

BLAST TEST STANDARD ADAPTATION FOR HAZARD ASSESSMENT OF EVOLVING CONSTRUCTION TECHNIQUES

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Abstract

With constantly evolving building materials and construction techniques due to drivers such as cost, speed of construction, and most recently, climate change, the testing industry must also evolve new standards. This need is especially true for extreme loading cases such as blast hazards and weapons effects on structures, where the focus is on the design of protective buildings, rather than the performance of standard buildings against the effects of accidental or terrorist-related explosive events. Our research study adapts an existing standard for curtain walling to assess the hazards of modular building walls subject to a large free-field blast. It uses the modified standard to assess internal and external hazards and creates novel hazard maps to enable designers and specifiers to compare wall performance against metrics such as Global Warming Potential and thermal transmittance, drivers to achieve net-zero carbon. The research concludes that rapid adaptation of test standards is a useful means of assessing and comparing hazards when no other standards exist, and the approach could be further developed to assess other threat scenarios, including near-field blast and fragmentation effects. This research is of interest to the

explosive test community, especially those developing new protective structures or setting test standards.

Keywords

Blast, Explosion, IED, Risk, Low carbon, Blast Protection

Introduction

Construction methods and materials are constantly evolving with technological developments and drivers such as cost and carbon reduction. One such evolution is the rise of modern methods of construction (MMC) (Ministry of Housing, n.d.) which can refer to modular, volumetric, or off-site construction, where the majority of the building is pre-manufactured in a factory. This type of building technique offers a fast, cost-effective, and efficient alternative to traditional building methods. It has application in a range of building sectors including: houses, hotels, residential accommodation and various public and educational sector buildings. To achieve the desired appearance, price and durability, a range of external cladding materials for modular buildings are available. These claddings include full bricks to thin adhered brick slips; fibre cement boards to timber products; silicon renders to high pressure laminates (MTX Education, 2024).

Recently, the UK government produced a paper on Volumetric Modular Construction research (Brennan et al., 2024) highlighting the potential risks to general safety, longevity, and performance of such buildings. A key finding was the perceived gaps in design standards and codes, especially around connecting systems. A lack of design codes was also noted by industry in the United States (Modular Building Institute, 2020). In addition to the lack of general design standards, very little research has been publicly published on the vulnerability of these buildings to blast or fragmentation damage from either accidental explosions or terrorist threats. Some research has been conducted on modular buildings specifically designed to be blast-resistant for applications in high-risk industries such as petrochemical processing (Erkmen, 2018; Erkmen & Balci, 2019; Harrison, 2003; RedGuard, n.d.). These studies show that it is possible to reduce the risk from blast; however, these buildings, which are typically steel containers without windows, are not suitable for applications such as schools, etc., in a low-risk environment.

With an increase in the use of glazed facades and large windows, glazing hazard has become a focus of research and test standard production over the past 25 years (Beton et al., 2015). Glass is typically the most fragile part of the structure, with the ability to scatter lethal fragments and cause serious injury (Larcher et al., 2016). However, with modular

buildings, the walls are becoming much lighter, with only thin rainscreen cladding or brick slips providing protection from extreme external loads. Researchers have noted the need to understand blast loading in the urban environment (Ratcliff et al., 2023) due to threats from accidental explosions, terrorist attacks, and war (Rufolo et al., 2021; T. Ngo et al., 2007). As construction techniques such as modular buildings evolve, the testing and evaluation industry must keep pace in developing new test standards or have the ability to adapt existing standards to allow hazard assessment. This research and its case study demonstrate how an existing standard can be adapted to enable hazard assessment, identify design considerations, and enable better material selection for building designers.

A full literature review in the field of blast research on buildings is contained in Laycock et al., (2025). However, a summary graphic of research front is shown in Figure 1 from the *Litmaps* software package. The articles were identified using the search terms Vehicle Borne Improvised Explosive Device (VBIED), blast and “building damage” with relevant references from Laycock et al., (2025) added to the map.

Figure 1 *Litmaps* graphical representation of articles related to VBIEDs, blast and building damage

2019), a research gap was identified around the testing of modular wall systems against a large blast event. Since modular buildings are becoming more common in urban areas, an understanding of performance against large blast is required to enable more accurate damage assessment and modelling.

Hazard assessment case study

This case study used data from testing conducted by the United Kingdom's (UK) Defence Infrastructure Organisation (DIO). The objective of the testing was to compare the performance of a variety of modular wall systems against a large, free-field blast representing a Vehicle Borne Improvised Explosive Device (VBIED). With no specific test standard for modular walls (Laycock et al., 2025), designers and specifiers can currently only refer to protection levels and component damage as found in security engineering design and planning manuals (Canadian Standards Association Group, 2012; Department of Defense, 2008). The first reference suggests five levels of protection from 'below very low' to 'high', while the Canadian standard has four levels ranging from 'very low' to 'high', along with component acceptable damage levels from 'superficial' to 'hazardous'. These standards can be used to describe damage observed through testing, and they specify a repeatable test from which hazards can be recorded and compared. For this case study, the testing was conducted as an arena trial based on the National Protective Security Authority (NPSA) test standard for the 'Explosion Resistance of Curtain Walling' (National Protective Security Authority, 2024b, 2024a). For the analysis of the performance, the test standard was adapted to be relevant for grading internal and external hazards caused by the response of the walls to blast.

