constant U-values

The selection of U-values to compare wall technologies was based on guidelines from the LETI Climate Emergency Guide, Passive House Institute recommendations, and the Building Domestic Handbook (London Energy Transformation Initiative, 2020; Passive House Institute, 2012; The Scottish Government, 2024).

It was decided to achieve the U-values between 0.13 and 0.14 Wm^2K with minimal differences resulting from variations in materiality.

<u>Walls: 0.13-0.14 [W/m^2K]</u>

Const. Door/Window: 0.8 [W/m^2K]

Const. Roof: 0.12 [W/m^2K]

Const. Floor: 0.12 [W/m^2K]

2.2.4 Thermal Bridging and Dewpoints

Thermal bridging and dewpoints are considered ‘silent killers’ in building structures. Their presence can severely impact the integrity of the building and pose safety risks for its occupants. These issues typically arise when the building fabric exhibits increased thermal transmittance, leading to significant heat loss. Such losses not only have financial implications connected to unplanned heat loss, but they can also drastically reduce a building's lifespan, thereby affecting its economic and environmental sustainability.

In some architectural schools in Poland, students are taught not to use internal insulation due to the higher risks of thermal bridges forming or the need for highly skilled builders to achieve acceptable performance levels. Exceptions are made for historic buildings, where aesthetics are important, or recreational structures like holiday homes, where the occupation is not constant. However, it is often observed that historic buildings are more frequently insulated externally, allowing facades to remain architecturally preserved and enhancing their historical and social value within communities.

Boundary Conditions

As presented on the Passive House Resource website by the Passive House Institute (Passive House Institute, 2022), the following boundary conditions for temperature are established:

For component certification, the Passive House Institute uses slightly more stringent temperature conditions:

- **Indoor air temperature (θi)** = 20°C
- **Outdoor air temperature (θe)** = -10°C

Thermal Bridge/Energy Flow Testing Areas

Thermal bridge tests will focus on areas such as the wall corner, wall junction, and wall segment details.

Thermal Bridge Testing Temperatures:

- **External air temperature:** -10°C
- **External heat transfer coefficient:** 24.00 W/m^{2}K
- **Internal air temperature:** 20°C
- **Internal heat transfer coefficient:** 18.00 W/m^{2}K

Environmental Information

The full lifecycle of materials and their environmental impact is considered through standards like **EN 15804**, which looks at Global Warming Potential (GWP) and Ozone Depletion Potential (ODP).

Materials Examples:

- **Timber Frame** – exemplar: Kingspan
- **Masonry Walls** – exemplar: H+H

2.2.5 Lifespan

The lifespan of a building is one of the most critical factors when assessing its economic and environmental affordability. To accurately evaluate these aspects, it is essential to first determine how long the building will remain functional and durable. If one technological solution can last ten times longer than another, it logically follows that it can accommodate ten times more embodied carbon while maintaining a balance. A longer-lasting solution may also come at a higher initial cost, as the payback period extends over a longer time frame.

To determine the expected lifespan of the solutions being evaluated, the key factors that could impact the overall integrity of the building will be identified. These will be based on the lifespan data provided by manufacturers in their environmental performance declarations, particularly focusing on the most vulnerable components of the wall construction (Wood Protection Association, 2021; NHBC, 2024; Certified Commercial Property Inspectors Association, n.d.).

2.3 Environmental Criteria – Indicators

2.3.1 Introduction (EPD, LCA, EPI)

An Environmental Product Declaration (EPD) is a standardised document that follows international standards such as ISO 14025 or EN 15804 (specific to European construction materials) to assess and communicate the sustainability and environmental performance of various materials.

According to ConstructionLCA, a project led by Dr. Jane Anderson during her PhD studies, over 130,000 EPDs for construction products have been identified globally, with more than 40,000 using the EN 15804 standard (ConstructionLCA and Anderson, 2023).

EPD declarations are collected in libraries operated by different organisations, some of which are international bodies like the International EPD System or EPD Ireland, while others are privately managed. Unfortunately, many private companies responsible for these databases fail to comply with one of the key rules of ISO 14025 – ensuring public availability and accessibility. Many databases remain behind paywalls, requiring expensive access fees.

As stated in Section 6.3 Responsibilities of the programme operator, subsection e) of ISO 14025, the programme operator is responsible for administering a Type III environmental declaration programme, which includes maintaining publicly available lists of PCR documents and Type III environmental declarations (International Organisation for Standardisation, 2006). Unfortunately, access to many of these resources is restricted, with some requiring costly software subscriptions, often priced over £6,000, which creates a significant financial barrier for many.

The International EPDR System is a database based on the ISO 14025/EN 15804 standard, designed to standardise the assessment of sustainability and performance for building products. EPDs are based on

Life Cycle Assessment (LCA), which evaluates the environmental impacts of a product from raw material extraction to manufacturing, transportation, use, and disposal. To ensure credibility and transparency, these declarations must be verified by third parties (EPD International, n.d.).

The British equivalent of this database is IMPACT DB, managed by BRE. This database is only accessible through four software programmes, for which prices are not publicly listed. However, IMPACT DB is relatively small, containing around 17,000 datasets (BRE, 2018), compared to EC3, a free, publicly accessible tool that includes 150,000 datasets (Building Transparency, 2024). The downside of the limited access to IMPACT DB is that it contains a substantial portion of British materials.

To evaluate the environmental impact of construction materials used in building projects, several environmental indicators were chosen, including **GWP (Global Warming Potential), AP (Acidification Potential), EP (Eutrophication Potential), POCP (Photochemical Ozone Creation Potential), ADPE (Abiotic Depletion Potential for Elements),** and **ADPF (Abiotic Depletion Potential for Fossil Fuels).** These indicators represent the environmental impact across different areas.

These indicators cover all stages of the product life cycle, which are divided into the following phases:

- Product stage
- Construction process stage
- Use stage – building fabric
- Use stage – building operation
- End of life

Each of these stages is further subdivided into more detailed parts. There is also a stage that shows the potential for reuse, recovery, or recycling, which can help optimise the production chain. However, this paper will focus on the actual environmental impacts rather than on potential that has not yet been fully realised.

2.3.2 Global Warming Potential – GWP

Global Warming Potential (GWP) is an indicator used to measure the greenhouse gas emissions associated with a material or product. It quantifies the impact of different greenhouse gases on climate change, expressing their effect in kilograms of carbon dioxide equivalent ($kgCO_2eq$) to enable easy comparison (A. Vallero, 2019).

The equivalence of common greenhouse gases is as follows (EPD International, 2022):

- **1 kg of carbon dioxide (CO_2)** is equal to **1 $kgCO_2eq$**
- **1 kg of methane (CH_4)** is equal to **29.8 $kgCO_2eq$**
- **1 kg of dinitrogen oxide (N_2O)** is equal to **273 $kgCO_2eq$**

GWP further distinguishes the origins of these emissions into specific categories, including:

- **GWP-fossil**: Emissions from fossil fuel sources
- **GWP-biogenic**: Emissions from biological sources such as organic material
- **GWP-luluc (Land Use and Land Use Change)**: Emissions resulting from changes in land use, such as deforestation or urban development

The total GWP is then calculated as the sum of these three categories, providing a comprehensive understanding of the greenhouse gas emissions associated with a product or material. This differentiation allows for a more detailed analysis of a product's environmental impact, helping to identify key areas for improvement in reducing its contribution to climate change.

2.3.3 Acidification Potential – AP

Acidification Potential (AP) measures the environmental impact of emissions that lead to acid rain and soil acidification. It quantifies the effects of acidifying substances such as sulphur dioxide (SO_2), nitrogen oxides (NO_x), and other acidic pollutants (Dincer and Abu-Rayash, 2020).

Similar to Global Warming Potential (GWP), AP is expressed as kilograms of sulphur dioxide equivalent ($kgSO_2eq$), allowing for the comparison of different acidifying substances.

By standardising the measurement, AP provides insight into the cumulative impact of these pollutants on ecosystems, enabling the assessment of materials and processes for their contribution to soil degradation, water acidity, and harm to plant and animal life. This comparability is essential for identifying more sustainable solutions in construction and manufacturing.

2.3.4 Eutrophication Potential – EP

Eutrophication Potential (EP) measures the environmental impact of nutrient-rich substances that can lead to the excessive fertilisation of aquatic and terrestrial ecosystems. This process often results in the uncontrolled growth of algae and other biomass, which can disrupt ecosystems, deplete oxygen levels in water bodies, and harm biodiversity (Department of Environment, Food and Rural Affairs, 2024).

EP is expressed in kilograms of phosphorus equivalent (kgPeq), standardising the measurement of various nutrient pollutants (Brough and Jouhara, 2020). These include phosphates, nitrates, ammonia, nitrous oxides, and other compounds contributing to nutrient overloading.

By quantifying the effects of these substances, EP serves as a critical indicator for assessing the environmental sustainability of materials and processes, particularly in construction and manufacturing, where nutrient runoff can be a significant concern.

2.3.5 Photochemical Ozone Creation Potential – POCP

Photochemical Ozone Creation Potential (POCP) evaluates the potential of emissions to form ground-level ozone, commonly known as smog. (Brough and Jouhara, 2020). This process occurs when certain pollutants react with sunlight, negatively impacting air quality and human health.

POCP is expressed in kilograms of non-methane volatile organic compounds equivalent (kgNMVOCeq). Key contributors to photochemical ozone formation include sulphur dioxide (SO2), volatile organic compounds (VOCs), and nitrogen oxides (NOx).

By quantifying these emissions, POCP provides an essential metric for understanding and mitigating the environmental impacts of materials and processes that contribute to air pollution and smog formation.

2.3.6 Ozone Depletion Potential – ODP

Ozone Depletion Potential (ODP) measures a substance's ability to degrade the stratospheric ozone layer, which plays a crucial role in shielding the Earth from harmful ultraviolet (UV) radiation (Farinha, de Brito and Do Veiga, 2021).

ODP is quantified in terms of trichlorofluoromethane equivalents (commonly known as freon-11) and is expressed as kilograms of CFC-11 equivalent (kgCFC11eq). This metric helps assess and compare the environmental impact of materials or processes that contribute to ozone layer depletion, aiding in the selection of more sustainable and environmentally friendly alternatives.

2.3.7 Abiotic Depletion Potential for Non-Fossil Resources – ADPE

Abiotic Depletion Potential for Non-Fossil Resources (ADPE) measures the impact of depleting finite, non-living resources such as minerals, clay, and metals (Biron, 2016). This indicator focuses on the over-extraction of these materials, which can lead to resource scarcity and ecological imbalances.

ADPE is expressed in kilograms of antimony equivalent (kgSbeq), a standard metric that enables comparison of the environmental effects of different materials or production processes. By highlighting resource depletion, this metric emphasises the need for sustainable practices in material sourcing and usage.

2.3.8 Abiotic Depletion Potential for Fossil Resources – ADPF

Abiotic Depletion Potential for Fossil Resources (ADPF) assesses the environmental impact of depleting finite fossil-based resources, such as coal, oil, and natural gas (Biron, 2016). Unlike ADPE, which targets non-fossil materials, ADPF emphasises the energy-intensive nature of fossil resource extraction and usage.

This indicator is often associated with energy consumption throughout a product's life cycle and is expressed in megajoules equivalent (MJeq). ADPF serves as a critical measure for understanding the environmental cost of energy reliance and highlights the importance of transitioning to renewable and sustainable energy sources.

2.3.9 Mandatory Disclaimer for Abiotic Depletion Potential (ADPE and ADPF)

The assessment of abiotic depletion, whether for fossil (ADPF) or non-fossil (ADPE) resources, is accompanied by a mandatory disclaimer to ensure responsible interpretation of the results. This disclaimer, required in both Life Cycle Assessment (LCA) reports and Environmental Product Declarations (EPDs), states:

"The results of this environmental impact indicator shall be used with care as the uncertainties of the results are high and as there is limited experience with the indicator." (EPD International, 2022).

This statement underscores the inherent complexities and limited data availability associated with these indicators, reminding users to approach conclusions cautiously and consider additional context when interpreting results.

2.3.10 Embodied Carbon

Embodied carbon is a critical metric calculated for each proposed technological solution. Represented as Global Warming Potential (GWP), it measures the greenhouse gas emissions resulting from material extraction, manufacturing, transportation, and construction processes (Weir, Rempher and Esau, 2023).

To ensure consistent analysis, fixed parameters such as layout and targeted U-values will guide the preparation of material schedules. These schedules enable precise calculations of the total embodied carbon footprint, expressed in kilograms of CO_2 equivalent (kg CO_2eq), for the delivery phase of the building (SE 2050, n.d.).

Additionally, the embodied carbon results will be evaluated against the lifespan of materials as declared in their respective Environmental Product Declarations (EPDs). This comparison allows for an assessment of carbon footprints across the building's entire lifecycle, offering a holistic view of sustainability impacts for different wall construction solutions.

2.3.11 Embodied Energy

Embodied energy calculations follow a similar methodology to those for embodied carbon. It involves summing the total primary energy consumption, which includes both non-renewable primary energy (PENRT) and renewable primary energy (PERT) (EPD International, 2022). These values, originally measured in megajoules per unit (MJ/unit), are converted into megajoules per kilogram (MJ/kg) of material for consistency and comparability.

This approach ensures a comprehensive understanding of the energy demands associated with each material, contributing to a holistic evaluation of sustainability across different wall construction solutions.

