Low Energy Building Optimisation through Supply Chain Collaboration

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Balfour Beatty

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Summary

This paper, developed by a collaboration of Tier 1 contractors, responds to the increasing number of low energy and low carbon project being undertaken in Scotland, of which a significant number are being delivered to the Passivhaus standard. It shares insights and lessons learned regarding their practicality, buildability, and quality, as well as the commercial implications.

While acknowledging broader project drivers such as client brief requirements, functionality, site constraints, and aesthetics, this paper specifically focuses on four key topics;

1.The consideration and importance of ‘form factor’ as a project metric.

2.How employing a ‘Design for Manufacturing and Assembly’ (DfMA) approach to technical performance and detailing drives consistency and quality.

3.An industry-informed holistic approach to thermal and airtightness detailing.

4.The importance of structural and MEP (mechanical electrical and plumbing) coordination from project inception.

Open question:

How can the above approaches be embedded into project briefs and be measured and tracked throughout project development stage so they positively influence the design process, and not just be ‘outcomes’?

Consider form factor as a key metric

Form factor, or heat loss form factor, is the ratio of thermal envelope surface area to the treated floor area (TFA). Effectively it is the ratio of the surface area that can lose heat (the thermal envelope) to the floor area that gets heated (TFA).

Heat loss form factor is a useful measure of how compact a building is, and the more compact the easier it is to be energy efficient. Conversely, the less compact a building is, the harder the thermal envelope must work to be energy efficient.

Form Factor – how does it impact?

Figure 1 demonstrates the impact form factor can have on building layout and strategy. Applying a standard GIFA of 10,000m2 – representing a typical high school metric – across each of the options, the two main areas of impact are the surface area, and the U-value.

A higher form factor results in more envelope to construct and, in most cases, requires lower u-values to achieve the same heat demand.

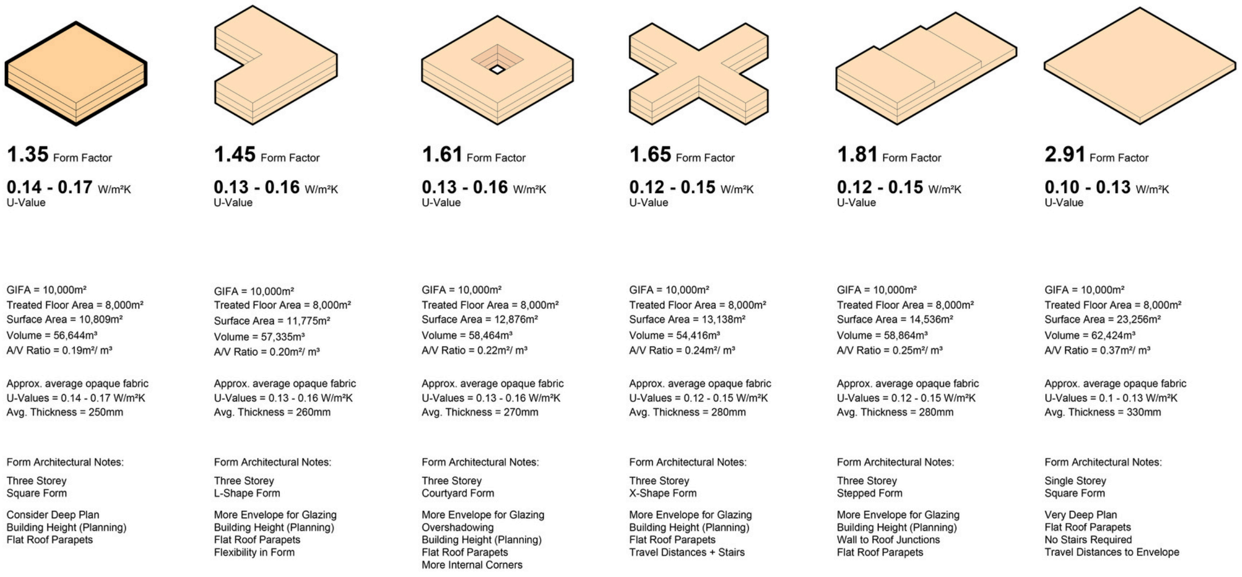


Figure 1: Diagram demonstrating the efficiency of a lower form factor, in terms of u-values, to achieve performance outcomes, as well as overall extent of envelope efficiency.

Two buildings having the same GIFA are subject to the same cost metrics at project planning stage. However, when looking through the realms of form factor, you can have two buildings with identical GIFA and project briefs, but considerably different form factors, and as a result, significantly different capital expenditure (capex) and operational expenditure (opex) cost profiles when the projects are costed at developed design stage. A significant difference in form factor between each building can mean;

- The building with the higher form factor must work harder to achieve low operational energy due to the greater extent of external envelope that is subject to heat loss.
- As higher form factor will likely require lower u-values to achieve compliance to counteract the heat loss areas.
- As a result of the lower u-values, this introduces the possibility of more complex detailing and materials to achieve the required u-value.

Also, treating GIFA in isolation can lead to contradictory design decisions, such as creating insets into the building that save GIFA but increase the envelope area and unnecessary voids internally, which may save money during the design phase, but adds real cost through increased design complexity and materials.

In short, more envelope that is subject to lower u-values will in most cases result in increased project costs.

How should form factor be applied?

Form factor can be influenced by several aspects of the project, such as site constraints, number of storeys, building type and building volume. However, a baseline metric using the building type and building scale can be generated as a project starting point.

Applying form factor alongside GIFA as a key metric will provide a good indicator of the developing designs thermal efficiency (project u-values) at the early-stage design, allowing for visibility on both the commercial and practical deliverability to project budgets and timescales.