Blast test method

The large blast tests were conducted in July 2023 at the test facilities at Det Norske Veritas (DNV) Spadeadam (DNV, 2025) as a set of arena trials. Ten types of wall targets were manufactured in steel cassettes with apertures measuring approximately 2.7 m wide by 3.3 m tall. Each cassette contained a pair of targets which were lifted by crane and slotted into the front of purpose-built reaction structures known as Extremely Large Steel (ELS) cubicles, as shown in Figure 2.

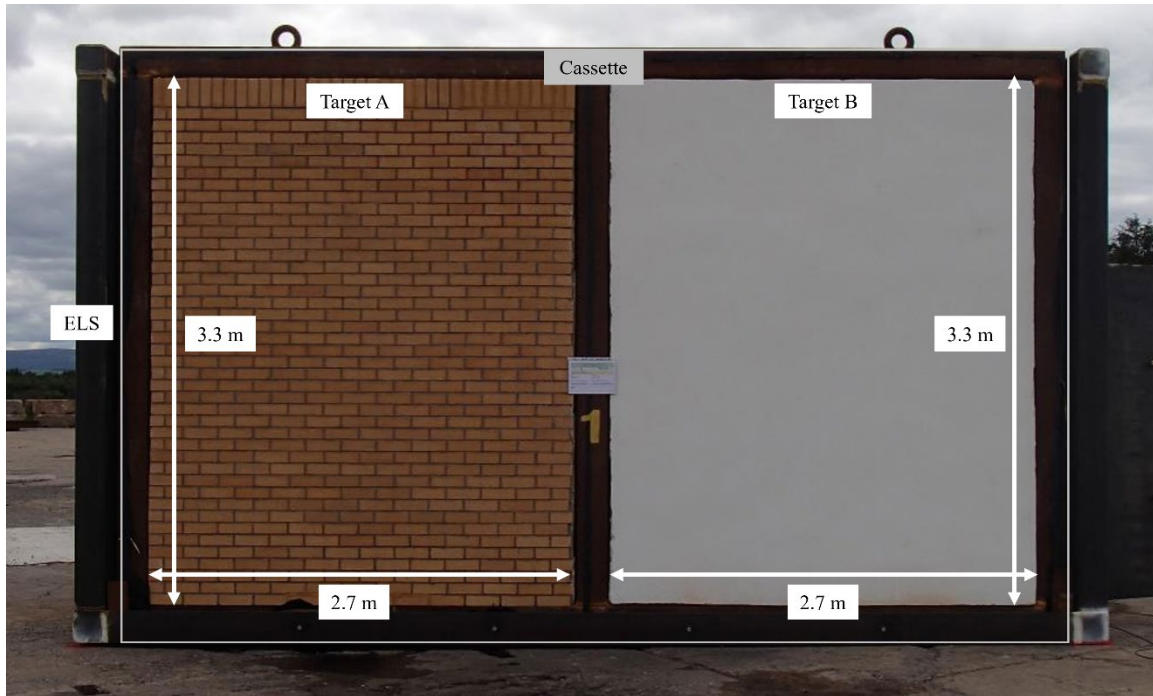


Figure 2 ELS cubicle containing two wall targets with dimensions

The materials used within the walls typically consisted of a cladding layer and core materials as shown diagrammatically in Figure 3.

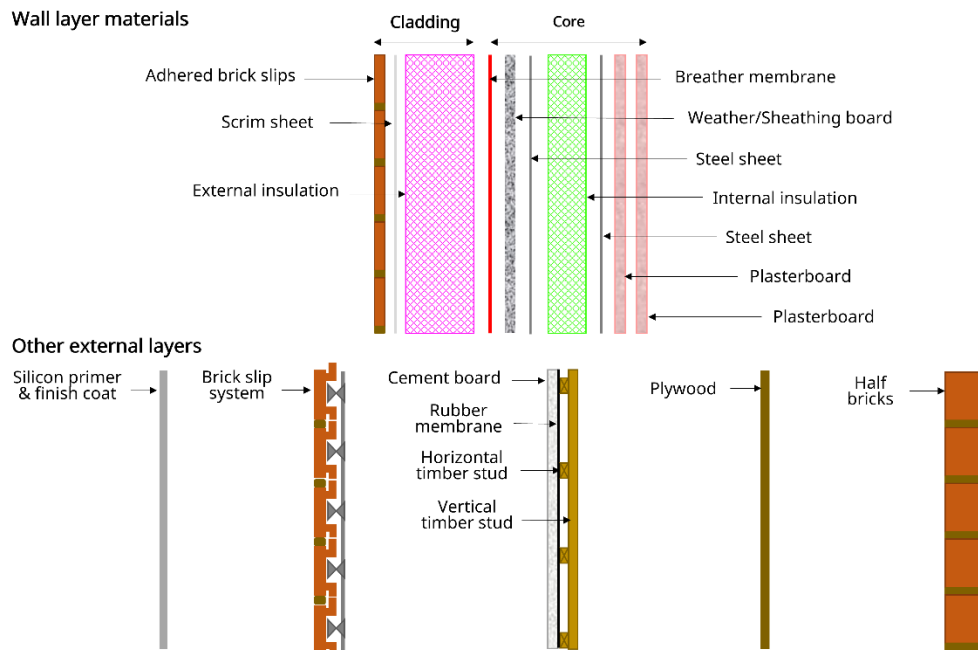
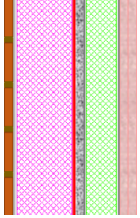
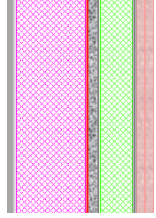
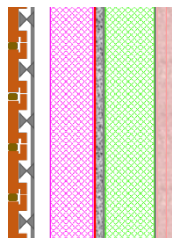
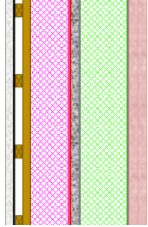
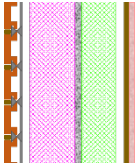


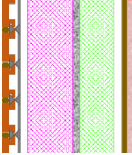
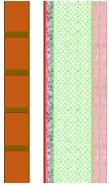
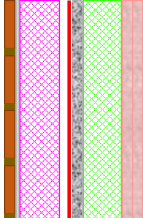
Figure 3 Wall material layer types, typical cladding, core materials, and other external layers

The full list of targets¹, material layers and section diagrams are shown in Table 1. The main differences between the materials used in each target are underlined in the table.