Chapter 3 – SELF-BUILDtecture

3.1 Introduction

The term 'self-build' refers to a process where individuals, families, or groups take responsibility for designing and constructing their own homes. This can be achieved either through direct involvement in the building process or by hiring professionals to execute the work. This approach offers significantly more control over the design, materials, and specifications, allowing properties to be fully tailored to meet the specific needs of end-users.

Self-build projects can vary in their approach, including:

- **DIY Self-Build** – The homeowner is directly involved in the construction work, reducing costs.
- **Self-Managed Self-Build:** The homeowner hires and manages a contractor to oversee the construction process, with minimal direct involvement in the building work.
- **Turnkey or Custom-Build** – The homeowner collaborates with a company that manages the entire building process based on the homeowner's specifications (Benson, 2017).

Self-building presents an opportunity to create highly personalised, eco-friendly homes that cater to the unique needs, preferences, and budgets of the most critical stakeholders in the housing sector: the end-users.

However, decades of dissatisfaction caused by the prolonged housing crisis and the delivery of defective or short-lived homes by private companies - 30% of which are publicly funded (Competition & Markets Authority, 2024) - have visibly diminished the architecturally significant role of end-users. This disconnect has further disrupted communities, starting with the fundamental relationship between homes and homeowners.

Self-build projects can address these issues by delivering more end-user-focused homes with better budget control. Furthermore, they have the potential to positively influence local markets. When multiple self-build projects in a given location adopt affordable, sustainable, or location-specific technologies, developers may feel pressured to improve the standards of their own housing offerings.

3.2 Self-Build Organisations

The UK hosts a range of organisations and companies dedicated to supporting self-build projects. These include:

- **Self-Build Portal** – Operated by the National Custom and Self Build Association, this platform offers valuable guidance and resources for individuals embarking on self-build projects.
- **Build It Live** – A triannual exhibition event specifically tailored to the self-build community, providing access to experts, products, and innovative solutions.
- **National Self Build & Renovation Centre (NSBRC)** – A comprehensive research facility offering support with finances, land acquisition, planning permission, design and specification, building control, cost planning, and the construction stage.

Additionally, the UK Government provides official guidance to assist self-builders in navigating the process effectively (The UK Government, 2021; The UK Government, 2016).

3.3 Technologies

Many of the technologies identified by organisations, such as the National Self Build & Renovation Centre (NSBRC), are complex and often require professional expertise. Examples of such technologies include:

- **Timber frame**
- **Traditional masonry**
- **Thin joint masonry**
- **Green Oak frame**
- **Structural straw panels**
- **Structural insulated panels (SIPs)**

These systems demand a higher level of technical skill than the average DIY enthusiast can typically offer.

Other technologies, like **Passivhaus**, are not actually a building system but rather a performance standard. Another example, **Insulated Concrete Formwork (ICF)**, initially appears promising as a DIY-friendly option. ICF systems involve constructing the structure from light, Lego-like Styrofoam blocks, which are then filled with concrete to create a solid, durable framework. However, potential issues with this system will be discussed later in this document, along with other technologies.

Given the vast number of available solutions for wall construction, this document will focus on a select few technologies that have proven to be leaders in the countries where the author has gathered architectural experience. The chosen technologies are:

- **Timber Kit Frame**
- **Thin Joint Masonry with External Insulation**
- **Insulated Concrete Formworks (ICF)**
- **Hempcrete Blockwork**

Chapter 4 – INVESTIGATIVEtecture

4.1 Introduction

The investigation was sparked by observations made by the author regarding various technologies used in buildings intended for residential purposes.

The starting point was two contrasting technologies:

- **Lightweight**, internally insulated timber frame walls, widely used in countries such as Great Britain, Sweden, Canada, the United States, and Australia, cladded with timber siding, stucco, or half-brick on the outside.
- **Medium-weight**, externally insulated aircrete walls reinforced with concrete at each floor level, widely used in countries such as Poland, Germany, the Czech Republic, Slovakia, Hungary, Bulgaria, Lithuania, Latvia, and Estonia.

From an early age, the author observed in Poland that many families built their houses themselves. The main materials used were aircrete or hollow clay blocks (240x240x490 mm), externally insulated with polystyrene boards and finished with render on the outside.

This technology, which emerged in the 1960s, enabled many families to build their own homes. As a result, the architectural landscape was shaped in such a way that by the 2000s, it was rare not to know someone who had built their own house using light- or medium-weight masonry technology.

There are also many contrasting opinions - some criticise timber frame buildings as unsuitable for permanent dwellings, or note the difficulty in finding a skilled workforce to achieve a high-quality build. Others perceive masonry technology as too complex for the average non-professional person.

This dissertation presents a range of information to assess which building methods can benefit different communities and how architectural choices relate to safety, comfort, and practicality.

In this work, different construction technologies are explored, some of which appear simple enough for community-led or DIY construction.

The technologies selected for this study include:

- Lightweight thin-joint masonry

  (Further research on thin-joint masonry was discontinued as biofibre-based materials were identified as potentially offering better environmental performance)

- Insulated Concrete Formwork (ICF)

  (Further research on ICF was discontinued due to concerns regarding internal humidity levels and the requirement for highly skilled professionals)

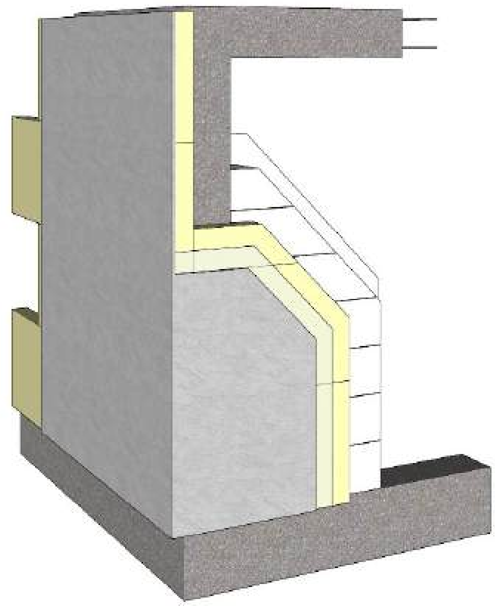
- Timber frame

- Biofibre-based masonry (hempcrete)

Different skillsets

Different communities or groups of people may have varying skill sets available to them. These differences can depend on factors such as group characteristics, regional distinctions, or country-specific experiences. For example, individuals who have experienced a catastrophic event that required community involvement in fixing, repairing, or rebuilding their area are more likely to possess technical skills. These individuals may also have a stronger belief in their ability to achieve their goals.

4.2 Thin-Joint Masonry Aircrete Wall



The thin-joint masonry has been widely used since the 1970s in many European countries. The production process of aircrete blocks requires less carbon, as they are dried in autoclaves rather than being burnt out in kilns. A thickness of 24 centimetres corresponds to a 1 brick thick wall (length-wise), providing better stability of the structure and greater thermal mass.

The porous structure of the block is achieved through the use of aluminium granules, which interact with the chemical properties of lime, creating tiny air bubbles during the production process.

The most common insulation method for this technology is Expanded Polystyrene (EPS), which is a highly effective insulator with virtually zero moisture absorption, allowing the wall to remain dry (British Plastic Federation, 2024). However, its extremely slow degradation process (Mendiola, n.d.) raises concerns about long-term sustainability.

When constructed properly, buildings using this technology can achieve a lifespan of at least 60 years.

The construction process itself is relatively simple, and many low-skilled workers can be trained within a week to build and insulate the walls. However, it should be noted that the external finishing layer should be applied by a professional company, which can provide both warranty and ongoing maintenance.

While this technology offers potential benefits, the production of all materials involved is controlled by specialised companies competing to enhance product performance. This introduces complexity into the supply chain and makes it impossible to reproduce the building material on-site. Construction becomes increasingly dependent on the quality and geographic location of the manufacturers. Moreover, mass production requires heavy machinery, which emits a high carbon footprint. Large-scale manufacturing can also result in reduced quality control.

However, there is now growing knowledge on how DIY aircrete blocks can be made more affordably and closer to home, making them more accessible to those with limited financial resources. (Bb Amazing Skills, 2023)

Pros	Cons
Larger block size significantly reduces the labour required during the building process, streamlining construction and saving time.	Expanded Polystyrene harms the environment and is not biodegradable.
EPS acts as a water-resistant material, blocking all possible moisture from penetrating the wall.	Complex manufacturing process
High thermal mass retains warmth, making internal temperatures more stable.	
Stable indoor temperatures help to dry out any excessive moisture, as the walls are warmer.	

4.3 Insulated Concrete Formwork (ICF)

Unfortunately, Insulated Concrete Formwork (ICF) does not perform as well as many people expect. The Lego-like building blocks may seem relatively easy to construct; however, the entire assembled “form” must be filled with concrete (Allan Corfield Architects, n.d.). While the building process may appear straightforward, it is critical because every piece must fit perfectly. If the form is not connected properly, it can fail, potentially resulting in concrete spillages (Pro Crew Schedule, 2021).

ICF also presents material-related issues. Polystyrene, being a low vapour-permeable material, is used on both the internal and external sides of the wall, which can lead to the accumulation of moisture and humidity. These problems are more common in drier, warmer climates than in Scotland. As a result, the decision was made to discontinue the investigation of this technology.

Pros	Cons
Improved structural integrity due to the use of a foundational reinforced concrete wall.	Poor performance in low temperatures.
Conserves energy and improves indoor air quality.	Higher costs due to the need for specialised labour.
Cost-efficient in terms of materials.	Prone to indoor humidity issues.
Reduced setup time.	Releasing the ICF too early may lead to structural issues.

4.4 Timber Frame Wall

Construction Difficulty:	5/5
U-Value:	0.132 Wm^2K
Thermal Mass:	LOW
Wall Thickness:	296mm

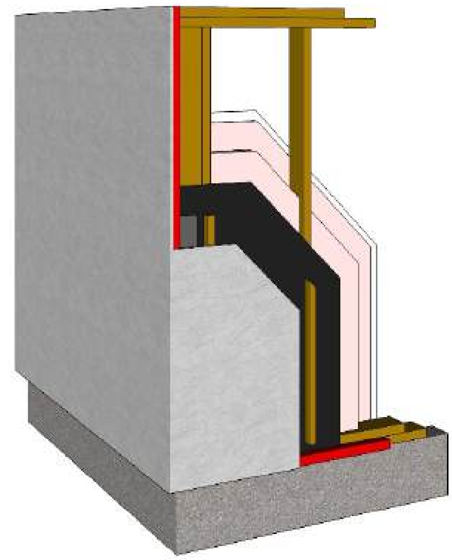


Figure 4 Timber Frame Wall

Environment

Lifespan:	30 years *see 4.4.4
Embodied Carbon Footprint: (walls only)	84,5 $kgCO_2/m^2$ 5990 $kgCO_2/70{,}9m^2$
CO_2 emissions:	28,34 $kgCO_2/m^2a$
Total:	2009,3 $kgCO_2/a$
Total – Lifetime:	60 279,18$kgCO_2$ (WEC*+OE*)

*WEC - Wall embodied carbon *see 4.4.4

*OE - Operational emissions *see 4.4.5

Pros	Cons
Efficient and time-saving construction process, allowing for faster project completion.	Highly complex construction process, requiring the expertise of skilled professionals.
Lightweight and easy to handle, reduces foundation costs.	Susceptible to rot, particularly in environments with high moisture levels or poor ventilation.
Energy-efficient due to excellent insulation and airtightness.	The lifespan can be significantly reduced if materials are poorly chosen, lack durability, or if the assembly process is improperly executed.
	Fire risk due to combustible material; may lead to higher insurance costs.
	Weaker than masonry; often requires additional materials for sound insulation.
	Less suitable for tall or heavy-load buildings.
	Weather sensitive due to timber warping or shrinking with humidity and temperature changes.
	Requires additional treatments to prevent decay and pest damage.

4.4.1 Overview

Timber frame technology is recognised by the NSBRC as one of the self-build methods and is widely used in housing developments. This light-weight construction method relies on timber frame studs (75mm, 100mm, or 150mm x 50mm) positioned vertically at 600mm intervals, with the gaps infilled with insulation materials such as mineral wool, glass fibre, or organic fibre.

Figure 5 Timber Frame Wall Construction

To achieve the required U-value, phenolic insulation is added to the plasterboard and reinforced with an additional plasterboard layer on the habitable side. On the exterior, the timber frame and insulation are enclosed with a 9-12mm thick OSB sheet and sealed with a breathable membrane. A 50mm cavity is left, which must be secured with a set of firestops (50mm x 50mm timber or fibre). The wall can then be finished in various ways, such as:

- **Half a brick wall** tied to the timber frame with provision for wall vents to provide sufficient ventilation of cavity.
- **Half a brick wall (rendered)** tied to the timber frame with provision for wall vents to provide sufficient ventilation of cavity.
- **Timber siding (rendered)** fixed to the timber frame with provision for wall vents to provide sufficient ventilation of cavity.
- **Render on carrier boards** fixed to the timber frame with provision for wall vents to provide sufficient ventilation of cavity (rendered).