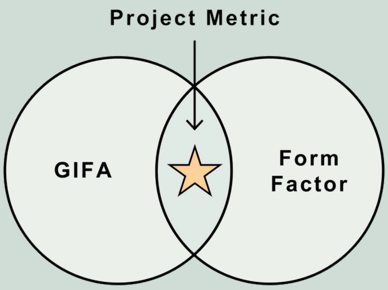
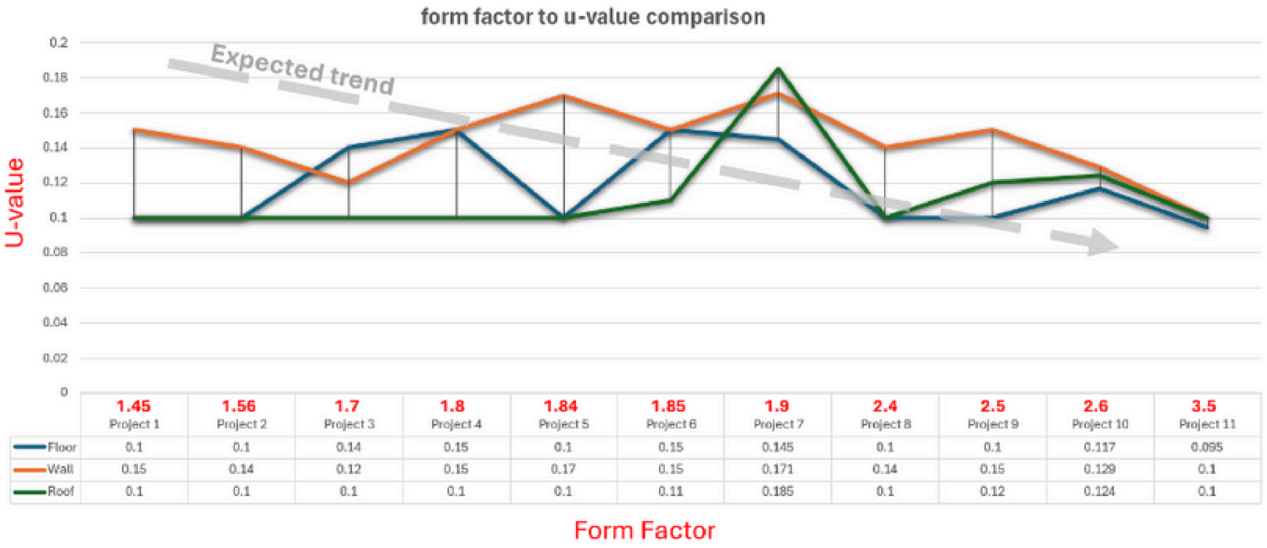


Figure 2 looks at the form factor and corresponding u-values of 11 major Passivhaus projects in Scotland.

The general rule, noted above, would suggest that the u-values for the lower form factors should be higher (more relaxed) than that of the higher form factor.



	1.45 Project 1	1.56 Project 2	1.7 Project 3	1.8 Project 4	1.84 Project 5	1.85 Project 6	1.9 Project 7	2.4 Project 8	2.5 Project 9	2.6 Project 10	3.5 Project 11
Floor	0.1	0.1	0.14	0.15	0.1	0.15	0.145	0.1	0.1	0.117	0.095
Wall	0.15	0.14	0.12	0.15	0.17	0.15	0.171	0.14	0.15	0.129	0.1
Roof	0.1	0.1	0.1	0.1	0.1	0.11	0.185	0.1	0.12	0.124	0.1

Figure 2: Form factor and u-values of 11 Passivhaus projects in Scotland.

However, the diagram does not immediately reflect this, with u-values remaining relatively consistent throughout despite the differing form factors.

There may be other project factors that are influencing the u-values; however, design teams should be challenged to avoid excessively low u-values, especially when project form factors are favourable, and revisited throughout the design stage to check if relaxations are possible as the design matures.

Next steps:

Establish what optimal form factors can be applied to building typologies as a baseline metric reference.

Summary of Section Reading

- Establish a target form factor at the outset and understand how it will impact on technical and commercial performance

- Challenge design team to balance u-values and continuously revisit as the design progresses to align with design standardisation.

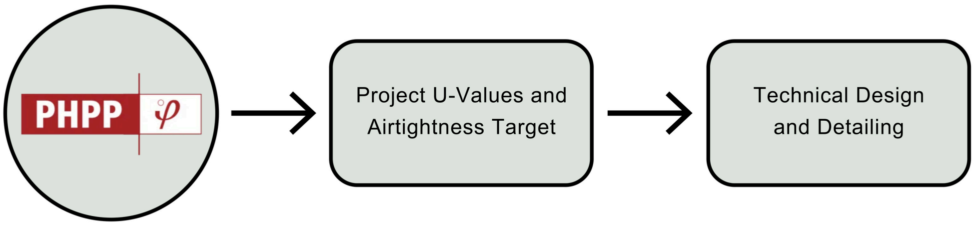
- Ensuring design and cost remain aligned from the outset will help avoid the disruptive and undesirable impacts of late-stage value engineering requirements.

Recently completed Montgomerie Park Primary School by Robertson Construction

Advantages of Design for Manufacturing and Assembly (DfMA) in low carbon projects

DfMA is the concept of designing products and systems that are tailored for ease of manufacture, transport and assembly. DfMA drives quality by using industry-led details and technical solutions, resulting in greater cost certainty and a reduced performance gap.

The traditional approach to technical detailing is to generate project technical performance requirements (i.e. u-values and airtightness targets) through TM54 (operational energy performance modelling) or PHPP (Passivhaus Planning Package) modelling, with the technical solution and details generated in response.



Current technical design process

However, as the drive to low energy design pushes technical requirements lower, the unintended consequence is that details are increasingly reinvented, resulting in bespoke and one-off solutions to achieve the required u-values (Figure 3). These solutions don't follow DfMA principles and can result in the following challenges:

- One-off solutions are not desirable for sub-contractors to price and command premium costs.
- Non-standard components and unproven build-ups are not warranted.
- Thermal bridging can be increased to accommodate deeper and more complex build ups (i.e. greater number of fasteners used).
- Decreased performance of components and materials resulting from non-manufacturer recommended installation (see next section).
- Ongoing maintenance and replacement can be problematic to recreate a one-off detail.

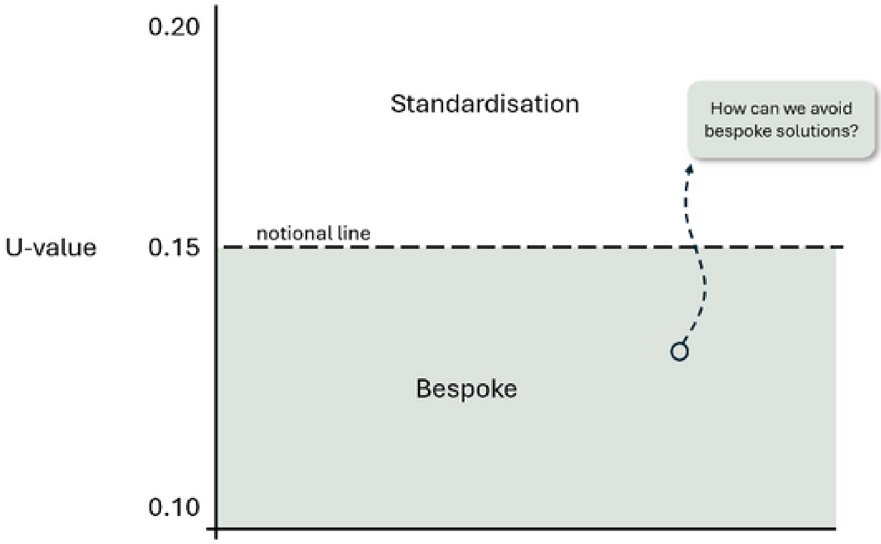
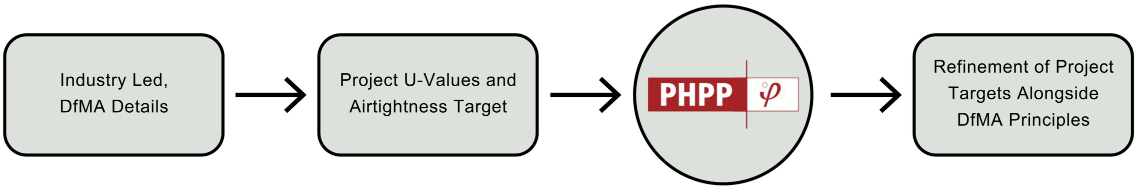