Table 1 Target materials and section drawings

Target	Target type	Cladding layers	Internal core layers	Section diagram
A	Adhered brick slips	<ul style="list-style-type: none"> - <u>15 mm brick slips</u> with injected mortar pointing - Scrim sheet and adhesive - 200 mm insulation - 25 mm steel rail spacer 	<ul style="list-style-type: none"> - Breather paper - Sheathing board - 0.7 mm steel sheet - Steel frame system - 100 mm stone wool insulation - 0.7 mm steel sheet - Fireproof plasterboard - Universal plasterboard 	
B	Stone wool silicon render	<ul style="list-style-type: none"> - <u>Silicon primer & finish coat</u> - Scrim sheet - 200 mm insulation - 15x50 mm treated timber batten 	Same as Target A	
C	Bricks slips in tray	<ul style="list-style-type: none"> - <u>Brick slip system</u> - Aluminium support bracket - 75 mm insulation 	Same as Target A	
D	Fibre cement board	<ul style="list-style-type: none"> - <u>Fibre cement board</u> - Rubber membrane - 64x38 mm cant rail - 25x50 mm treated timber batten - 75 mm insulation 	Same as Target A	
E	Fixed brick slips 600 mm studs	<ul style="list-style-type: none"> - <u>Brick slip system</u> - 50 mm residual cavity - Support brackets - 240 mm slab insulation 	<ul style="list-style-type: none"> - 12.5 mm weather board - 100 mm insulation - <u>Steel studs @600 mm centres</u> - <u>9 mm plywood</u> - 15 mm fireproof plasterboard 	

¹ Brand names and manufacturers are omitted due to commercial sensitivity.

F	Fixed brick slips 300 mm studs	Same as Target E	<ul style="list-style-type: none"> - 12.5 mm weather board - 100 mm insulation - <u>Steel studs @300 mm centres</u> - <u>9 mm plywood</u> - 15 mm fireproof plasterboard 	
G	Half thick brick	<ul style="list-style-type: none"> - <u>Half brick thick clay bricks</u> c/w standard mortar - 50 mm cavity - Wall ties screwed to steel uprights 	<ul style="list-style-type: none"> - Breather membrane - 12 mm fibre cement sheathing board - 100 mm glass wool insulation - Light gauge steel studs @600 mm centres - 15 mm fireproof plasterboard - 15 mm fireproof plasterboard 	
H	Brick slips on rails	<ul style="list-style-type: none"> - <u>Mechanically clamped brick slips</u> - Aluminium brick slip track - 110 mm slab insulation - Aluminium vertical rail & brackets 	Same as Target G	
I	Adhered brick slips	<ul style="list-style-type: none"> - <u>15 mm brick slips & injected mortar pointing</u> - Stainless steel mesh & adhesive - 100 mm mineral wool insulation - 19x100 mm timbers fixed to studs 	Same as Target G	
J	No outer	- Nil	Same as Target G	

Each type of wall was tested at two representative ranges: R_1 and R_2 from an explosive charge at the centre of the arena. The explosives used were made using nitromethane charges initiated with a PE-4 booster to represent a TNT equivalency of 100 kg. The distance R_1 was selected to represent a truck bomb and R_2 a car bomb; the exact distances are redacted to allow unrestricted publication. The charges were contained in a plastic sphere on a Styrofoam base to achieve a ‘centre of charge height’ of 1.2 m above ground level, as shown in Figure 4.

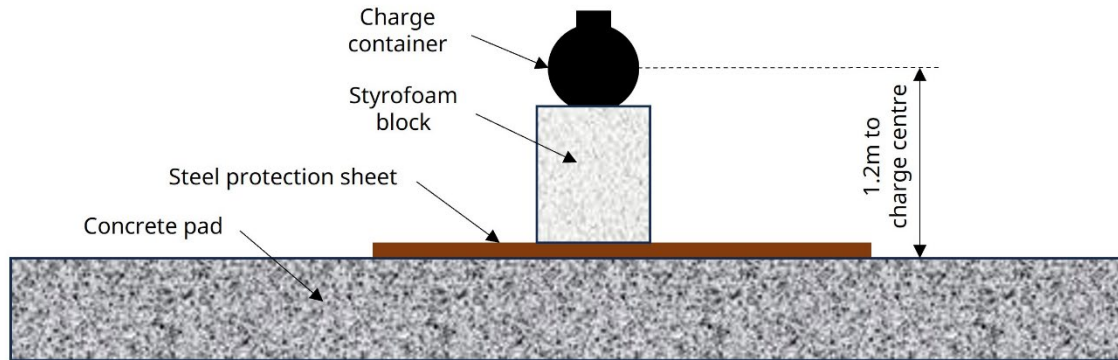


Figure 4 Charge set-up (adapted from (National Protective Security Authority, 2024b))

The arena and instrumentation were set out to enable each pair of targets to be tested simultaneously at R_1 and R_2 . During the tests, overpressure was measured using dynamic pressure gauges. At both R_1 and R_2 , the free-field incident pressure was recorded using standalone pencil-type sensors². The reflected pressure was measured at R_2 , using six pressure sensors³ mounted within a large gauge block structure designed to replicate the clearing effects experienced by the ELS cubicles. A HBM Gen7t high-speed data acquisition system was used to record the readings from the sensors⁴. The arena test layout is shown in Figure 5.