4.4.2 Floor Plans

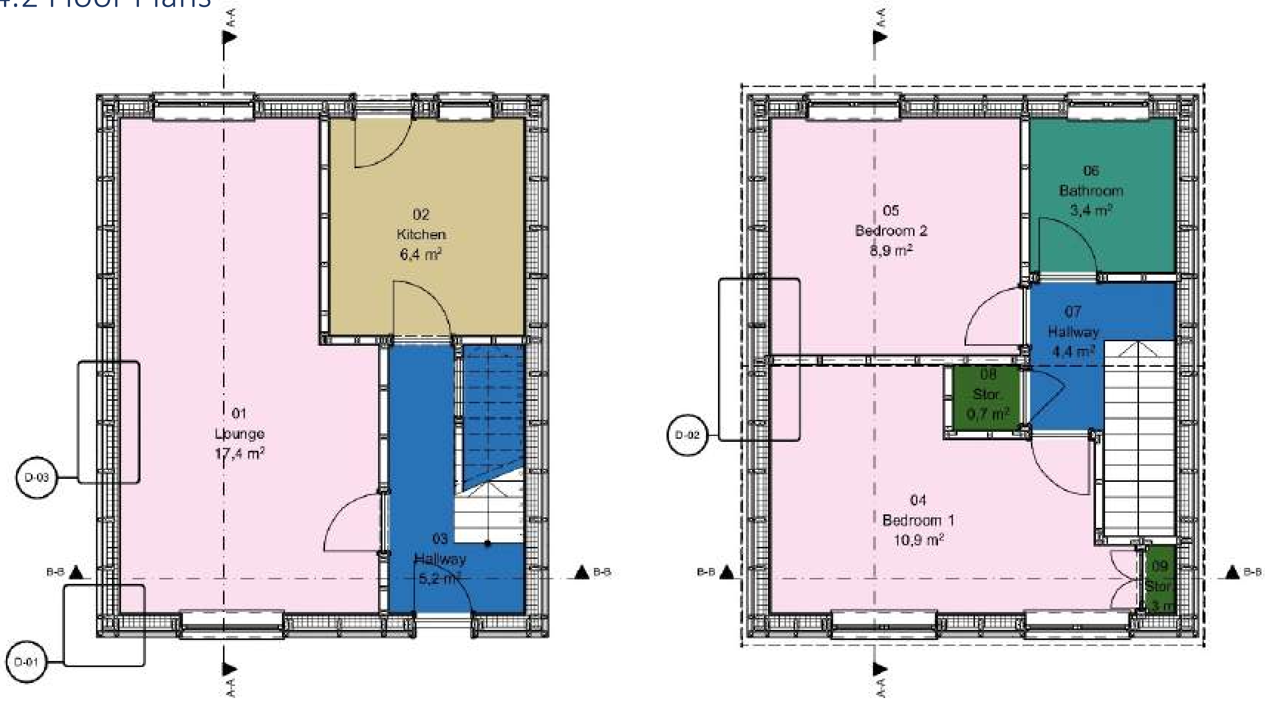
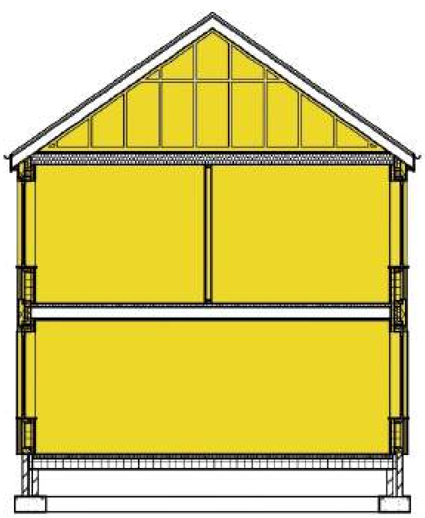


Figure 6 Timber Frame Wall Floor Plans

4.4.3 Sections



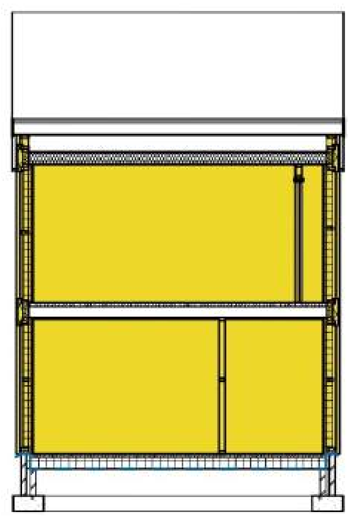
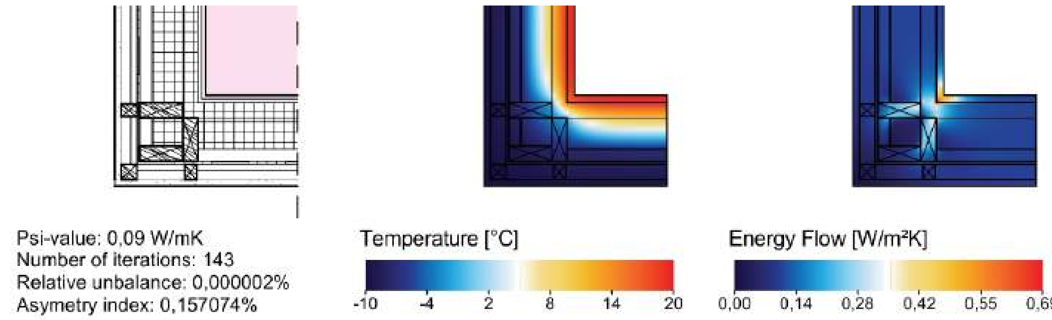


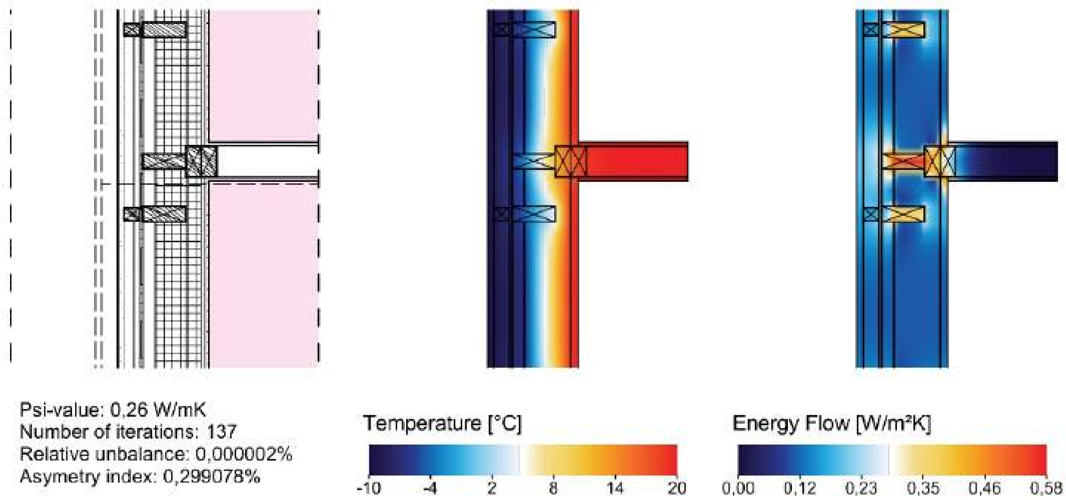
Figure 7 Timber Frame Wall A-A Section

Figure 8 Timber Frame Wall B-B Section

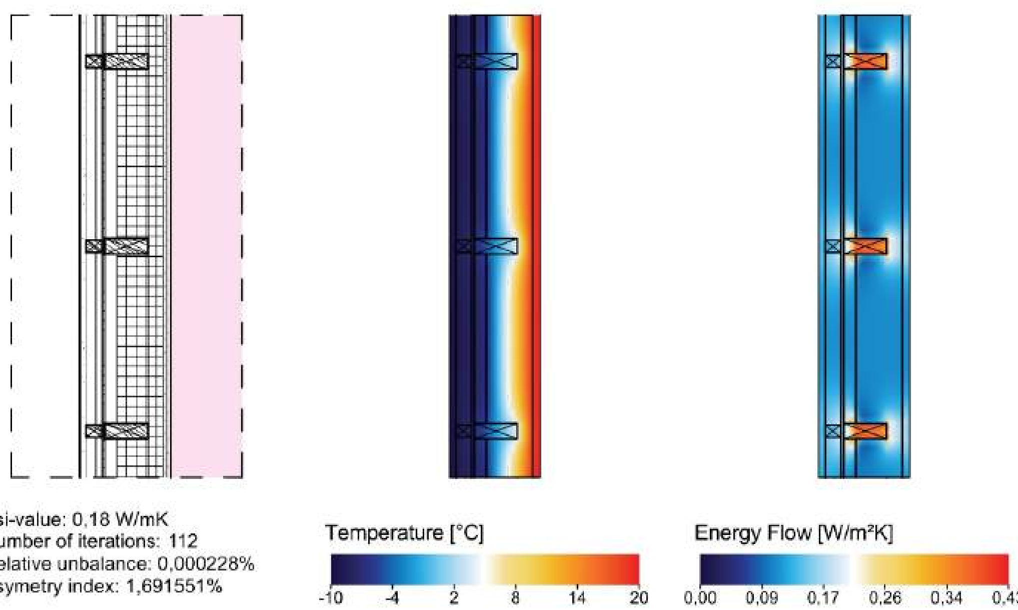
4.4.4 Simulation of Thermal Bridging and Energy Flow



Detail D-01



Detail D-02



Detail D-03

Figure 9 Timber Frame Wall – Simulation of Thermal Bridging Archicad 26

4.4.5 Wall Components and Environmental Impact

As presented in the Appendix 2.2 – *Timber Frame Wall Material Schedule*, the weakest element in terms of lifespan is the Rainproof -Tyvek membrane, with a service life of only 30 years. This element is crucial for protecting the timber frame from bad weather conditions. Its absence or loss of integrity can lead to rapid absorption of water vapour from the external environment. Increased moisture within the timber frame and insulation drastically reduces thermal performance and accelerates the deterioration process.

While this membrane can be monitored and maintained in projects where the external finish is removable (e.g. timber siding), it becomes inaccessible in constructions with fixed finishes, such as half-brick cladding or rendered walls. In such cases, any failure in the membrane would require partial demolition of the external wall to address the issue.

The limited lifespan of this single element ultimately reduces the overall durability of the wall structure, raising concerns about long-term feasibility — both for occupants who will live in and pay for such homes, and for environmental sustainability. Due to this "bottleneck effect," it is essential that environmental criteria (GWP, AP, EP, POCP, ODP, ADPE, ADPF) are calculated based on the component with the shortest lifespan. After this point, the structure should be expected to begin deteriorating.

The material schedule also enabled the calculation of embodied carbon and embodied energy, with particular emphasis on materials used in wall construction.

4.4.6 Wall Performance Evaluation

Wall performance evaluation is presented in Appendix 2.3, which provides a calculation of the building's annual energy consumption based on this construction technology, in order to determine operational emissions. According to the document, the building requires 10255 kWh/a/a of primary energy, of which 3446 kWh/a is covered by heat gains, resulting in a needed quantity of 6802 kWh/a. A dwelling delivered in this technology would generate 1470 kgs of CO_2 annually if it were gas-heated.

4.5 Hempcrete Wall

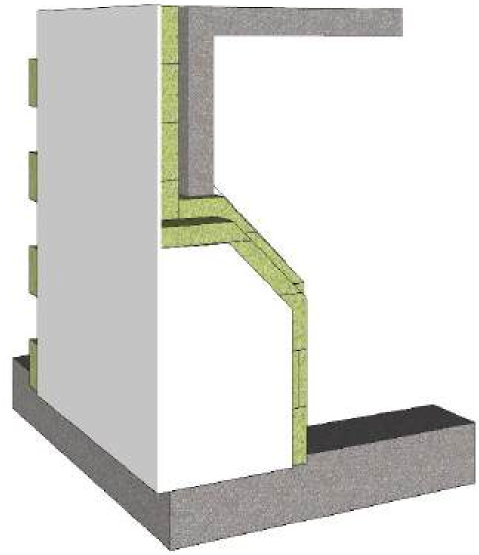


Figure 12 Hempcrete Wall

Construction Difficulty:	3/5
U-Value:	0.133 Wm^2K
Thermal Mass:	Medium
Wall Thickness:	590mm

Environment

Lifespan:	100 years*
Embodied Carbon Footprint:	-8,6 $kgCO_2/m^2$
(walls only)	-809 $kgCO_2/93{,}9m^2$
CO_2 emissions:	27,33 $kgCO_2/m^2a$
Total:	2566,3 $kgCO_2/a$
Total - Life Time	256 628,7 $kgCO_2$ (WEC*+OE*)

*WEC - Wall embodied carbon

*OE - Operational emissions

Pros	Cons
Larger block size significantly reduces the labour required during the building process, streamlining construction and saving time.	Requires an additional load-bearing structure.
Easy to build as more manufacturers now offer Lego-like shaped blocks for simplified construction.	Requires thicker walls to achieve optimal U-values compared to other materials.
Breathable material regulates indoor humidity and helps prevent mould growth.	As a relatively new technology with limited supply, material costs may become disproportionately high compared to production costs.
The alkaline nature of lime prevents from possible viral/bacterial/fungal growth.	
Can achieve a significantly longer lifespan than, for example, a timber kit frame wall.	
Made from renewable and carbon-sequestering materials.	

4.5.1 Overview

Hempcrete is a bio-composite material made by mixing hemp shiv (the woody core of the hemp plant) with a lime-based binder and water. Hempcrete blocks are prefabricated in various sizes; for the purposes of this test and to achieve the desired U-values, blocks 360mm thick and 200mm wide were selected.