Figure 3: Identification of the line where bespoke detailing starts is important when setting performance targets – the diagram represents a notional line, hence identification of where this line sits relative to the building element in development is important.

Performance led approach

A recommended approach is to start with u-values and performance requirements that are derived from optimised industry led details and technical solutions. These can then be run through the PHPP/ TM54 models to assess how the building will perform in the first instance.



Suggested technical design process

Where performance requirements are required to be enhanced beyond these levels to meet project energy targets, a best value (cost v benefit) should be used to identify which elements can be improved with minimal impact on cost and quality.

For example, in most cases, increasing the depth of insulation under a ground floor slab or to the roof of a structure, has low relative cost to the overall project, due to low complexity of installation, but significantly enhances the thermal performance of the building.

Conversely, increasing insulation to external wall envelope can impact on various supporting elements such as wall ties for cavity depth, extended cantilever supports for window and, flashings etc. In turn, this can negatively impact the thermal performance through the unintended consequences of bespoke design solutions.

A DfMA approach enables robust, repeatable details that have been developed with input from the supply chain and reflect real life buildable solutions, and commercially economical solutions to drive building performance.

Installation of composite panels at Faifley Campus- Morrison Construction developed a DfMA solution with the supply that started with the test rig at BE-ST

An approved database of details

As the number of low carbon projects in Scotland increases, a series of 'best practice' details, that have been tried and tested, are in the process of being collaboratively discussed between the working group of this report.

It is recommended this best practice is held in a database through the T1C collaboration exercise at BE-ST and encouraged to be utilised at the commencement of projects to generate standardised solutions from day one.

The developed database will be publicly available and will be continuously updated to incorporate new insights, industry advancements, and best practices, ensuring buildability and consistent solutions.

Detail and component testing at the Tardis at BE-ST

Next steps:

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Generate an agreed, and evolving, set of technical solutions informed by best practice that can set performance requirements at project inception.

Summary of Section Reading

- Utilise industry led/ collaborated details and solutions to inform performance criteria, not vice versa.

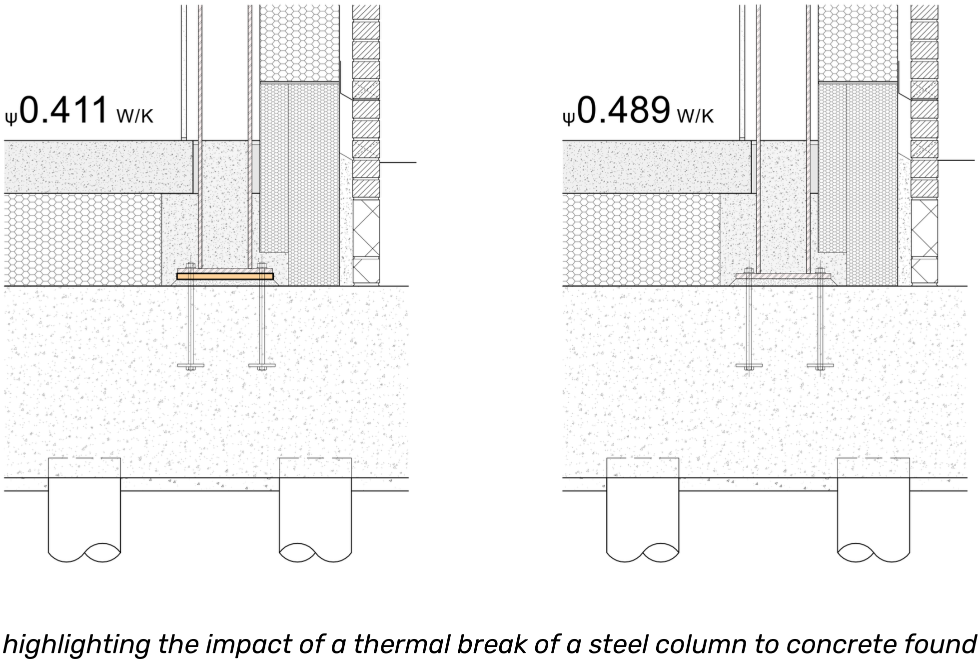
- Avoid bespoke solutions as a last resort

A holistic and industry informed approach to thermal and airtightness detailing

Low energy/ Passivhaus design has placed an increasing emphasis on designing out thermal bridges as it improves operational energy performance of the building.

To do this, emphasis is placed on keeping the thermal line as continuous as possible. However, attempting to design out thermal bridging entirely can lead to complex and costly details that, when viewed in isolation, may seem necessary, but when factored into the overall performance of the building, can make a minor performance enhancement for significant cost and complexity uplift.

For example, except for thermal comfort and condensation assessment, Passivhaus certification is not awarded on meeting or bettering an overall thermal bridge allowance ('Y' value), but instead takes a whole building approach. The primary focus therefore should be focused on the overall heating and energy demand with a cost/benefit analysis applied to thermal bridge reduction, where there is not an obvious solution to design out.