² [Model 137B24A | PCB Piezotronics](#)

³ [Model 113B26 | PCB Piezotronics](#)

⁴ [Shock, Vibration and Impact Testing with Genesis High Spe | HBM](#)

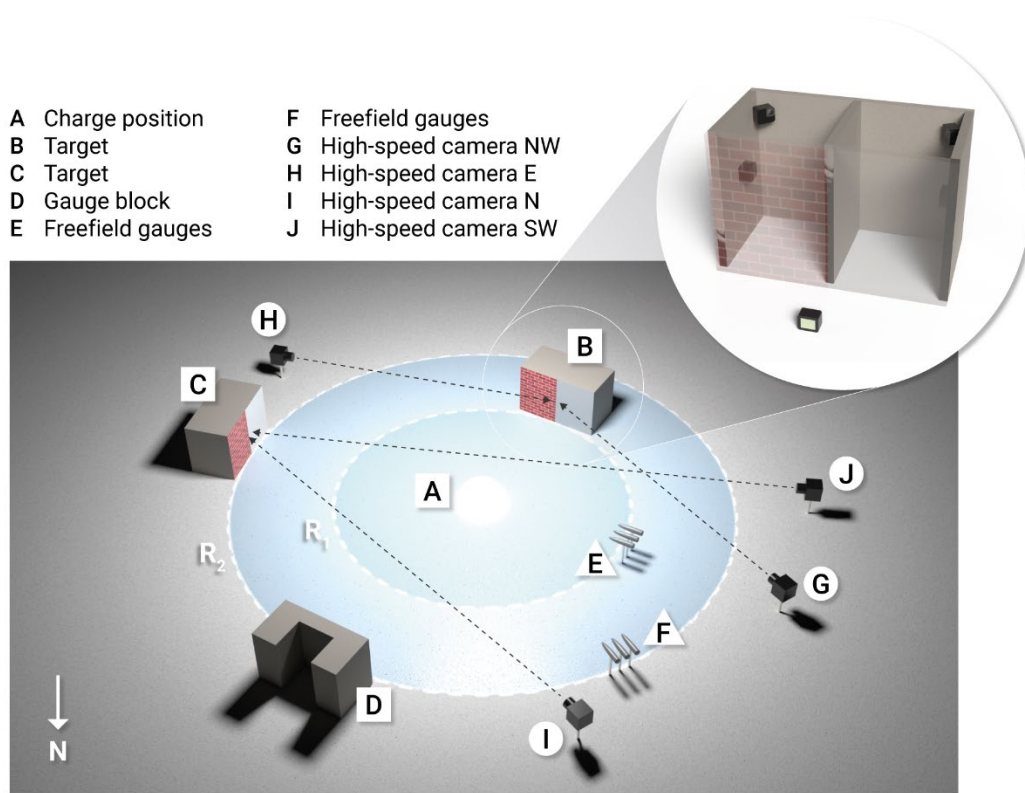


Figure 5 Arena test layout showing location of the charge, targets, sensors and cameras

Imagery was captured via four high speed cameras with two focused on each cubicle from different angles (G to J on Figure 5). *GoPro* cameras were placed in front of each cubicle and two were placed inside, behind the targets to observe from the side and the rear of the cubicles. Pre and post-test photos were taken internally and externally on a digital camera. Within the cubicles, foam witness panels were mounted on the rear wall to capture any internal movement and fragmentation. Grids were also painted on the side walls to allow tracking of internal fragmentation using the side-mounted *GoPro* cameras. The internal deflection of the wall was to be recorded by the displacement of a wooden rod held within a steel frame behind the wall. The inside of a cubicle, behind the target, is shown in Figure 6.



Figure 6 Deflection gauge and witness screens behind each target

Hazard assessment method

The part of the test standard which required amending to suit this application was the hazard rating assessment in Part 2: Test method (National Protective Security Authority, 2024b). The test plan and procedure remained the same, along with the internal and external hazard areas which are shown in Figure 7.