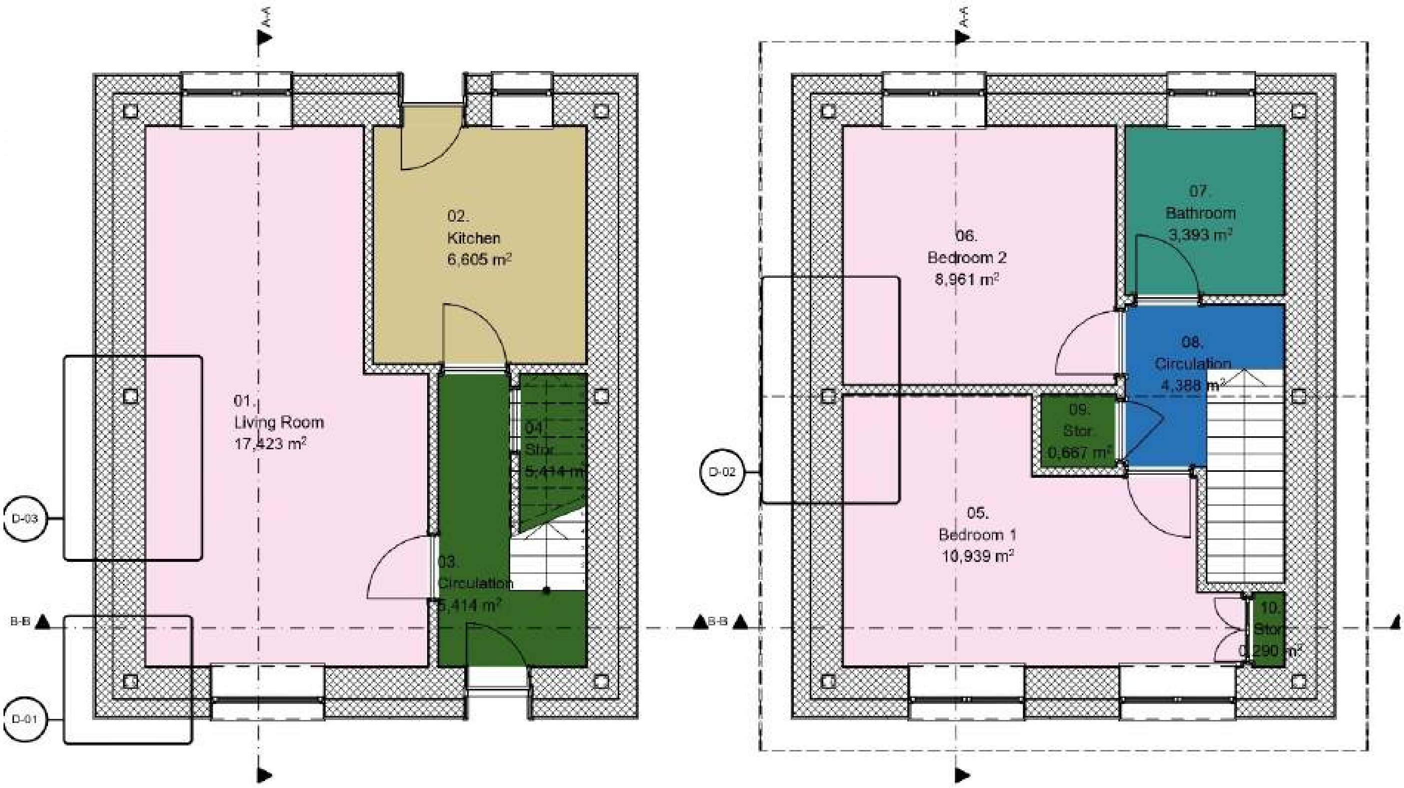
Hempcrete is renowned for its exceptional sustainability, as it absorbs more carbon dioxide during the hemp plant's growth than is emitted during production. These blocks offer both insulation and moderate thermal mass, creating a comfortable indoor environment with reduced heating and cooling needs. Hempcrete blocks can also accumulate humidity, which influences the overall thermal capacity of the wall. In winter, this can help maintain a stable temperature in the dwelling.

Construction Process:

- **Foundation**: A stable and waterproof base is required to prevent moisture ingress.
- **Installation**: Blocks are laid in a staggered bond using natural lime mortar to ensure breathability.
- **Finishing**: Exterior surfaces can be finished with lime render or breathable cladding to preserve the material's vapor-permeable properties.
- **Interior**: Can be finished with plaster or left exposed for a rustic aesthetic.

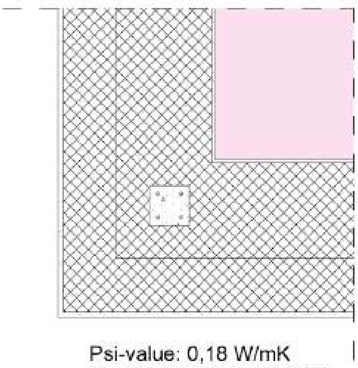
Hempcrete is particularly well-suited for sustainable and energy-efficient housing, offering excellent indoor air quality and thermal comfort. While it requires careful planning to accommodate features such as thicker walls and curing times, it provides long-term environmental and performance benefits.

4.5.2 Floor Plans

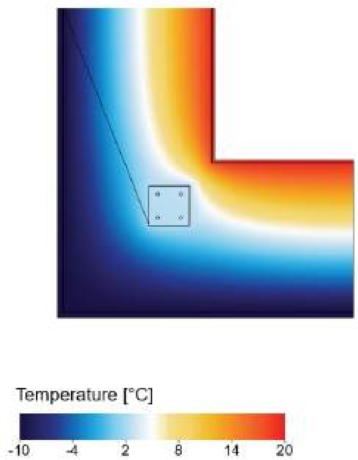


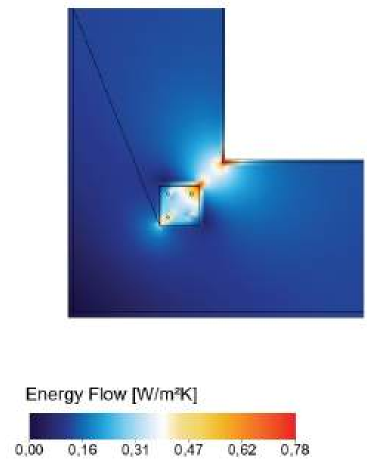
4.5.3 Sections

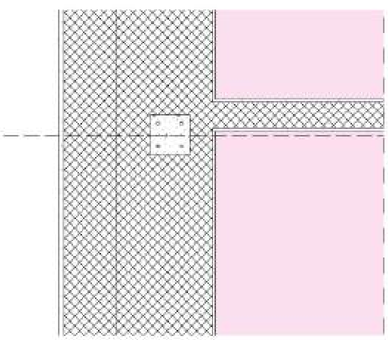
4.5.4 Simulation of Thermal Bridging and Energy Flow



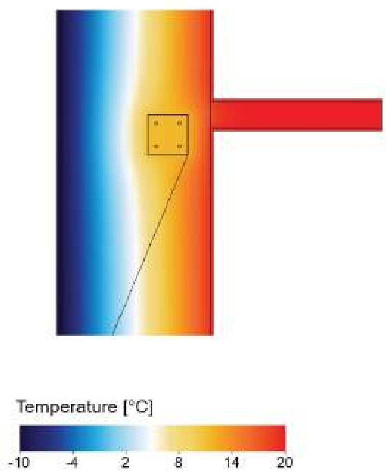
Psi-value: 0,18 W/mK
Number of iterations: 1895
Relative unbalance: 0,000070%
Asymetry index: 0,190333%

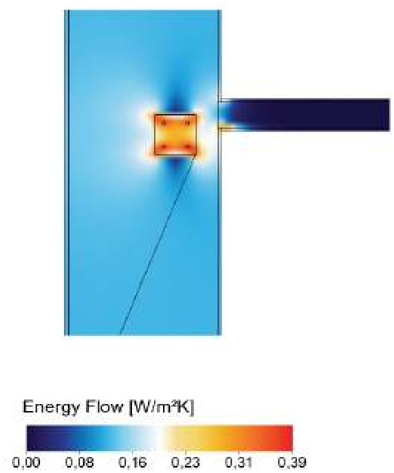


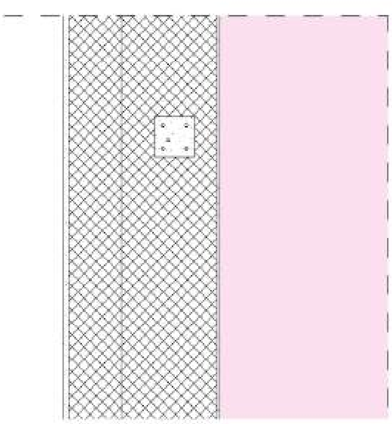




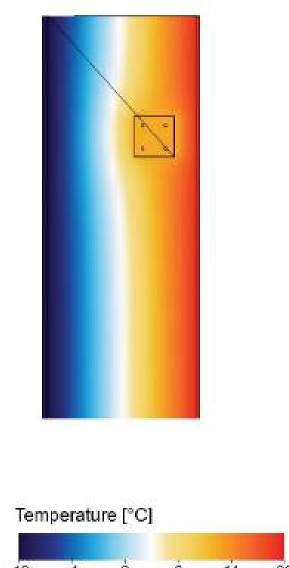
Psi-value: 0,31 W/mK
Number of iterations: 201
Relative unbalance: 0,000080%
Asymetry index: 0,005047%







Psi-value: 0,29 W/mK
Number of iterations: 320
Relative unbalance: 0,000024%
Asymetry index: 0,191315%



4.5.5 Wall Components and Environmental Impact

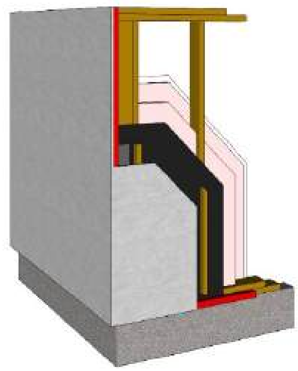
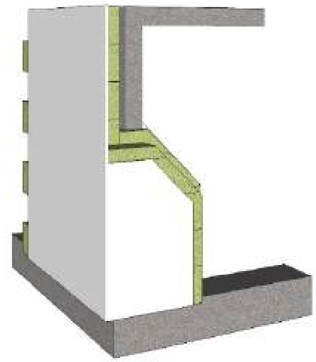
As presented in Appendix 3.2 – *Hempcrete Wall Material Schedule*, the weakest element in terms of lifespan is the lime render used for both external and internal finishes. Unlike the example previously discussed, this element functions as a surface finish and can be repaired or replastered without significant intervention into the wall structure. The remaining materials have a lifespan of approximately 100 years, meaning the load-bearing structure could, in practice, last nearly three times longer than the render.

It is also important to note that any required load-bearing columns should be reinforced with anti-corrosion-painted steel and poured out of concrete. This seals the steel from exposure to oxygen, preventing potential oxidation and ensuring structural integrity.

4.5.6 Wall Performance Evaluation

The wall performance evaluation, attached as Appendix 3.3, includes the calculation of annual energy consumption for a building constructed using this technology, in order to estimate operational emissions. According to the document, this building requires 11781 kWh/a of primary energy, of which 3775 kWh/a is covered by heat gains, resulting in a needed quantity of 8006 kWh/a. If heated with gas, a dwelling built with this technology would emit 1729 kg of CO_2 annually.

4.6 Timber-Hemp Comparison

		
	Timber Frame Walls	Hempcrete Walls
General Information:		
Life span (years):	30	100
Gross Floor Area (m^2):	70,9	93,93
Treated Floor Area (m^2):	57,6	63,49
Wall Thickness (mm)	296	590
Embodied Carbon:		
Embodied Carbon - walls only ($kgCO_2/m^2$)	84,5	-8,6
Embodied Carbon - walls only ($kgCO_2$)	5990	-809
Energy Consumption:		
Primary Energy (kWh/a):	10255	11781
Thermal Gains (kWh/a):	3446	3775
Quantity (kWh/a):	6806	8006
CO2 emissions (kg/a)	1470	1729

5. Open Discussion

5.1 Role of vertical ventilation with directional flue

Building (Scotland) Regulations Mandatory Standard 3.14.0 states:

'Every building must be designed and constructed in such a way that ventilation is provided so that the air quality inside the building is not a threat to the building or the health of the occupants.'

The National Air Duct Cleaners Association recommends that air ducts be cleaned every three to five years to maintain system efficiency and prevent the accumulation of dust and allergens in the home's air.

The inspected housing development on New Harbour Way serves as an excellent example of the necessity for regular ventilation inspections. A brief conversation with the tenants, who have lived there since the building was erected, revealed that they do not recall any inspection being conducted on the ventilation system. The current appearance of the extract fans for the bathrooms and kitchens is documented below.

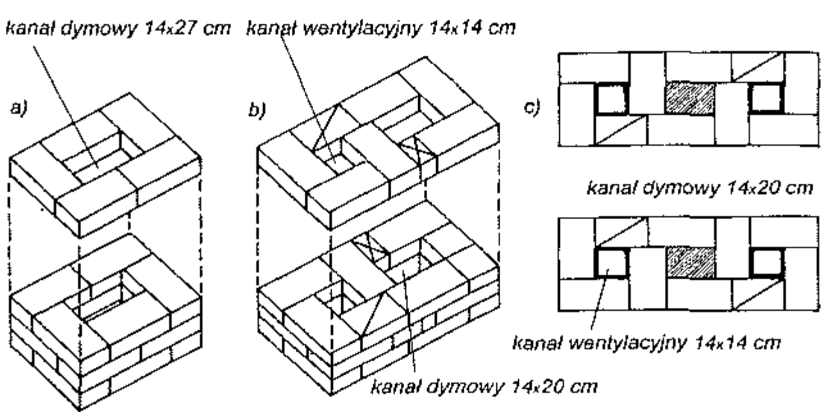
As mechanical extractor fans are typically installed in rooms with higher temperature and humidity levels, they extract stale air filled with indoor pollutants, human skin, and fibers, creating a perfect environment for bacteria, fungi, and other microorganisms to grow.