Example highlighting the impact of a thermal break of a steel column to concrete foundation detail. The incorporation of the thermal break (left image) made a very minor difference to the overall heat demand of 0.1 kWh/m2.yr at a significant cost of thermal break – every scenario is different, however a whole buildings approach should be considered when introducing thermal interventions

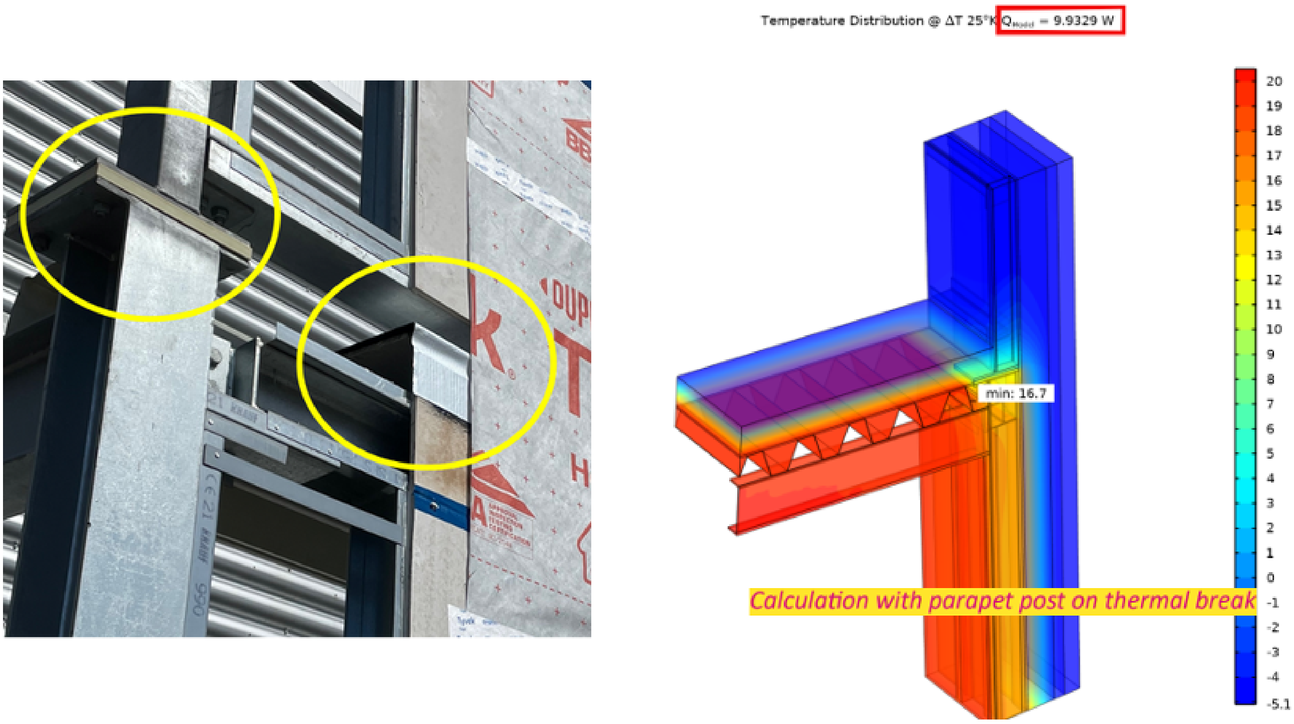
Reality versus Design

Computer modelling is increasingly productive in generating technical solutions, however translating complex 3D computer generated geometry onto site can lead to buildability and quality led challenges.

In short, if it looks complicated on paper, then under most circumstances it will be complicated to build and likely lead to quality being compromised on site due to the unfamiliarity by the supply chain of bespoke details (see previous section).

Rather than working to make a complex detail work digitally, project teams should take a step back and ask what value the detail is bringing, how big an impact is it making to the overall performance and aesthetic of the building, and can it be simplified.

It is important to think practically and seek input from contractors, sub-contractor and suppliers to ensure best practice approaches are adopted.



Example from BE-ST test rig indicating thermally broken parapet with airtightness and thermal line running below parapet – this is a complex and costly detailing for minimal performance benefits. Taking the thermal and airtightness line up and over the parapet simplifies the detail and retains the design benefits and considerations provided by the parapet.

Example: Separating thermal line from structure

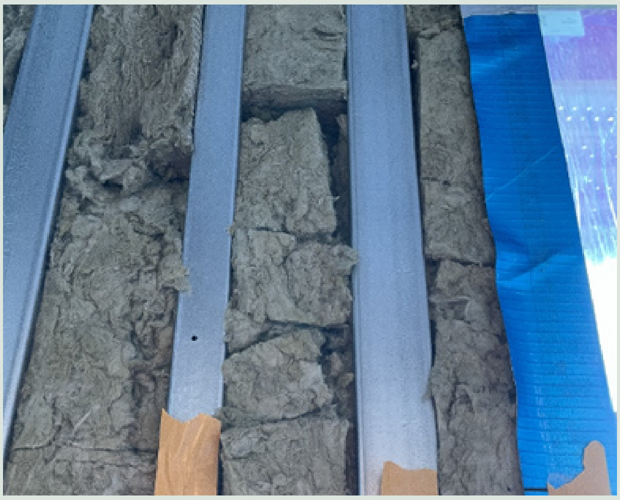
Currently, most large-scale educational buildings are steel frame with SFS (Steel Frame System) due to the economic benefits it brings. However, with it brings added complexities that are not so prevalent in timber and concrete structures, namely thermal bridging and airtightness detailing.

To meet required u-values, coupled with increasingly stringent requirements around non-combustibility, build-ups typically use a combination of insulation in the cavity, alongside insulation in the SFS/ structural zone which can result in unintended consequences:

- As the insulation line is constantly thermally broken by SFS studs and steel frame, the overall performance compared to the amount of insulation is greatly reduced, therefore resulting in poor value in terms of both cost and thermal efficiency.

- It introduces the requirement of an internal vapour control layer (VCL), to manage internal condensation. The VCL often doubles as the airtightness membrane, and to maintain continuity around complex steelwork and various interfaces can prove problematic

Image highlighting complexities of achieving internal airtightness lines highlighting the range of interfaces that it is required to seal around/ against.



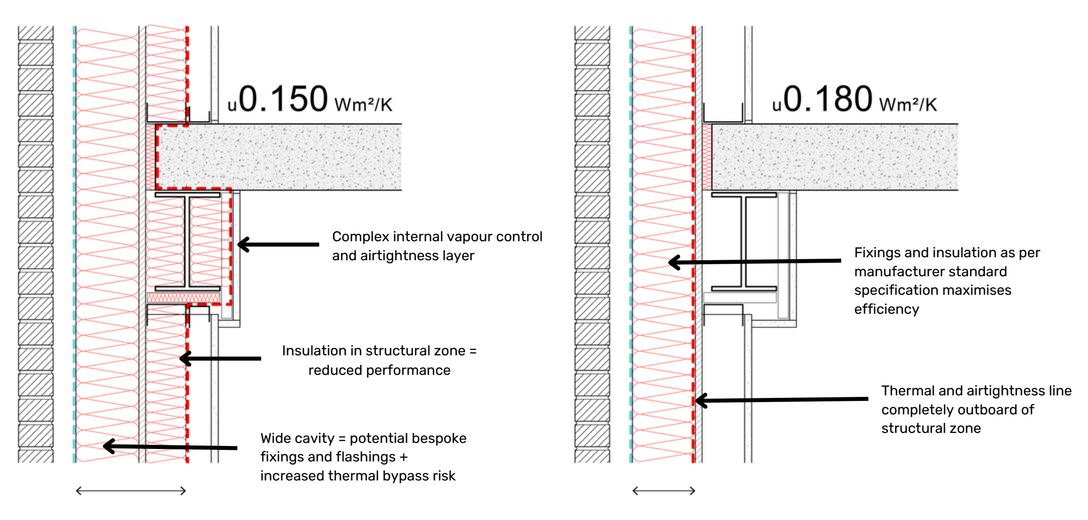
Insulation within structural zones can be tricky to maintain thermal continuity and is broken by structure and infill