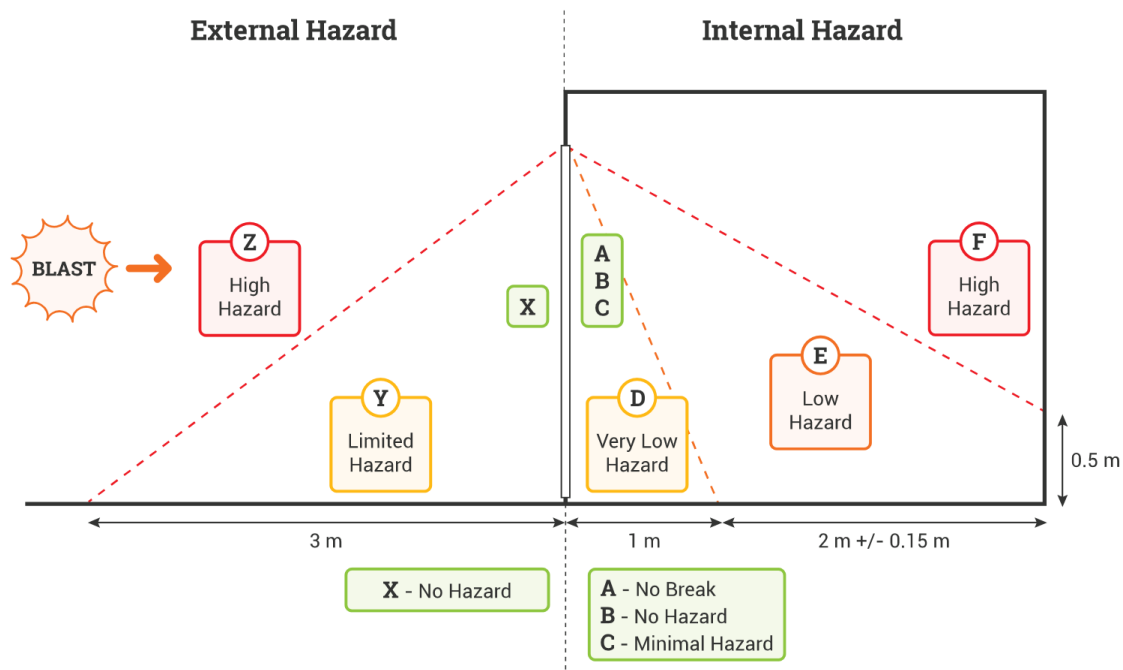


Figure 7 Test standard internal and external hazard areas

Since the standard was written to assess curtain walling, the definitions for the hazard ratings required amending from glazing components to those found within modular

cladding wall systems. Initially this was a simple case of replacing the descriptions of glazing components with parts that were likely to be found in wall constructions. For example, internal glazing was replaced with plasterboard or internal lining material, and cladding for external hazard assessment. The more difficult part was specifying an equivalent fragment hazard where the standard uses objective criteria such as the mass of glass fragments in an area. Since wall materials do not fragment in the same way as glazing, an alternative method was researched based on lethal fragments. There has been debate and discussion over the definition of a lethal fragment in technical papers for decades (Henderson, 2010; Zaker, 1975) and while hazardous fragments can be defined and calculated, the reality is that some small fragments can cause catastrophic injury through skin penetration (Takamiya et al., 2009) and larger ones can cause blunt force trauma (Wolf et al., 2009). Both are difficult to measure objectively with only post-damage photos and *GoPro* video footage; therefore, a subjective definition was proposed. A lethal fragment was classed as having sufficient velocity and mass to either penetrate the skin and cause damage to internal organs or catastrophic bleeding (e.g., screws, metal shards) or cause significant blunt trauma such as a head or chest injury (e.g., brick sections, frame components, plasterboard sections). This determination could be judged from the photos and videos to see the size and rough speed of flying debris and whether any objects penetrated the internal witness screens. The hazard ratings and proposed definitions created as part of the study are shown in Table 2.

Table 2 Hazard rating definitions developed in this study

Hazard rating	Suggested wall system definition
Internal hazard assessment	
A No break	The internal wall remains intact with no signs of visible damage.
B No hazard	The internal wall is damaged but remains in place with no material lost. Minor damage (small cracks) to the plasterboard or internal lining material which is easily repairable. No damage to stud work or main framing system.
C Minimal hazard	The internal wall is damaged but remains in place with no material lost. Plasterboard or lining material may be torn and badly cracked or deformed. Plasterboard or internal lining material could be removed and replaced. The studwork and main framing system should remain undamaged.
D Very low hazard	The internal wall is damaged and plasterboard or lining material is located no further than 1 m behind the original location of the rear face. Non-lethal fragments may be found on the floor between 1 and 3 m from the interior face of the specimen. Studwork may be deformed or damaged and require replacement and the main framing system remains intact.
E Low hazard	The internal wall is severely damaged and large parts of plasterboard, lining material or have fallen between 1 m and 3 m behind the interior face of the specimen, but not more than 0.5 m above the floor at the rear wall vertical witness panel. No more than 25% of the studs have failed and the main framing system is repairable. or

	Less than 5 lethal fragments are found up to 0.5 m above the floor on the rear wall witness panel.
F High hazard	The internal wall is destroyed, and large parts or entire sheets of plasterboard or lining material have fallen inside. or Lethal fragments may have penetrated the rear face over 0.5 m above the floor. or More than 25% of studs have failed. Main framing system has failed or the whole system is projected inwards and is unlikely to be repairable
External hazard assessment	
X No hazard	The exterior cladding is intact and shows no damage or only minor damage which can be easily repaired (e.g. cracked mortar). All components remain attached to the external face.
Y Limited hazard	The exterior cladding suffered minor damage with fragments or cladding material on the ground up to a maximum of 3 m from the face of the specimen. Cladding components may become detached, but no studwork and framing components are projected more than 3 m from the exterior face of the test specimen.
Z High hazard	The exterior cladding suffered severe damage with fragments or component parts projected more than 3 m from the original test specimen surface.

Assessment results

The post-blast test photographs and video footage were analysed and hazard rating were awarded based on the terminology described in Table 2. All of the rating definitions were used in the testing over the two ranges. Examples of each external rating are shown in Figure 8.