A significant issue for these systems is the strong gusts of wind commonly experienced in Scotland. If the terminal lacks proper shielding, there is a risk of external air being pushed back into the habitable space, bringing with it the microorganisms living in the ducts, creating a biohazard and violating the aforementioned standard.

The ventilation standard also mentions stack ventilation, which is widely used in European countries. This system typically begins at the floor level it serves and provides a horizontal path for stale air to escape, terminating through the roof with a directional flue that is always aligned with the prevailing wind direction.

At first glance, it may seem that ventilation is unrelated to the choice of wall technology. However, this is not the case, as different wall technologies can provide varying thermal mass and moisture capacity. Walls with high thermal mass will retain warmth for longer, allowing excessive moisture to evaporate. A more stable indoor temperature helps maintain a consistent relative humidity level, as lower temperatures reduce the air's capacity to hold water.

Before the advent of thin masonry technology, ventilation, smoke, and exhaust stacks were often integrated into the wall and made from bricks. This solution took advantage of the stack effect to continuously extract stale air and trap pollutants without allowing them to be pushed back into the habitable areas.



Today, with the use of aircrete blocks, these stacks have transitioned from heavy bricks to lighter aircrete stack blocks. Enclosed within the wall, these blocks offer an effective ventilation solution with excellent fire resistance, reducing the need for intumescent strips or other fire sealants as they do not interfere with other spaces.

5.2 Heat and water vapour capacity

A double layer of plasterboard may not provide sufficient thermal mass or water vapour capacity, as evidenced in the photograph taken. The area surrounding the window opening appears visibly swollen due to water condensation. This effect likely results from either insufficient drying time for the wall or rapid heat loss, which prevents moisture from evaporating. Another possible cause is an uncontrolled draught, introducing excessive cold air and making it difficult for the wall to release moisture. Further evidence of this issue can be observed at the cold air outlet in the corner of the corridor wall leading towards the exit.

Swollen walls

Swollen walls

5.3 Timber humidity in humid countries vs less humid

Temperature and humidity should be under strict control, especially for timber-based structures in countries with a humid environment. According to the standards, the moisture level for structural timber is increased from 12% to 20% for countries with a more humid climate (e.g., the United Kingdom). As far as it seems to be reasonable for the timber materials used externally. It needs to be remembered that the timber frame in the wall is supposed to be weather-sealed with the use of a rainproof membrane. Also, all structural timber, both for wall and floor construction, is partially placed on the warm side of the building's envelope. As in the energy flow simulation (see 4.4.4), timber studs are the elements exposed to the biggest energy flow. According to Wood4Floor, which identifies the equilibrium moisture content at 20 °c as 9.3% (Wood4Floors, 2021). This means that if timber used internally has 20% of moisture content, it will dry out to achieve the value of 9.3, causing the possibility of shrinkage. Such an occurrence can disintegrate the wall by exposing sealants and potentially creating gaps, which later can be a starting point for further wall deterioration, leading to structural failure.

5.4 Common staircase often not heated,

During previous studies, 5A which were focused on the existing pre-1919 housing stock and which mentioned the negative impact of cold temperatures within the common staircase resulting in the dewpoint being created in the wall between bathrooms and the staircase.

Similar problem appears in the 2019-built dwelling. Because each flat has its own source of heating (gas boiler) the staircase is becoming a no-man's land with a single glazed entrance door becoming the coldest internal part of the whole building. Let' please come back to point 5.2 and lets recreate the route of incoming fresh air. Yes if we consider privileged wind, we can see the whole fresh air incoming through windows pushes out stale air from the flats to the common area. Together with the lowering temperature the moisture capacity of air decreases, physically forcing water to end up on walls. Good evidence of it waits on the stair landing where the concrete stair structure forms additional thermal bridge, resulting in visible black mouldy spots, or on the entrance's soffit where the stale air finally terminates its journey.

5.5 Leśniowksi's- Crohn's Disease and the Impact of Timber Construction, Humidity, and Ventilation

The presence of pink or reddish mould-like growth in humid indoor environments, particularly in areas like bathrooms or kitchens, is widely recognised (Webb, 2022). Often attributed to Serratia marcescens, this bacteria is typically considered harmless in many sources, including construction-focused platforms and even Forbes (Simon, 2022; Young, 2023; Hygiene Pro Clean, 2023; ACo, 2024; Nazzaro, 2019).

'Red mold' - Serratia marcescens

Figure 14 Serratia marcescens

However, medical research presents a different perspective, identifying *Serratia marcescens* as a significant cause of invasive infections in neonatal intensive care units, with high morbidity and mortality rates (Northern Ireland Ambulance Service, 2024). Notably, this bacteria has been found in the gut microbiota and fungal communities of patients suffering from Leśniowski-Crohn's Disease (LCD), and is known to interact with fungi like *Candida tropicalis* and bacteria such as *E. coli*, forming biofilms that are far more problematic than those formed by single or double-species microbes (Lichtarowicz and Mayberry, 1988; Hoarau et al., 2016).

While the connection between these health concerns and the built environment may not be immediately apparent, there are noteworthy patterns. When looking at the worldwide incidence map of Crohn's disease, we observe that the biggest problems are in countries where the most common technology choice for houses is timber-framed buildings. For instance, regions with high incidences of Crohn's disease, such as Canada, the United States, Japan, New Zealand, and Australia, predominantly feature timber-framed housing, a construction method used in more than 70% of the population's homes in these areas. In Canada and the United States, the timber-frame method is used in 90% of low-rise constructions (Husline JSC, 2024). Much lower rates of the disease are shown in countries with dry climates and where building technologies use materials of higher thermal mass, like rammed earth or earth-connected technologies in Southern Asia (Mehjabeen Ratree, Farah and Shadat, 2020).

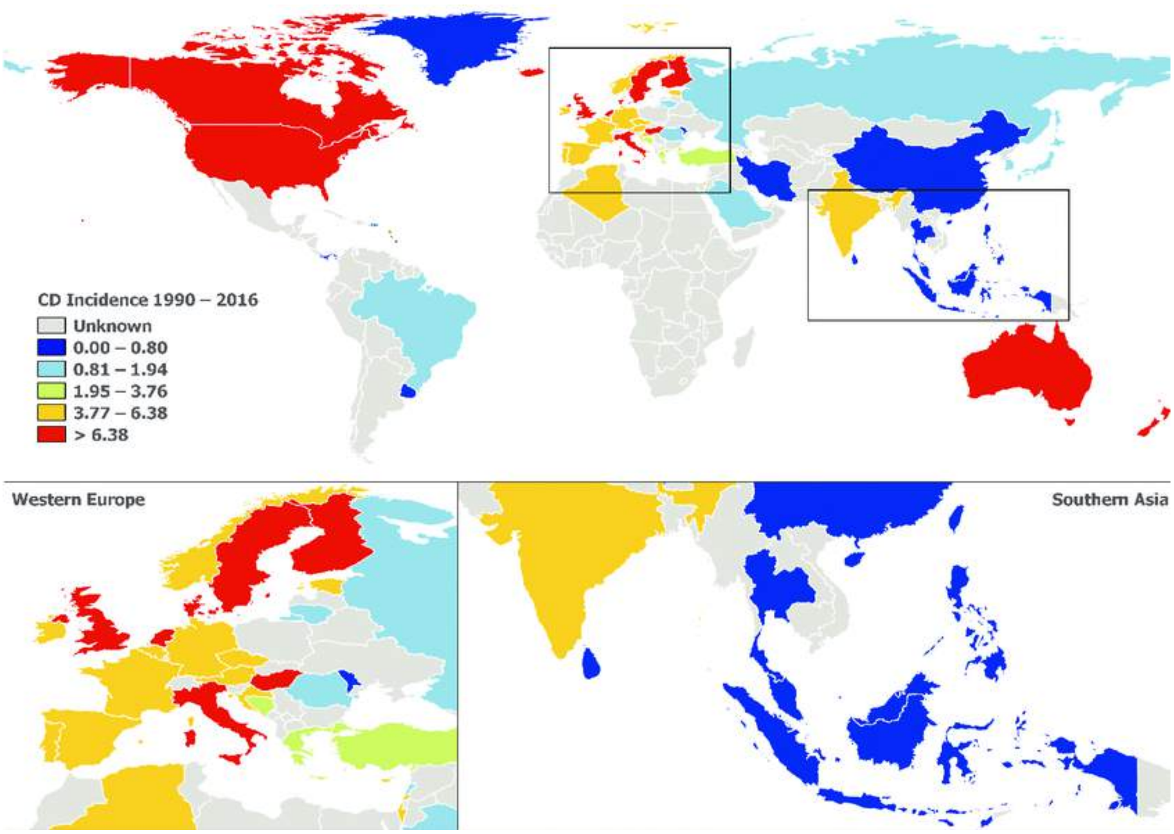


Figure 15 Worldwide incidence of Crohn's disease stratified from low to high incidence (per 100,000)

A publication from Edinburgh University states that the world's highest rate of Crohn's disease is 322 per 100,000 people in Hesse, Germany (The University of Edinburgh, 2019). This region also has a significant architectural history connected to timber-frame technology. It is home to the oldest timber house in Germany, Römer 2-4-6, constructed in 1289 and now a historical monument of Hesse. This region is also located at the junction of three different regional sections of the German Timber-Frame Road, which connects over 100 timber-framed towns that created the "Timber-framed houses unite" network (Deutsche Fachwerkstrasse, 2024). Because many timber buildings are prevalent in this region's historical context, developers often justify the proposal for newly built houses using timber-frame technology.

These observations point to the potential link between the growth of hazardous microbiomes in timber-framed buildings and the incidence of chronic diseases like LCD. Further research is necessary to explore the impact of light construction technologies, like timber-frame houses with low thermal mass, on indoor air quality and the potential health risks posed by mould and bacteria growth. Given the increasing cases of LCD, it is imperative to investigate whether the built environment, especially in timber-frame homes, could contribute to the development of this disease and other health issues, as these buildings expose inhabitants to various pollutants and pathogens over prolonged periods.

6. Conclusions

Both Timber Frame and Hempcrete technologies are coming back from ancient times, with examples dating back over a thousand years. While both materials are bio-based, trees require significantly more time to grow and reach their optimal carbon sequestration capacity. In contrast, hemp is a seasonal plant that, if not harvested and used, will decompose through dry or wet rot, releasing the carbon it previously sequestered. The production of hempcrete captures this carbon in the form of a durable building material, effectively storing it for decades. Hempcrete is also fire-resistant, making it an excellent choice for protecting elements such as steel structures from extreme temperatures.

This document highlights the importance of considering the overall lifespan of a building. Unlike the assumptions made by Mesh Energy, where all wall technologies are evaluated over the same 60-year lifespan, such an approach can misrepresent the real-world durability and environmental impact of considered systems. (Mesh Energy, 2020)

Unfortunately, there is little point in introducing new technologies if we still fail to understand the old ones. A clear example of this is the introduction of reinforced autoclaved aerated concrete. As the basic principles of porosity, breathability, and the alkaline properties of the aerated concrete are already known, it is hard to understand how this material and idea had even appeared. These failures of several public buildings, which also serve the youngest community members should not happen, and there is no doubt that they should be foreseen. Structural steel, for instance, requires protection from water, and is therefore commonly encased in concrete and before it's painted with anticorrosive, where both paint and concrete act as a sealant against environmental degradation.

Today, we continue to see buildings being constructed in ways that disregard long-established principles. Before we move forward with new technologies, we must properly understand and apply existing knowledge.

Based on the findings presented in this dissertation, it is recommended to prioritise long-lasting technologies to minimise recurring labour costs, such as those associated with systems requiring major interventions every 30 years (e.g. timber frame). Additionally, the use of nature-based materials should be maximised to enhance sustainability and reduce environmental impact, but we need to respect the natural cycle and provide it enough time to grow to make it sustainable, not only for the purpose of greenwashing.

A lot of possible harmful substances urge us to put more control on publicly funded developments. As far as monitoring each possible indicator could be too much, monitoring temperatures and humidity levels in specified corners of the researched rooms could alert and bring faster reaction times for intervention.

We cannot require regular citizens to have the same knowledge about buildings as construction engineers or architects. However, we should consider the possibility where buildings are equipped with devices to measure humidity levels and temperatures, and offer the possibility of mechanical ventilation to operate in a way to find the perfect balance between temperature and air exchange. Such solutions would eliminate the possibility of the growth of any harmful organisms for human beings.