Applying the logic noted in the above section 'Advantages of design for manufacturing and assembly (DfMA) in low carbon projects' above, a recommended approach would be:

How can you maximise the extent of insulation outward of the structural zone, whilst keeping product standardisation?

And then,

What other areas of the building can be enhanced to compensate, that are more economical and technically more straightforward?

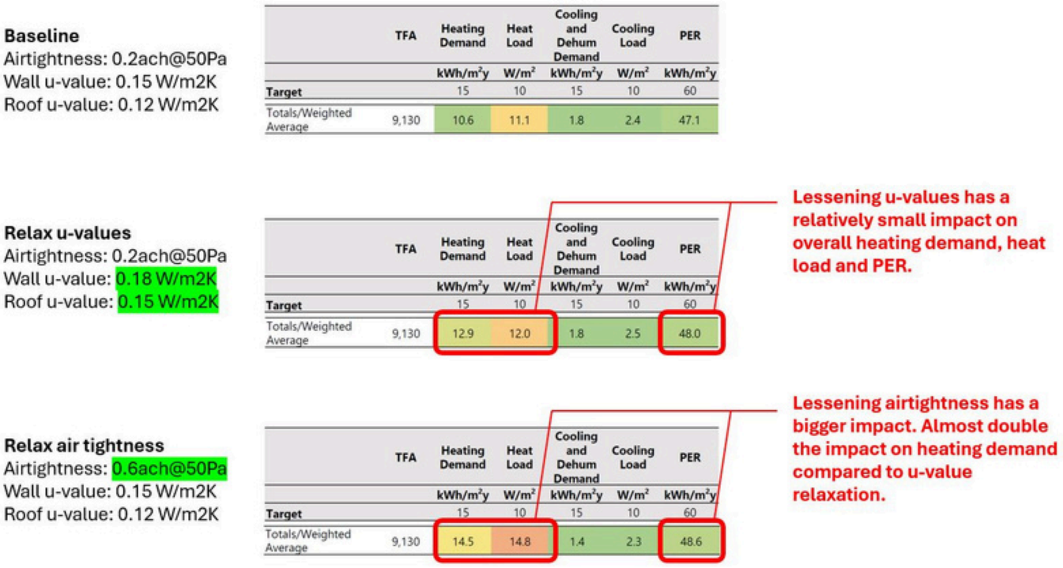


Sketch showing a 'bespoke' build-up on the left designed to meet a target u-value. Detail on the right indicates how a DfMA approach can greatly simplify and standardise the approach. The higher u-value should be viewed holistically across the rest of the building strategy as described in the section 'Performance Led Approach'.

Airtightness is central to high performing buildings

From an energy performance standpoint, improving the airtightness target is more beneficial than improving u-value performance due to the benefits of controlling unplanned air infiltration. Unplanned air infiltration can be regarded as the unintentional flow of external air into the building, hence the more unplanned air infiltration into the building, the more the heating system must work to compensate for this.

Airtightness can be viewed as a high value/ low-cost element, as it is the interface of components, and simplistically it is the element that provides by far the most value from an energy performance perspective.



Baseline
Airtightness: 0.2ach@50Pa
Wall u-value: 0.15 W/m2K
Roof u-value: 0.12 W/m2K

	TFA	Heating Demand	Heat Load	Cooling and Dehum Demand	Cooling Load	PER
		kWh/m^{2}y	W/m^2	kWh/m^{2}y	W/m^2	kWh/m^{2}y
Target		15	10	15	10	60
Totals/Weighted Average	9,130	10.6	11.1	1.8	2.4	47.1

Relax u-values
Airtightness: 0.2ach@50Pa
Wall u-value: 0.18 W/m2K
Roof u-value: 0.15 W/m2K

	TFA	Heating Demand	Heat Load	Cooling and Dehum Demand	Cooling Load	PER
		kWh/m^{2}y	W/m^2	kWh/m^{2}y	W/m^2	kWh/m^{2}y
Target		15	10	15	10	60
Totals/Weighted Average	9,130	12.9	12.0	1.8	2.5	48.0

Lessening u-values has a relatively small impact on overall heating demand, heat load and PER.

Relax air tightness
Airtightness: 0.6ach@50Pa
Wall u-value: 0.15 W/m2K
Roof u-value: 0.12 W/m2K

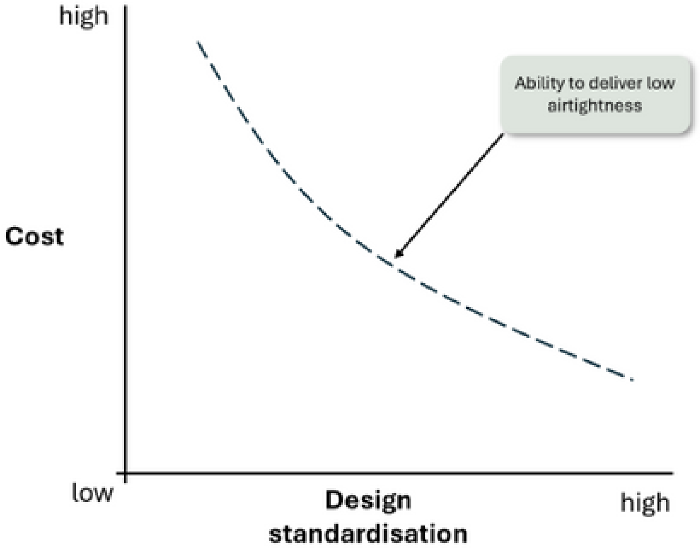
	TFA	Heating Demand	Heat Load	Cooling and Dehum Demand	Cooling Load	PER
		kWh/m^{2}y	W/m^2	kWh/m^{2}y	W/m^2	kWh/m^{2}y
Target		15	10	15	10	60
Totals/Weighted Average	9,130	14.5	14.8	1.4	2.3	48.6

Lessening airtightness has a bigger impact. Almost double the impact on heating demand compared to u-value relaxation.