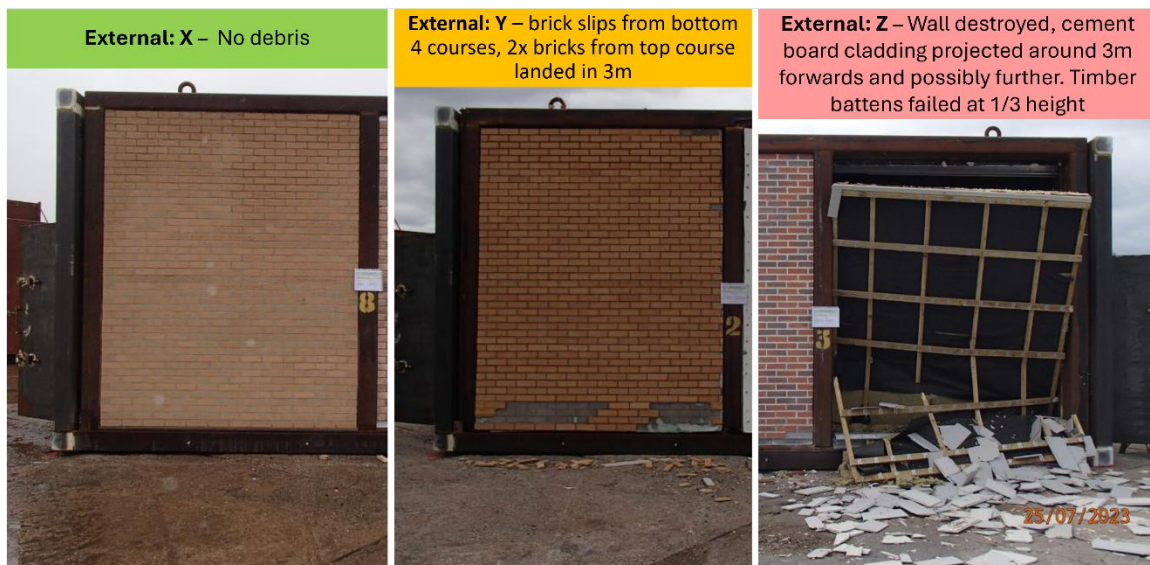


Figure 8 External hazard rating examples

The internal hazard ratings were graded in a similar manner, and examples of each grading are shown in Figure 9.



Figure 9 Internal hazard rating examples

Based on ratings described above, the targets were graded at both ranges as shown in Table 3. A colour coding has been used with green for Rating X externally and ‘A-C’ internally, which represents a low risk of injury. The amber colour is used for external rating Y and internal rating of D or E suggesting a medium overall risk. High hazards ‘Z’ and ‘F’, and therefore high overall risk, are shown in red. An overall ranking can be awarded, initially based on the overall risk and then ordered according to the individual ratings for both ranges.

Table 3 Blast hazard assessment results

Target	Target type	Range R ₁			Range R ₂			Overall ranking
		External hazard rating	Internal hazard rating	Overall hazard	External hazard rating	Internal hazard rating	Overall hazard	

A	Adhered brick slips	Y	D	Medium	Y	C	Medium	=4 Med Med
B	Stone wool silicon render	Y	F	High	Y	C	Medium	7 High Med
C	Bricks slips in tray	Y	E	Medium	X	B	Low	3 Med Low
D	Fibre cement board	Z	F	High	Y	E	Medium	8 High Med
E	Fixed brick slips 600 mm studs	Y	E	Medium	Y	B	Medium	=4 Med Med
F	Fixed brick slips 300 mm studs	Y	E	Medium	X	A	Low	2 Med Low
G	Half thick brick	X	C	Low	X	A	Low	1 Low Low
H	Brick slips on rails	Y	D/E	Medium	Y	C	Medium	6 Med Med
I	Adhered brick slips	Z	C	High	Z	B	High	9 High High
J	No outer	Z	F	High	Z	E	High	10 High High

To represent the data graphically, each hazard rating was plotted on a hazard map with external hazard on the y-axis and internal hazard on the x-axis as shown in Figure 10. The black markers represent range R_1 and grey shows the scores at R_2 , while an arrow shows how the increase in stand-off affects the result. The red, amber and green colours represent the overall risk score as high, medium and low.

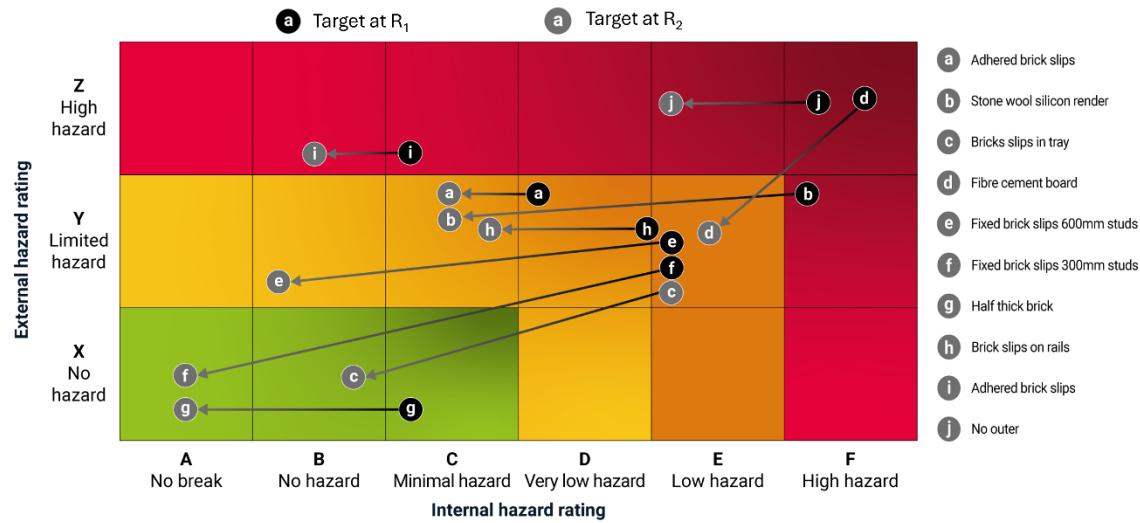


Figure 10 Hazard map showing external and internal hazards for each target at both ranges