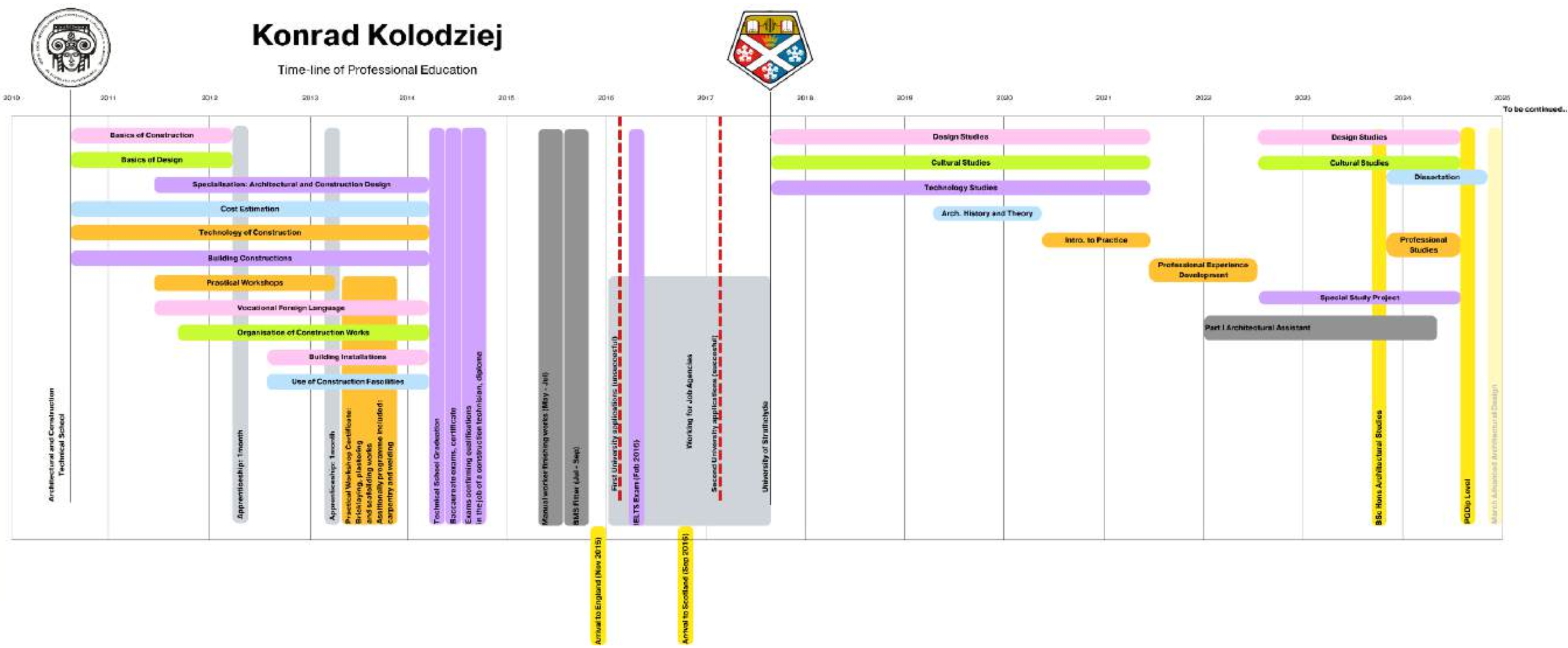
About the Author

I am a fifth-year Master's student in Architecture at the University of Strathclyde, with a passion for creating sustainable and accessible housing solutions. My dissertation focuses on self-build systems using carbon-free materials and simple construction techniques that can be implemented by untrained individuals. This interest stems from personal experiences living in poor housing conditions and observing the negative impact that poorly constructed new builds have on communities.

I completed an Architectural-Constructional technical school in Warsaw, where I gained foundational knowledge in architectural design, building construction, and material science. Currently studying in Scotland, I am exploring diverse architectural approaches and challenges, which have deepened my understanding of how materials like hempcrete can play a crucial role in addressing housing issues sustainably.

Konrad Kolodziej

Time-line of Professional Education



References

A. Vallero, D. (2019). *Global Warming Potential - an overview | ScienceDirect Topics*. [online] www.sciencedirect.com. Available at: https://www.sciencedirect.com/topics/earth-and-planetary-sciences/global-warming-potential

ACo (2024). *ACo*. [online] ACo. Available at: https://liveaco.com/pink-mold/.

Allan Corfield Architects (n.d.). Building With Izodom ICF Technology – With Econekt. [online] Building With Izodom ICF Technology – With Econekt. Available at: https://acarchitects.biz/self-build-blog/blog-self-build-eco-home-izodom-icf-econekt

Bb Amazing Skills (2023). Amazing process of making foam concrete blocks | production of foam blocks with subtitles. [online] YouTube. Available at: https://www.youtube.com/watch?v=-h6zBbVkuQI

Benson, M. (2017). *Self-build homes: social discourse, experiences and directions*. [online] London: University College London Press. Available at: https://muse.jhu.edu/book/81976/

Biron, M. (2016). Environmental Impact of Renewable Plastics: Pros and Cons, Indicators. In: *Industrial Applications of Renewable Plastics*. [online] William Andrew Publishing, pp.437–461. doi:https://doi.org/10.1016/B978-0-323-48065-9.00007-8

BRE Global (2018). *BRE Global Product Category Rules (PCR) For Type III EPD of Construction Products to EN 15804+A1*. [online] BRE EN 15804 PCR PN 514 Rev 2.0. Available at: https://www.greenbooklive.com/filelibrary/EN_15804/BRE-EN-15804-A1-PCR-PN-514--Rev-2.0.pdf

Brough, D. and Jouhara, H. (2020). The aluminium industry: A review on state-of-the-art technologies, environmental impacts and possibilities for waste heat recovery. *International Journal of Thermofluids*, 1-2. doi:https://doi.org/10.1016/j.ijft.2019.100007

Building Transparency (2024). *EC3 - Building Transparency*. [online] Building Transparency. Available at: https://www.buildingtransparency.org/tools/ec3/

Certified Commercial Property Inspectors Association (n.d.). *Estimated Life Expectancy Chart for Commercial Building Systems and Components - CCPIA*. [online] Certified Commercial Property Inspectors Association. Available at: https://ccpia.org/estimated-life-expectancy-chart-for-commercial-building-systems-and-components/

Climate.OneBuilding (2024). *Repository of Building Simulation Climate Data*. [online] climate.onebuilding.org. Available at: https://climate.onebuilding.org/

Competition & Markets Authority (2024). *Housebuilding Market Study - Final Report*. [online] *Housebuilding Market Study - Final Report*, Competition & Markets Authority, p.9. Available at: https://assets.publishing.service.gov.uk/media/65d8baed6efa83001ddcc5cd/Housebuilding_market_study_final_report.pdf

ConstructionLCA and Anderson, J. (2023). *ConstructionLCA - Almost everything you want to know about EPD, LCA and buildings, embodied energy and the CEN/TC350 standards*. [online] ConstructionLCA. Available at: https://constructionlca.co.uk/

Cousins, S. (2021). *'Part Z' embodied carbon cap tabled by industry group*. [online] www.ribaj.com. Available at: https://www.ribaj.com/products/part-z-embodied-carbon-building-regulations-fcbs-whole-life-carbon-network

Department of Environment, Food and Rural Affairs (2024). *Emissions of air pollutants in the UK – Non-methane volatile organic compounds (NMVOCs)*. [online] GOV.UK. Available at: https://www.gov.uk/government/statistics/emissions-of-air-pollutants/emissions-of-air-pollutants-in-the-uk-non-methane-volatile-organic-compounds-nmvocs

Designing Buildings (2023). *U-values*. [online] Designingbuildings.co.uk. Available at: https://www.designingbuildings.co.uk/wiki/U-values

Deutsche Fachwerkstrasse (2024). *Homepage - Deutsche Fachwerkstraße in der Arbeitsgemeinschaft Deutsche Fachwerkstädte e.V.* [online] Deutsche-fachwerkstrasse.de. Available at: https://www.deutsche-fachwerkstrasse.de/en/Homepage.html

Dincer, I. and Abu-Rayash, A. (2020). *Chapter 6 - Sustainability modeling*. [online] ScienceDirect. Available at: https://www.sciencedirect.com/science/article/abs/pii/B9780128195567000061

EPD International (2022). *Environmental Performance Indicators | EPD International*. [online] www.environdec.com. Available at: https://www.environdec.com/resources/indicators

EPD International (n.d.). *EPD International*. [online] www.environdec.com. Available at: https://www.environdec.com/home

Farinha, C., de Brito, J. and Do Veiga, M. (2021). Life cycle assessment. *Eco-Efficient Rendering Mortars*, [online] pp.205–234. doi:https://doi.org/10.1016/b978-0-12-818494-3.00008-8

GreenSpec (2022). *GreenSpec: Thermal Performance: Thermal Mass in Buildings*. [online] www.greenspec.co.uk. Available at: https://www.greenspec.co.uk/building-design/thermal-mass/

Hoarau, G., Mukherjee, P.K., Gower-Rousseau, C., Hager, C., Chandra, J., Retuerto, M.A., Neut, C., Vermeire, S., Clemente, J., Colombel, J.F., Fujioka, H., Poulain, D., Sendid, B. and Ghannoum, M.A. (2016). Bacteriome and Mycobiome Interactions Underscore Microbial Dysbiosis in Familial Crohn's Disease. *mBio*, 7(5). doi:https://doi.org/10.1128/mbio.01250-16

Husline JSC (2024). *Timber Frame Popularity*. [online] Husline.com. Available at: https://www.husline.com/articles/timber-frame-popularity/

Hygiene Pro Clean (2023). *Hygiene Pro Clean*. [online] Hygiene Pro Clean. Available at: https://www.hygieneproclean.com/news/is-pink-mould-dangerous

International Organisation for Standardisation (2006). *Environmental labels and declarations - Type III environmental declarations - Principles and procedures*. [online] International Organization for Standardization, pp.12–13. Available at: https://www.cscses.com/uploads/2016328/20160328110527052705.pdf

Kendrick, C., Ogden, R., Wang, X. and Baiche, B. (2012). Thermal mass in new build UK housing: A comparison of structural systems in a future weather scenario. *Energy and Buildings*, [online] 48. doi:https://doi.org/10.1016/j.enbuild.2012.01.009

Lichtarowicz, A.M. and Mayberry, J.F. (1988). Antoni Lésniowski and his Contribution to Regional Enteritis (Crohn's Disease). *Journal of the Royal Society of Medicine*, 81(8), pp.468–470. doi:https://doi.org/10.1177/014107688808100817

London Energy Transformation Initiative (2020). *LETI Climate Emergency Design Guide - How new buildings can meet UK climate change targets*. [online] London: LETI. Available at: https://www.levittbernstein.co.uk/site/assets/files/3494/leti-climate-emergency-design-guide.pdf

Lymath, A. (2015). *What is a U-value? Heat loss, thermal mass and online calculators explained*. [online] NBS. Available at: https://www.thenbs.com/knowledge/what-is-a-u-value-heat-loss-thermal-mass-and-online-calculators-explained

Mehjabeen Ratree, S., Farah, N. and Shadat, S. (2020). Vernacular Architecture of South Asia: Exploring Passive Design Strategies of Traditional Houses in Warm Humid Climate of Bangladesh and Sri Lanka. *Proceedings Article*. [online] doi:https://doi.org/10.38027/n212020iccaua316262

Mesh Energy (2020). How materials can be employed to reduce the carbon impact of new buildings, including efficient heating and cooling, and which materials are most effective at reducing embodied carbon. [online] Parliament.uk. Available at: https://committees.parliament.uk/writtenevidence/35996/html/

Nazzaro, G. (2019). Etymologia: Serratia marcescens. *Emerging Infectious Diseases*, [online] 25(11), pp.2012–2012. doi:https://doi.org/10.3201/eid2511.et2511

NHBC (2024). *3.3.2 Durability - NHBC Standards 2024*. [online] NHBC Standards 2022. Available at: https://nhbc-standards.co.uk/3-general/3-3-timber-preservation-natural-solid-timber/3-3-2-durability/.

Northern Ireland Ambulance Service (2024). *Serratia Marcescens | NIAS*. [online] Hscni.net. Available at: https://nias.hscni.net/other/ipc-resource/serratia-marcescens/

Oxford Net Zero (n.d.). *Net Zero Principles*. [online] Net Zero Climate. Available at: https://netzeroclimate.org/policies-for-net-zero/net-zero-principles/

Part Z (n.d.). *Part Z*. [online] Available at: https://part-z.uk/

Part Z (2024). *Proposal*. [online] Proposal - Part Z. Available at: https://part-z.uk/proposal

Passive House Institute (2012). *Certification criteria*. [online] Passive House Institute, pp.1–2. Available at: https://passiv.de/downloads/03_certification_criteria_EntryDoors.pdf

Passive House Institute (2022). *Basic principle for calculating thermal bridges*. [online] passipedia.org. Available at: https://passipedia.org/basics/building_physics_-_basics/thermal_bridges/tbcalculation/basic_principle_for_calculating_thermal_bridges

Pearman, H. (2011). *Lifespan*. [online] www.ribaj.com. Available at: https://www.ribaj.com/culture/lifespan

Pro Crew Schedule (2021). *What Are The Pros And Cons Of Using Insulated Concrete Forms (ICF)?* [online] PRO CREW SCHEDULE. Available at: https://procrewschedule.com/what-are-the-pros-and-cons-of-using-insulated-concrete-forms-icf/

Ratio Seven (2024). *Harnessing Thermal Mass for Energy Efficiency in UK Buildings*. [online] Ratio Seven - Building Consultants. Available at: https://www.ratioseven.co.uk/glossary/thermal-mass/

Royal Institute of British Architects (2019). *RIBA Housing Policy Statement*. [online] RIBA Architecture.com. Available at: https://www.architecture.com/knowledge-and-resources/resources-landing-page/riba-housing-policy-statement

Scottish Futures Trust, The Scottish Government, Zero Waste Scotland and NHS National Services Scotland (2021). *Net Zero Public Sector Buildings Standard*. [online] *The Standard - Net Zero Public Sector Buildings Standard*. Scottish Futures Trust. Available at: https://www.scottishfuturestrust.org.uk/storage/uploads/nzpsb_0s1_the_standard_v3.pdf

SE 2050 (n.d.). *What is Embodied Carbon? – SE2050*. [online] Available at: https://se2050.org/resources-overview/embodied-carbon/what-is-embodied-carbon/