Figure 4: Diagram showing the impact of airtightness relative to the u-value performance on a current Passivhaus project. Note that the impacts of technical considerations will vary across different project profiles, the above diagram is illustrative of the considerations that should be discussed.

A well-defined airtightness strategy is essential as a key technical design driver; without it, meeting a low airtightness target becomes significantly more challenging as the design progresses and construction begins. Lowering the airtightness target can introduce unintended complexities for the contractor, reduce buildability, and lead to intricate detailing that complicates the construction process if this is not done.

A standardised and repeatable technical design is not only cost effective and quality led, but it provides the basis for improved airtightness results in practice that in turn leads to a higher performing, more energy efficient building.



Enhanced design standardisation and repeatability will, in most cases, enable low airtightness detailing to be achieved at lower costs than non standardised technical solutions.

Designing to an airtightness target

Project performance criteria is determined by setting an agreed airtightness target, either in line with the technical requirements of building regulations (currently the Scottish non-domestic technical handbook recommends an air permeability of no more that 7 $m^3/(h.m^2)$@50Pa) warranty providers or certifying schemes. With greater focus on energy efficiency of projects, targets becoming increasingly onerous, for example being set by Passivhaus certification criteria (0.6 ach@50 PA).

How do you align details with the project airtightness target?

You don’t design to meet an airtightness limit, you design to achieve as close to zero as possible regardless of the limit.

The airtightness performance is ultimately a measure of the failure of the details to achieve zero during construction.

Agreeing on the airtightness strategy is one of the most important early-stage decisions. With proper consideration and planning there should be no more complex detailing attached to low energy/ Passivhaus project over a 'standard' project.

Low airtightness requires technical design maturity, with simplicity and robustness developed alongside the contractor and their supply chain.

Balancing airtightness, thermal bridging and u-values

As noted in the above section 'Advantages of design for manufacturing and assembly (DfMA) in low carbon projects' keeping u-values flexible allows for holistic technical solutions to develop, this is also true for airtightness and thermal bridging values.

As more projects are delivered, the supply chain will increasingly gain confidence in the ability to deliver 'technical solutions', i.e. gain confidence in the ability to deliver technical solutions to lower airtightness targets. These targets can in turn feed into the early-stage modelling, and influence the u-value targets, hence being able to balance achievable and realistic airtightness targets with u-values that align with industry led technical solutions leads to optimal solutions.

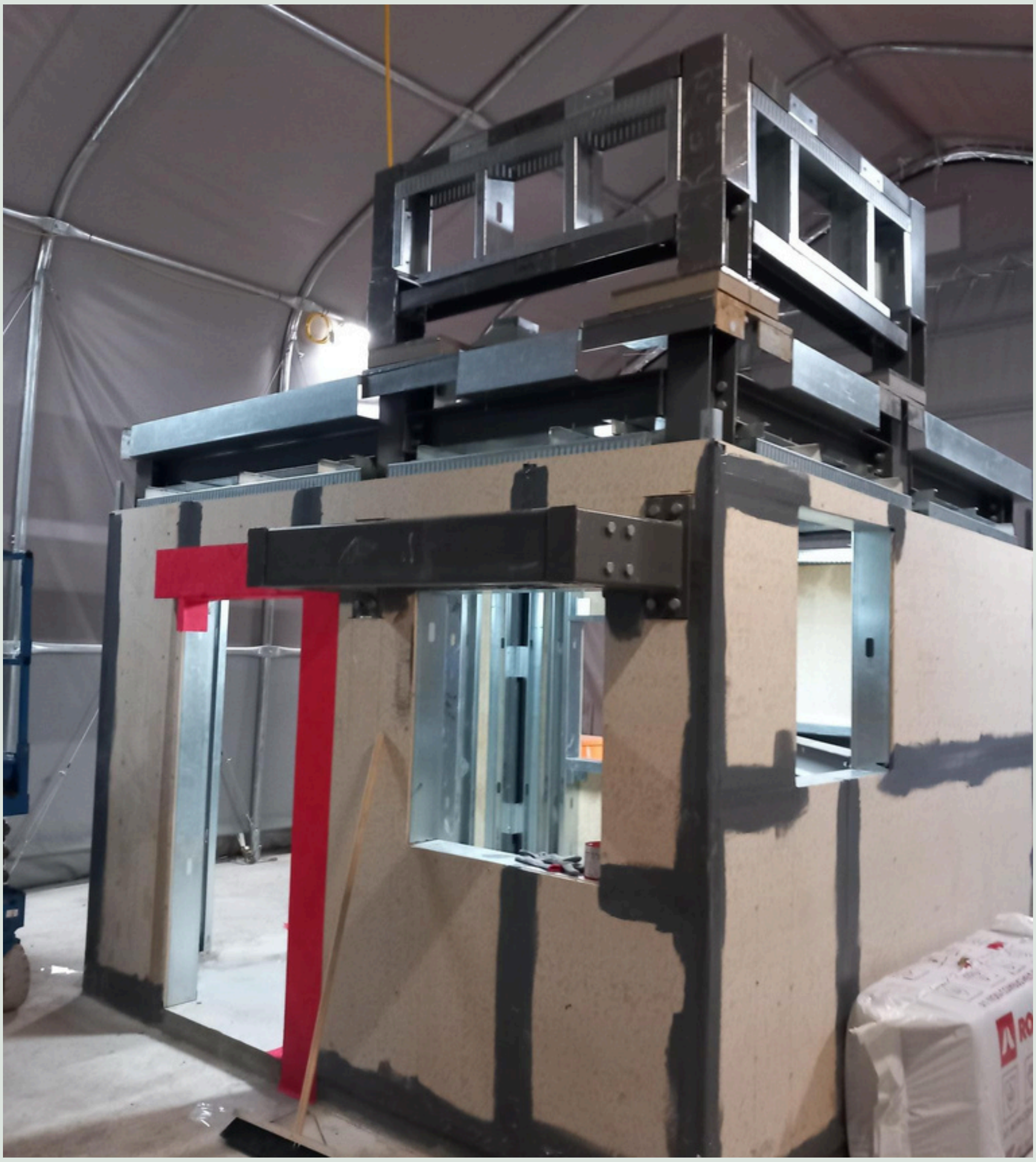
Morrison Construction using test rigs on site at Faifley Campus to test key junctions with supply chain ahead of site install

Quality led sub-structure details at Faifley Campus as a result of sub-contractor early engagement and testing to develop solutions.