Carbon comparison methods

For many buildings where protection is not a priority requirement, there are other influencers to material selection such as cost, aesthetics and most recently the drive to reduce carbon in infrastructure (British Standards Institution, 2023). Both embodied carbon (emissions associated with materials and construction processes) and operational carbon (emissions associated with in-use operation such as heating and cooling) are important factors in reaching net zero carbon (UK Green Building Council, 2021). Embodied carbon can be calculated using Environmental Products Declarations (EPDs) where emissions are split into stages and modules (Gibbons et al., 2022). For a direct comparison of products the 'product' stage can be used which comprises modules A1 (raw material supply), A2 (transport) and A3 (manufacturing) known as the 'cradle to gate' stages which occur making the product in the factory.

In this case study, a basic Global Warming Potential (GWP) score was calculated for each cladding target type using EPDs. Due to limited information on the exact products that were used, the cladding target types were simplified by comparing only the outer most cladding layers and the insulation, studwork, fixings or core layers were excluded. A square metre frontal area of wall was used as the unit of measurement for comparison and the functional units in the EPDs were converted to a one square metre section through the wall.

The second method of comparing whole-life carbon performance is by analysing the operational carbon emissions. Since these are mostly associated with the heating and cooling requirements of a building, the thermal conductivity of building elements such as walls, windows, roofs, etc is a useful predictor of heat loss or gain and therefore energy requirements. Heat loss of the building fabric layers is calculated using the thermal transmittance value or ‘U-value’(Lymath, 2015). A U-value is the rate of heat transfer through the materials, measured in $\text{W/m}^2\text{K}$ and the value reduces with increased insulative performance. These values can be estimated using the method described by Anderson & Kosmina (2019) using the thermal conductivity and thickness of a material, often found on material datasheets. Table 4 shows simplified GWP scores of the external cladding materials, references and calculated U-values.

Table 4 GWP and U-value calculations for external layers of each target

Target	Target type	Material	GWP A1-3 per m^2 ($\text{kg CO}_2\text{e}$)	Total GWP ($\text{kg CO}_2\text{e}$)	U-value ($\text{W/m}^2\text{K}$)
A	Adhered brick slips	15mm brick slips	5.4 (Moss & Chau, 2023)	6.69	0.108
		Injected mortar pointing	1.29 (CPI Mortars Ltd, 2022)		
B	Stone wool silicon render	Silicon primer & finish coat (assumed 10mm thickness)	11.84 (ISOMAT S.A., 2023)	11.84	0.108
C, E, F & H	Mechanically fixed brick slips	Brick slips (assumed 28mm)	8.73 (Moss & Chau, 2023)	80.18	C = 0.108
		Standard mortar	2.41 (CPI Mortars Ltd, 2022)		E&F = 0.095
		Carrier tray	55.26 (Beament, 2023)		
		Vertical aluminium rail	13.77 (Beament, 2023)		H = 0.171
		Fibre cement board	7.16 (Etex services, 2021)		0.178
D	Fibre cement board	Vertical aluminium rail	13.77 (Beament, 2023)	20.93	
G	Half thick brick	1/2 brick	27.22 (The Brick Development Association, 2019)	36.06	0.313
		Standard mortar	8.84 (CPI Mortars Ltd, 2022)		
I	Adhered brick slips	14mm brick slips	5.04 (Moss & Chau, 2023)	6.25	0.171
		Mortar pointing	1.21 (CPI Mortars Ltd, 2022)		
J	No outer	No outer	0	0	0.347

Carbon comparison results

The results of the carbon analysis can also be portrayed as heat maps showing high-low GWP or U-Values versus the blast effect hazard scores. The blast hazard has been shown using a combination of the overall hazard scores (Low, Medium, High) at R₁ and R₂ shown in Table 3. The target offering the best carbon score and level of protection is shown in the green section in the bottom left-hand corner and the worst score is in dark red in the top right section. Figure 11 shows the GWP against blast hazard score, with the best protection for a medium GWP being the brick wall of Target G. The mechanically fixed brick slips of ‘C’ and ‘F’ offer the next best protection, but the aluminium rails significantly increase the GWP compared to the adhered brick slips of Targets ‘A’ and ‘I’. This heat map is starting to form a materials selection chart where groups of materials will fall into bubbles of GWP compared with the hazard from blast.