Simon, S. (2022). *What Causes Pink Mold In Bathroom Showers*. [online] Forbes Home. Available at: https://www.forbes.com/home-improvement/bathroom/pink-mold-in-shower-causes/

The Chartered Institute of Building (2023). *New-build housing - how regulation can improve the consumer journey*. [online] www.ciob.org. Available at: https://www.ciob.org/industry/research/newbuilds

The Scottish Government (2024). *Building standards technical handbook April 2024: domestic*. [online] www.gov.scot. Available at: https://www.gov.scot/publications/building-standards-technical-handbook-april-2024-domestic/

The Scottish Government (n.d.). *Scottish House Condition Survey - gov.scot*. [online] www.gov.scot. Available at: https://www.gov.scot/collections/scottish-house-condition-survey/

The UK Government (2016). *The Self-build and Custom Housebuilding Regulations 2016*. [online] Legislation.gov.uk. Available at: https://www.legislation.gov.uk/uksi/2016/950/regulation/10/made

The UK Government (2021). *Self-build and custom housebuilding*. [online] GOV.UK. Available at: https://www.gov.uk/guidance/self-build-and-custom-housebuilding

The University of Edinburgh (2019). *Edinburgh Inflammatory Bowel disease rates amongst highest in the world*. [online] The University of Edinburgh. Available at: https://inflammation-research.ed.ac.uk/edinburgh-inflammatory-bowel-disease-rates-amongst-highest-world

Webb, S. (2022). *Pink mould in shower? Why it might be more disgusting than you think*. [online] Homebuilding & Renovating. Available at: https://www.homebuilding.co.uk/advice/pink-mould-in-shower

Weir, M., Rempher, A. and Esau, R. (2023). *Embodied Carbon 101: Building Materials*. [online] RMI. Available at: https://rmi.org/embodied-carbon-101/

Wood4Floors. (2021). What is Equilibrium Moisture Content? [online] Available at: https://www.wood4floors.co.uk/guides-and-info/what-is-equilibrium-moisture-content/

Yanatma, S. (2022). *Ranked: The European countries with the best and worst home insulation*. [online] Euronews. Available at: https://www.euronews.com/green/2022/12/09/europes-energy-crisis-in-data-which-countries-have-the-best-and-worst-insulated-homes

Wood Protection Association (2021). *Code of practice: Industrial Wood Preservation*. [online] WPA Code of Practice Industrial Wood Preservation. Available at: https://www.svw2000.co.uk/wp-content/uploads/2021/09/WPA-Code-of-Practice-Industrial-Wood-Preservation-v.2.pdf

Young, E. (2023). *How to Get Rid of Pink Mold in the Shower*. [online] Taste of Home. Available at: https://www.tasteofhome.com/article/how-to-get-rid-of-pink-mold-in-shower/

Bibliography

ArsLege (n.d.) *Rozdział 6. Wentylacja I klimatyzacja - rozporządzenie ministra infrastruktury W Sprawie Warunków technicznych, Jakim Powinny odpowiadać budynki i ich usytuowanie [tech. war. budynków]*, ArsLege. Available at: https://arslege.pl/rozporzadzenie-ministra-infrastruktury-w-sprawie-warunkow-technicznych-jakim-powinny-odpowiadac-budynki-i-ich-usytuowanie/k218/s3069/

Astbury, J. (2024). *Cairn uses hand-poured hempcrete for House Made by Many Hands in London*. [online] Dezeen. Available at: https://www.dezeen.com/2024/05/30/cairn-house-made-by-many-hands-hempcrete/

Astbury, J. (2024b). *Van Laethem Architecten uses hempcrete for own garden studio in Belgium*. [online] Dezeen. Available at: https://www.dezeen.com/2024/10/26/van-laethem-architecten-hempcrete-studio-belgium/ [Accessed 10 Dec. 2024].

Balson, K. (n.d.) *The importance of part Z*, Net Zero Carbon Guide - The Importance of Part Z. Available at: https://www.netzerocarbonguide.co.uk/guide/designing-and-building/materials-strategy/about-the-importance-of-part-z

British Plastic Federation (2024). The BPF Expanded Polystyrene Group | What are the sustainability credentials of EPS? [online] Eps.co.uk. Available at: https://www.eps.co.uk/sustainability/sustainability_credentials.html

Cairns, S. and Jacobs, J.M. (2017). *BUILDINGS MUST DIE: a perverse view of architecture.* S.L.: Mit Press.

Checkatrade (n.d.) *How much do timber frame houses cost in 2021? | Checkatrade*. Available at: https://www.checkatrade.com/blog/cost-guides/timber-frame-house-cost/

Checkatrade (n.d.) *Render cleaning prices in 2024* | Checkatrade. Available at: https://www.checkatrade.com/blog/cost-guides/render-cleaning-prices/

Checkatrade (n.d.) *What does a straw bale house cost in 2021? | Checkatrade*. Available at: https://www.checkatrade.com/blog/cost-guides/straw-bale-house-costs/

Crook, L. (2022). *Pink hempcrete brightens demountable Floriade pavilion by Overtreders W*. [online] Dezeen. Available at: https://www.dezeen.com/2022/08/22/the-voice-of-urban-nature-floriade-overtreders-w/

Construction Products Association (n.d.) *Environmental Product Declarations*, Sustainability - Environmental Product Declarations. Available at: https://www.constructionproducts.org.uk/our-expertise/sustainability/environmental-product-declarations/

Dsouza, K. (2024). *Welcome To Zscaler Directory Authentication*. [online] Thebetterindia.com. Available at: https://thebetterindia.com/312559/cannabis-helped-preserve-ancient-ellora-caves-sustainable-architecture-history/

Fleming Homes (2024) *Cost calculator - estimate costs of a new Fleming Homes Timber-frame home*, Fleming Homes. Available at: https://www.fleminghomes.co.uk/self-build-resources/cost-calculator/

Haisma, R. et al. (2023) *Impact scan for timber construction in Europe*. Available at: https://circulareconomy.europa.eu/platform/sites/default/files/2023-10/Impact%20scan%20for%20timber%20construction%20in%20Europe.pdf

Howieson, S. (2005). *Housing and Asthma*. Taylor & Francis Ltd.

GreenSpec (2022). *GreenSpec: Embodied Carbon & EPDs*. [online] www.greenspec.co.uk. Available at: https://www.greenspec.co.uk/building-design/embodied-energy/

Integrated Environmental Solutions (n.d.) *Table 6 Thermal Conductivity, Specific Heat Capacity and Density*, Table 6 thermal conductivity, specific heat capacity and density. Available at: https://help.iesve.com/ve2021/table_6_thermal_conductivity__specific_heat_capacity_and_density.htm

Jakubiec, M. (2022) *Im Starsze Budynki, Tym Więcej Strat Ciepła - Który Kraj W Europie Wypada Najgorzej?*, Termomodernizacja. Available at: https://termomodernizacja.pl/im-starsze-budynki-tym-wiecej-strat-ciepla-ktory-kraj-w-europie-wypada-najgorzej/

Lassitenaz, T. (2016). *1,500 Year Old Hempcrete*. [online] Hemp Gazette. Available at: https://hempgazette.com/news/hempcrete-india-cave-hg0095/

Mendiola, R.O. (n.d.). Expanded Polystyrene, friend or foe? - BioPlaster Research Inc. [online] www.bioplaster-research.com. Available at: https://www.bioplaster-research.com/blog-english/expanded-polystyrene-friend-or-foe

MidRender (n.d.). *Longevity of Lime Render in UK Homes Explained*. [online] Longevity of Lime Render. Available at: https://midrender.co.uk/how-long-does-lime-render-last/

Milne, G. and Reardon, C. (n.d.). *5.2 EMBODIED ENERGY material use Embodied Energy*. [online] Available at: https://ohp.parks.ca.gov/pages/1054/files/embodied%20energy.pdf

Neil, S. (2023). *7 Oldest Wooden Buildings in the World*. [online] Oldest.org. Available at: https://www.oldest.org/structures/oldest-wooden-buildings/

Powell, E.A. (2016). *News - Hemp Helped Preserve Ancient Sites in India - Archaeology Magazine*. [online] Archaeology Magazine. Available at: https://archaeology.org/news/2016/03/11/160311-india-ellora-caves-hemp-plaster/

Rizwanullah, S. (2016). *Hemp shielding Ellora caves from decay for 1,500 years*. [online] The Times of India. Available at: https://timesofindia.indiatimes.com/india/Hemp-shielding-Ellora-caves-from-decay-for-1500-years-Study/articleshow/51334725.cms

Rodrigues, L.T. (n.d.) *An investigation into the use of thermal mass to improve comfort in British housing*, PhD Thesis - Lucelia Taranto Rodrigues. Available at: https://eprints.nottingham.ac.uk/11872/2/PhD_Thesis_-_Lucelia_Taranto_Rodrigues_Single_Side.pdf

Singh, M. & Mamania, Divija & Shinde, Vasant. (2018). *The scope of hemp (Cannabis sativa L.) use in Historical conservation in India*. Indian journal of traditional knowledge. 17

The European Commission (n.d.) *European Platform on LCA | EPLCA*, European Platform on LCA. Available at: https://eplca.jrc.ec.europa.eu/LCDN/EN15804.html

University of the West of England (2008). *Traditional Timber Framing - A Brief Introduction*. [online] fet.uwe.ac.uk. Available at: https://fet.uwe.ac.uk/conweb/house_ages/timber/print.htm

www.changeplan.co.uk. (n.d.). *ChangePlan's Free Simple U Value Calculator*. [online] Available at:

https://www.changeplan.co.uk/u_value_calculator.php

Yu, C.W. and Bull, J.W. (2010) *Durability of materials and structures in building and civil engineering*. Dunbeath: Whittles Pub

List of Figures

Figures References

Figure 7 - Merlin Timber Frame (n.d.) *Timber Frame Kits*, Timber Frame Kits Leicester. Available at: https://merlintimberframe.co.uk/timber-frame-companies-near-me/leicester/.

Figure 14 - Harper Water Management Group (n.d.) *Serratia marcescens*, Think Pink – Serratia marcescens strikes again. Available at: https://www.harperwater.com/think-pink-serratia-marcescens-strikes-again/.

Figure 15 - Kaplan, Gilaad & Bernstein, Charles & Coward, Stephanie & Bitton, Alain & Murthy, Sanjay & Nguyen, Geoffrey & Lee, Kate & Cooke-Lauder, Jane & Benchimol, Eric. (2019). *The Impact of Inflammatory Bowel Disease in Canada 2018: Epidemiology*. Journal of the Canadian Association of Gastroenterology. 2. S6-S16. 10.1093/jcag/gwy054.

Appendixes

General

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Hempcrete Wall

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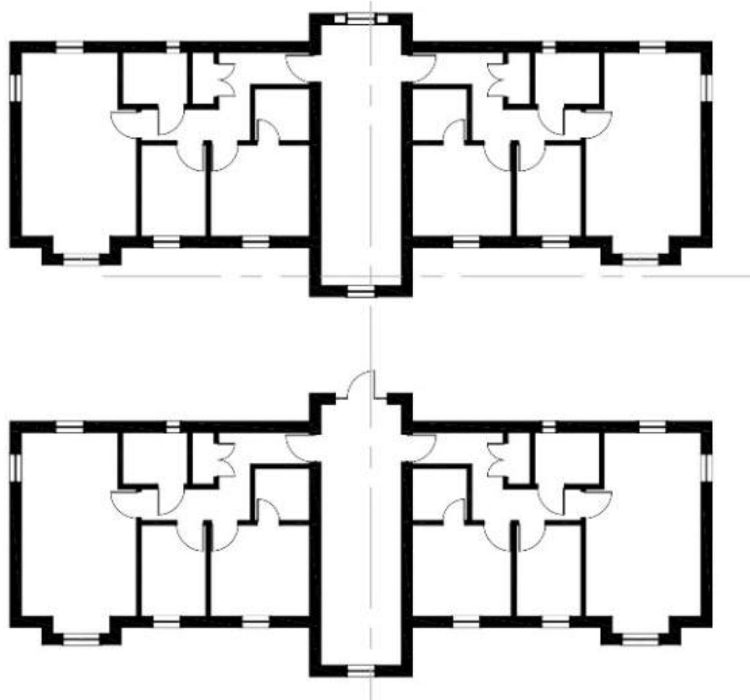
Small Snug Report



2 New Harbour Way,
Paisley PA3 2BZ,
Scotland

Planning Application No.: 16/0612/PP
Permission Status: Granted

The building was constructed and has been in use since 2019.

This Small Snug Report has revealed multiple instances of wall finish damage, roof finish damage, and other issues that should have been identified during the initial Building Inspection before the building was permitted for use.

The majority of these defects, which are easily detectable, can be observed with the naked eye, even by individuals without a background in the construction sector.

These defects can significantly reduce the building's lifespan and durability by failing to meet essential construction standards, particularly with regard to wall and roof ventilation. This puts the safety of building occupants at risk. Additionally, a similar report conducted for building number "5" revealed that, after just 5 years of use, the mastic around 63% of the windows has loosened, creating gaps that should not occur.

When considered together, these findings raise concerns about the overall condition and quality of the building's architecture.

Appendix 1.1 – Small Snug Report

Scale 1:200


Cavity Vent


Roof Finish


Cavity Vent


Cavity Vent


Cavity Vent


Cavity Vent + Excesive mortar


Roof Finish


Cavity Vent


Cavity Vent


Cavity Vent


Roof Finish


Dissapearing dpc


Loose vent cover


Roof Finish, mastic, cav. vent.