Ground slab solution at Maybury Primary School: Morrison Construction worked with their groundworker to introduce a concrete blinding to create a flat surface for insulation slabs.

Summary of Section Reading

- Review thermal bridging allowance holistically with energy performance to avoid costly solutions that provide minimal impact.
- Establish airtightness strategy at outset.
- Retain flexibility in performance criteria to allow quality led best practice/ value approaches to be employed



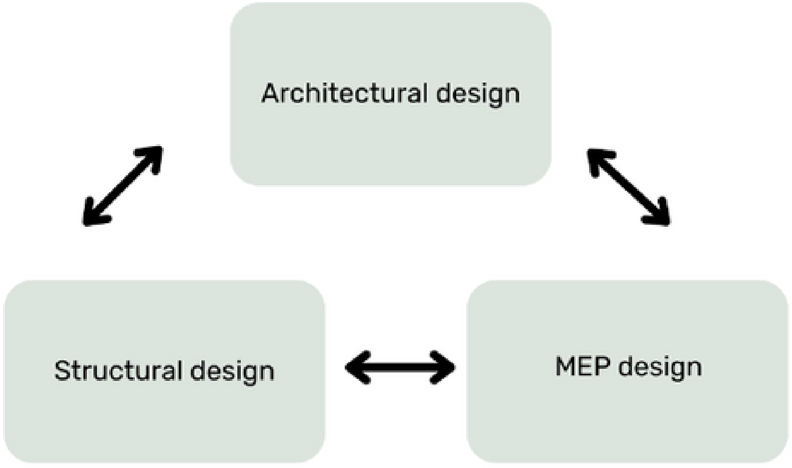
Kier Construction Test rig at Currie High School to agree best practice details and solutions with supply chain

Elevate importance of structural and MEP co-ordination

With project brief requirements focusing strongly on energy performance, and more increasingly embodied carbon, it is placing greater emphasis on both the structural integration with the mechanical, electrical and plumbing (MEP) solutions to ensure the design is optimised to meet both the technical performance requirements, but crucially also project cost metrics.

Rising costs and technical complexity can quickly become unintended consequences when architectural design and layout are developed in isolation from the increasingly demanding MEP and structural requirements during the early design stages. Therefore, the importance of moving away from traditional design modelling to a more collaborative approach to design co-ordination is critical to successfully achieve the project objectives.

Traditional model of design co-ordination



Proposed model of design co-ordination

Service and structural co-ordination

The growing complexity of buildings, driven by the inclusion of full mechanical ventilation and associated ductwork requires early co-ordination to ensure several key factors are addressed:

- The structure and layout must remain efficient, accommodating client aspirations without adding unnecessary gross internal floor area (GIFA), service zones, or building height.
- The mechanical system layout should be optimised to avoid costly energy losses caused by inefficient routing and poor coordination.
- Maintenance and replacement strategies for large equipment need to be seamlessly integrated into the design.

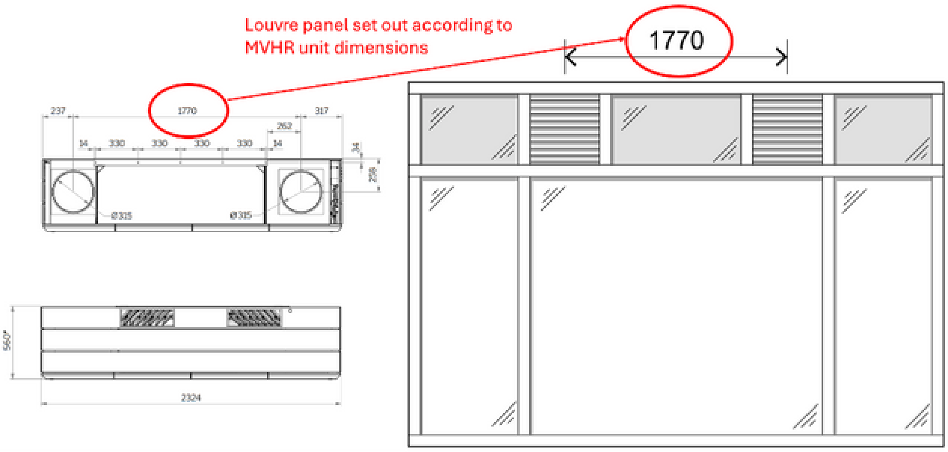
Two main strategies have been developed by way of ventilation strategy:

- Centralised consists of a ventilation system ventilating the entire building contained within a plant room, either internally or externally. Depending on the scale of the building, more than one unit may be needed.
- Decentralised consists of individual units that sit within each room, with individual intake and extract grilles to the envelope.

Each option has its pros and cons, which should be discussed with the project team. If the units are located internally and the main plant is kept off the roof, this enables the roof to be a lightweight structure with limited maintenance requirements, reducing the overall weight of the frame and foundations. Additionally, the location of the units should prioritise minimising duct runs and the extent of risers, which will help avoid losing valuable the gross internal floor area (GIFA) and decrease losses within the system.

Testing at the BE-ST Tardis showing the impact of excessive and poorly jointed ducts for airtightness performance

For a decentralised system, how the unit terminates at the envelope is a key project driver. Suitable space for installation and servicing can directly impact the ceiling heights, and extended runs of ducts to terminal points can have a significant impact on the losses in the system and in turn impact on the u-values of the envelope that may need to be enhanced to compensate.



Louvre panel set out according to MVHR unit dimensions

Sketch showing how a window/ curtain walling system could be designed with the MVHR unit duct terminal setting out dimensions to reduce/ eliminate duct bends and bespoke connections.

Setting targets for structural elements

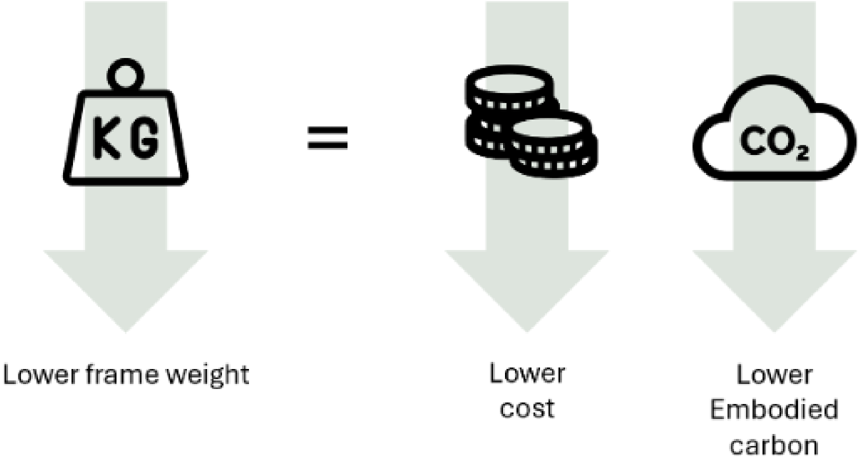
An efficient sub-structure strategy, and structural frame that has been co-ordinated with architecture and MEP design has multiple benefits, the primary benefit being that the less steel and concrete required, the lower the cost and by extension lower embodied carbon (The Low Energy Transformation Initiative (LETI) note that the superstructure of an educational building can account for almost 50% of the total upfront embodied carbon on a project).

To achieve this, designs should consider, at the outset:

- Limiting transfer structures and cantilevers
- Minimise/ eliminate retaining structures through cut and fill rationalisation
- Grid design load/ safety factor optimisation

It is important therefore that the structural frame and grid plays an integral role in the early-stage design of the project, alongside the MEP strategy to help inform the architectural strategy.

A way to check this is to set a target weight of frame per m2 – this will allow the structural design to show on an iterative basis how the design is developing compared to a defined target.



Given that the weight of steel and concrete is directly compared to the cost, then any reduction in weight will have a commercial benefit alongside carbon savings.

Next steps:

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Establish target frame weights for building typologies to be used as a baseline metric reference.

Summary of Section Reading

- Structural and MEP strategy optimisation to be integral to developing design decisions.
- Set targets for structural frame so that metrics can be tracked in design stages.

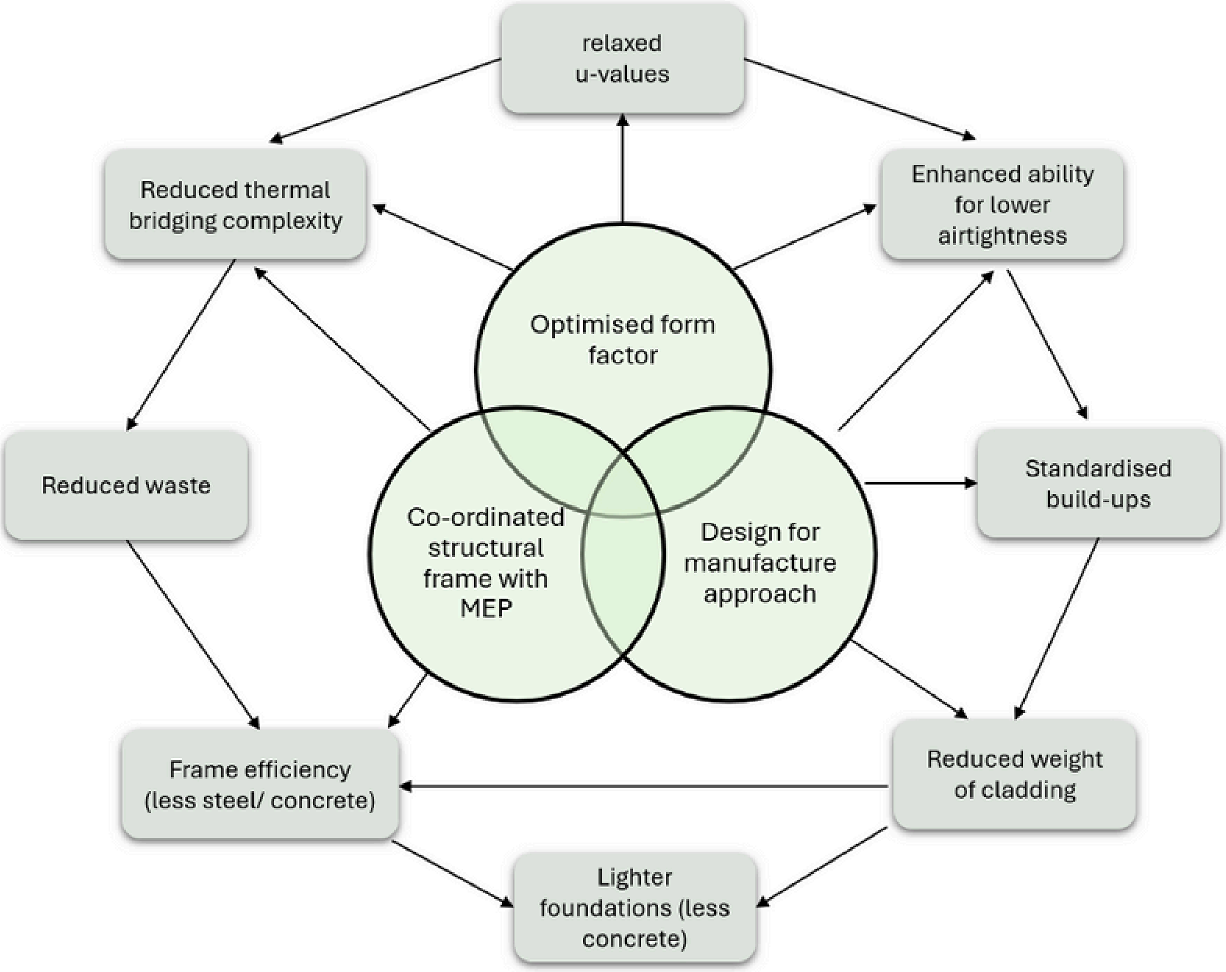
Morrison Constructions steel test rig at BE-ST.

Summary

This paper highlights the interdependence of form factor, technical detailing, performance criteria, and structural/ MEP strategies.

A holistic view and understanding is vital in achieving best outcomes for all project success criteria, including commercial, technical, aesthetic and functionality.
Early engagement with supply chain is key to delivering technical solutions that are robust, buildable, with quality embedded.

As the number of low carbon projects increases, it is critical that standardised approaches are developed and employed that will in turn accelerate quality and innovation and deliver desirable economical outcomes and high-quality buildings.



Summary of Report Recommendations

1. Establish a target form factor at the outset and understand how it will impact on technical and commercial performance

2. Challenge design team to balance u-values and revisit as design progresses to align with design standardisation.

3. Ensure design and cost remain aligned from the outset will help avoid the disruptive and undesirable impacts of late stage value engineering requirements.

4. Utilise industry led/ collaborated details and solutions to inform performance criteria, not vice versa.

5. Avoid bespoke solutions as a last resort

6. Review thermal bridging allowance holistically with energy performance to avoid costly solutions that provide minimal impact.

7. Establish airtightness strategy at outset.

8. Retain flexibility in performance criteria to allow quality led best practice/ value approaches to be employed

9. Structural and MEP strategy optimisation to be integral to developing design decisions.

10. Set targets for structural frame so that metrics can be tracked in design stages.

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