Roof Finish

Appendix 1.1 – Small Snug Report

U-Value Calculator

Thermal transmittance (U-value) according to BS EN ISO 6946:2017

Project Address
Paisley, Renfrewshire, United Kingdom

Project Reference
Timber Frame Wall
Building Use
Domestic
Build Type
New Build

Element Type: External Wall

Max U-Value $U = {}^{1}/_{RT} =$ **0.18** W/m^2K

Material	Conductivity W/mK	Percent %	Thickness mm	Resistance m^2K/W
Internal Surface (Rsi)	-	-	-	0.1300
Plaster Board Gypfor **	0.25	100	12.5	0.0500
Plaster Board Gypfor **	0.25	100	12.5	0.0500
Insulation KOOLTHERM K107, 108, 112 **	0.018	100	50	2.7778
Insulation KOOLTHERM K107,108,112 **	0.018	85	100	4.7222
Studwork 600mm c/c **	0.1200	15	140	0.1750
Unventilated airspace, normal (high) emissivity	0.1800	85	40	0.1800
OSB EGGER **	0.13	100	9	0.0692
Tyvek Membrane - Rainproof **	0.2	100	0.15	0.0007
External Surface (Rse)	-	-	-	0.0400

** denotes a custom material and/or values entered by the user and cannot be verified as to it's accuracy.

Total thickness:	.	224.2	mm (actual)
Total resistance:	$RT = Rsi+R+Rse =$	8.195	m^2K/W
U-Value (uncorrected):	$U = {}^{1}/_{RT} =$	0.122	W/m^2K
Total ΔU:	0.010		
U-Value (corrected):	$U = {}^{1}/_{RT} + \Delta U =$	**0.132**	W/m^2K ✓

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U-Value Calculator Version 3.70
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Appendix 2.1 – Timber Frame U-value calculation

Components																
Building Material	**Component Name**	Service Life (years)	**Volume [m3]**	**Area [m2]**	Projected Component Area (Gross)	Component Volume (Gross)	GWP (kgCO2eq.)	AP (kgSO2eq.)	EP (kgPeq.)	POCP (kgNMVOCeq.)	ODP (kgCFC11eq.)	ADPE (kgSbeq.)	ADPF (MJeq.)	Embodied Carbon (kgCO2)	Embodied Energy (MJ)	Data Source
Firestop - Cavity Wall Slab (CWS) 32 65-100																
	Firestop - Cavity Wall Slab (CWS) 32 65-100	50	3,4	40,6	43,6	3,8	1,93	0,01	0,01	0,00	0,00	0,00	30,62	182,6	5 779,2	EPD S-P-05653
Timber - CLS C16 (EPD)																
	Timber - CLS C16 (EPD)	60	2,8	71,6	72,2	3,4	141,53	1,13	0,22	0,07	0,00	0,00	1874,00	1 746,2	99 963,2	BREG EN EPD: 000124
Timber Frame Cav. 50																
	Insulation - KOOLTHERM K107,108,112	<Undefined>	11,7	161,8	278,8	20,4	4,10	0,06	0,01	0,00	0,00	0,00	126,30	885,6	31 626,9	BREG EN EPD: 000313
	Tyvek Membrane - Rainproof	30	0,0	100,2	149,5	0,0	1,02	0,00	0,00	0,00	0,00	0,00	13,69	102,2	1 499,0	EPD-DUP-20210185-IBC1-EN
	Render Carrier Board STO (EPD)	40	2,6	122,2	173,7	3,7	15,91	0,03	0,01	0,00	0,00	0,00	229,90	2 117,0	36 790,9	EPD-STO-20190105-IBA1-DE
	OSB EGGER (EPD)	50	0,8	100,2	149,3	1,3	214,00	0,93	0,22	0,52	0,00	0,00	4336,90	192,9	15 805,5	EPD-EGG-20180107-IBD2-EN
	Plasterboard - Gypfor Standard (EPD)	50	2,0	178,4	295,9	3,4	2,97	0,10	0,00	0,01	0,00	1,07	48,85	506,0	10 296,8	EPD S-P-01254
Timber Stud Wall 100mm																
	Plasterboard - Gypfor Standard (EPD)	50	0,9	87,6	118,5	1,6	2,97	0,10	0,00	0,01	0,00	1,07	48,85	260,5	5 302,8	EPD S-P-01254
														5 990,8 kgCO₂	207 055,3 MJ	

Appendix 2.2 – Timber Frame Wall Schedule

Key Values

General Project Data

Project Name:	Timber Frame Wall	
City Location:	Paisley	
Latitude:	55,8590° N	
Longitude:	4,4288° W	
Altitude:	7,00	m
Climate Data Source:	GBR_SCT_Gl...7-2021.epw	
Evaluation Date:	08.12.2024 01:50	

Building Geometry Data

Gross Floor Area:	**70,9**	m²
Treated Floor Area:	**57,6**	m²
External Envelope Area:	**95,6**	m²
Ventilated Volume:	**134,8**	m³
Glazing Ratio:	**9**	%

Building Shell Performance Data

Infiltration at 50Pa:	**2,45**	ACH

Heat Transfer Coefficients	U value	[W/m²K]
Building Shell Average:	**0,27**	
Floors:	**0,11 - 0,11**	
External:	**0,12 - 1,09**	
Underground:	**--**	
Openings:	**0,70 - 0,98**	

Specific Annual Values

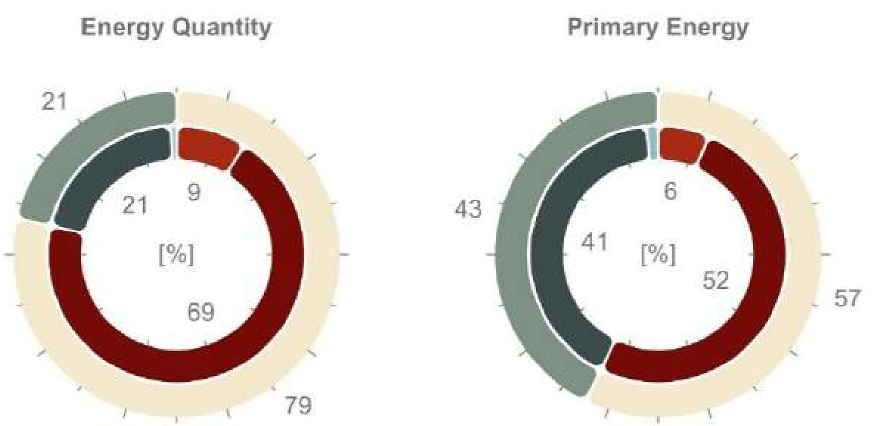
Net Heating Energy:	**10,43**	kWh/m²a
Net Cooling Energy:	**0,00**	kWh/m²a
Total Net Energy:	**10,43**	kWh/m²a
Energy Consumption:	**118,14**	kWh/m²a
Fuel Consumption:	**118,14**	kWh/m²a
Primary Energy:	**178,01**	kWh/m²a
Fuel Cost:	**14,87**	GBP/m²a
CO_2 Emission:	**25,52**	kg/m²a

Degree Days

Heating (HDD):	**4069,30**
Cooling (CDD):	**650,40**

Energy Consumption by Sources

Source Type	Energy Source Name	Quantity kWh/a	Primary kWh/a	Cost GBP/a	CO_2 Emission kg/a
Fossil	Natural Gas	5349	5883	417	1155
Secondary	Electricity	1457	4371	438	314
	Total:	**6806**	**10255**	**856**	**1470**



Appendix 2.3 – Timber Frame Performance Evaluation

U-Value Calculator

Thermal transmittance (U-value) according to BS EN ISO 6946:2017

Project Address
Paisley, Renfrewshire, United Kingdom

Project Reference
IsoHemp Wall
Building Use
Domestic
Build Type
New Build

Element Type: External Wall

Max U-Value $U = {}^{1}/_{RT} =$ **0.18** W/m^2K

Material	Conductivity W/mK	Percent %	Thickness mm	Resistance m^2K/W
Internal Surface (Rsi)	-	-	-	0.1300
Plaster Lime Green Solo **	0.5400	100	10	0.0185
IsoHemp Block **	0.071	100	360	5.0704
IsoHemp Block **	0.071	100	200	2.8169
Exterior Finish Clayworks **	0.8400	100	20	0.0238
External Surface (Rse)	-	-	-	0.0400

** denotes a custom material and/or values entered by the user and cannot be verified as to it's accuracy.

Total thickness:	.	590.0	mm (actual)
Total resistance:	$RT = Rsi+R+Rse =$	8.100	m^2K/W
U-Value (uncorrected):	$U = {}^{1}/_{RT} =$	0.123	W/m^2K
Total ΔU:	0.010		
U-Value (corrected):	$U = {}^{1}/_{RT} + \Delta U =$	**0.133**	W/m^2K

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U-Value Calculator Version 3.70
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Appendix 3.1 – Hempcrete U-value calculation

Building Material	Component Name	Service Life	Volume [m3]	Area [m2]	Projected Component Area (Gross)	Component Volume (Gross)	GWP (kgCO2eq.)	AP (kgSO2eq.)	EP (kgPeq.)	POCP (kgNMVOCeq.)	ODP (kgCFC11eq.)	ADPE (kgSbeq.)	ADPF (MJeq.)	Embodied Carbon (kgCO2)	Embodied Energy (MJ)	Data Source
Concrete - Structural																
	Concrete - Structural	100	5,40	27,20	27,20	5,40	149,77	0,61	0,13	0,59	0,00	0,00	1327,23	807,04	7 816,56	S-P-11236
IsoHemp Partition Wall 100mm																
	Lime Render - INTERMIX Water Resist Finish	70	0,86	85,63	116,15	1,17	140,00	0,54	0,01	0,41	0,00	0,00	1210,00	191,86	2 488,46	EPD-IES-001 4251
	IsoHemp Block	100	4,42	44,37	59,62	5,96	-13,30	0,21	0,01	0,12	0,00	0,00	532,00	-195,59	18 021,89	EPDItaly SEN-01_22
IsoHemp Wall																
	Lime Render - INTERMIX Water Resist Finish	70	3,95	252,07	366,81	5,74	140,00	0,54	0,01	0,41	0,00	0,00	1210,00	881,51	11 434,35	EPD-IES-001 4251
	IsoHemp Block	100	70,24	268,23	382,48	102,25	-13,30	0,21	0,01	0,12	0,00	0,00	532,00	-3 113,15	286 854,65	EPDItaly SEN-01_22
Steel - Structural																
	Steel - Structural	100	0,00	6,72	6,72	0,00	981,23	2,85	0,02	2,55	0,00	0,01	15862,00	619,20	13 221,60	EPD-IES-0015620
														-809,09 $kgCO_2$	339 837,91 MJ	

Appendix 3.2 – Hemprete Wall Schedule

Key Values

General Project Data

Project Name:	Hempcrete Blocks Wall	
City Location:	Paisley	
Latitude:	55,8590° N	
Longitude:	4,4288° W	
Altitude:	7,00	m
Climate Data Source:	GBR_SCT_Gl...7-2021.epw	
Evaluation Date:	09.12.2024 05:09	

Building Geometry Data

Gross Floor Area:	**93,93**	m²
Treated Floor Area:	**63,49**	m²
External Envelope Area:	**133,59**	m²
Ventilated Volume:	**140,53**	m³
Glazing Ratio:	**7**	%

Building Shell Performance Data

Infiltration at 50Pa:	**3,42**	ACH

Heat Transfer Coefficients

	U value	[W/m²K]
Building Shell Average:	**0,23**	
Floors:	**--**	
External:	**0,12 - 1,41**	
Underground:	**--**	
Openings:	**0,70 - 0,98**	

Specific Annual Values

Net Heating Energy:	**26,33**	kWh/m²a
Net Cooling Energy:	**0,00**	kWh/m²a
Total Net Energy:	**26,33**	kWh/m²a
Energy Consumption:	**126,10**	kWh/m²a
Fuel Consumption:	**126,10**	kWh/m²a
Primary Energy:	**185,56**	kWh/m²a
Fuel Cost:	**15,35**	GBP/m²a
CO_2 Emission:	**27,24**	kg/m²a

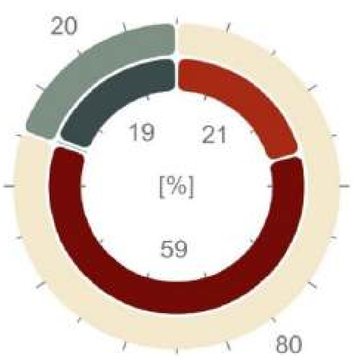
Degree Days

Heating (HDD):	**4069,30**
Cooling (CDD):	**650,40**

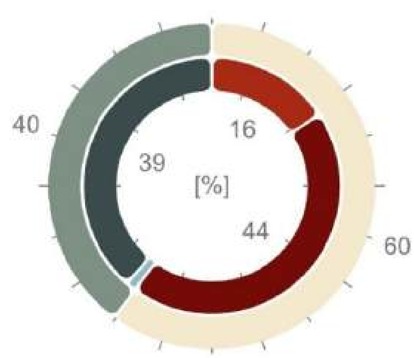
Energy Consumption by Sources

Source Type	Energy				CO_2 Emission
	Source Name	Quantity kWh/a	Primary kWh/a	Cost GBP/a	kg/a
Fossil	Natural Gas	6440	7084	503	1391
Secondary	Electricity	1565	4696	471	338
	Total:	**8006**	**11781**	**974**	**1729**

Energy Quantity



Primary Energy



Appendix 3.3 – Hempcrete Performance Evaluation