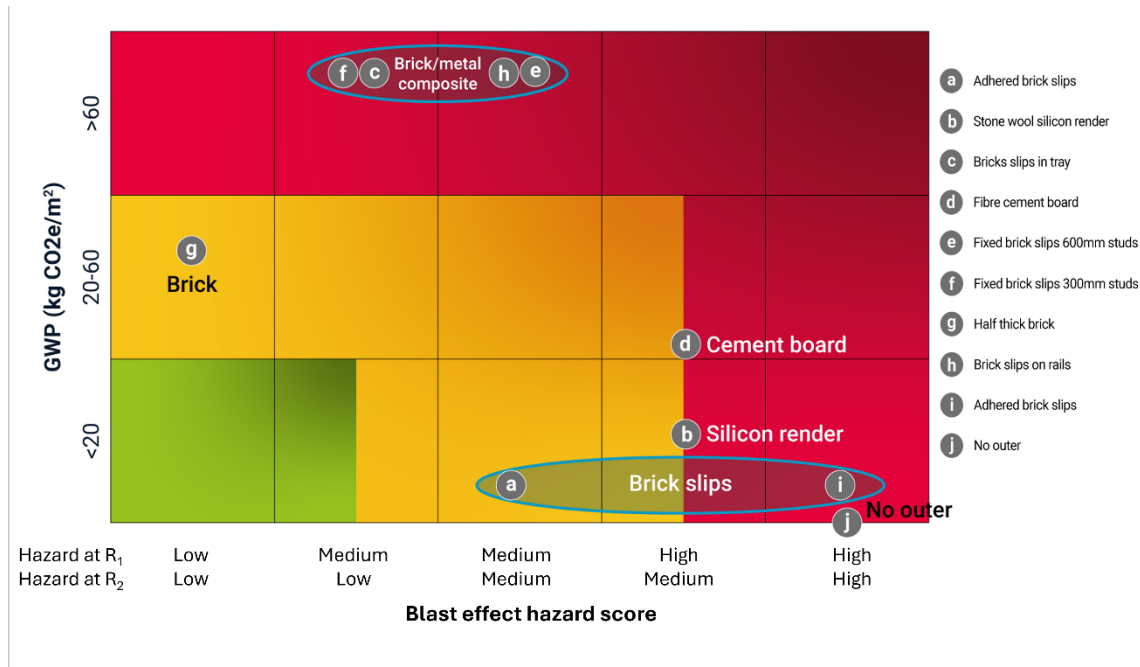


Figure 11 GWP vs overall blast hazard score with material groupings

The U-value hazard map paints a different picture when the limiting U-value from the English Building Regulations 2010, Approved document L (HM Government, 2021) is plotted. As shown in Figure 12, Target G would not be permitted without improving the insulation to lower the U-value to under the required 0.26 W/m²K. In this chart the mechanically fixed bricks perform better, but it must be noted that details such as thermal bridging were not calculated in this study. It would also be possible to improve the U-values of each target by increasing the insulation thickness of selecting a type with a lower conductivity, as this dominated the results more than the external material type.

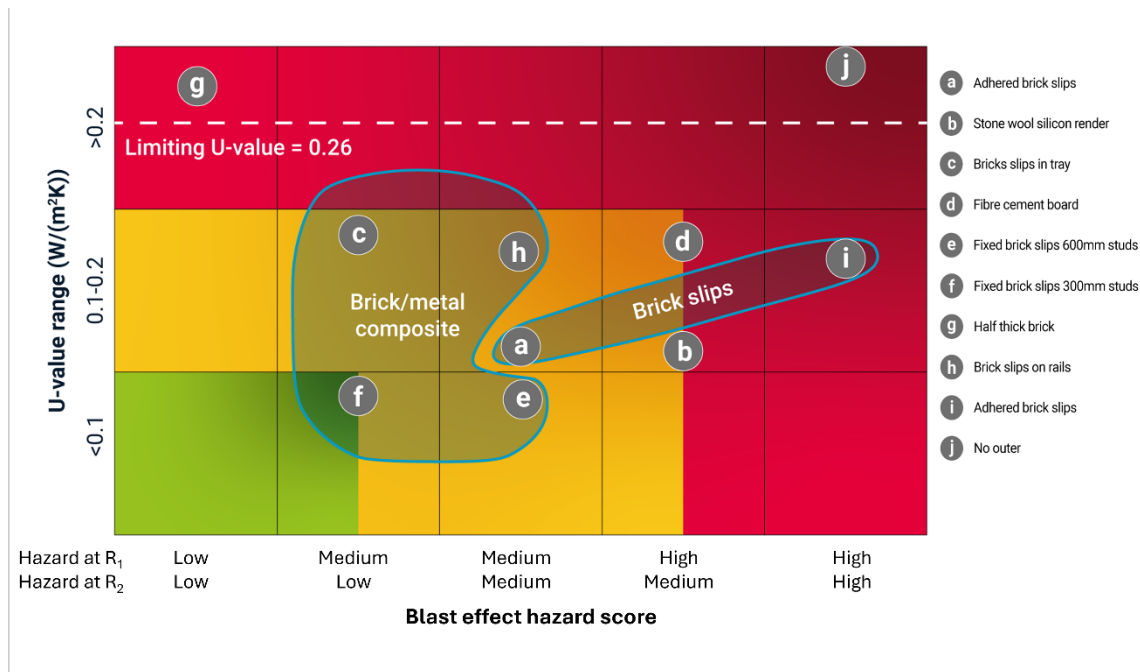


Figure 12 U-value vs blast effect hazard score and material groups

Discussion

In the absence of a specific wall or modular cladding test standard, this case study has shown that an adapted NPSA curtain walling standard (National Protective Security Authority, 2024a, 2024b) is a useful tool in comparing products. The scoring system allows the grading of external, internal and overall hazards for the full range of wall types with only minor adaptations to the hazard descriptions in the curtain walling standard. The ability to select and adapt an appropriate test method is extremely important when no other tools exist, or the application is bespoke, and a specific test is unlikely to be developed. The hazard ratings allow the production of novel hazard maps which portray the different performances of material types and wall build ups. These provide a useful tool for decision makers such as designers, engineers, protective security experts and clients to enable the selection of the appropriate wall type for their buildings.

The creation of the heat maps for carbon comparison provided a useful insight into how the hazard ratings can be compared to a wide range of other properties to assist in material selection. The methodology could also be used for other metrics such as cost, durability, maintenance requirements, construction speed, etc. It was also noted that not all targets with the same external material (e.g., brick slips) performed in the same way. This delineation was especially noted in the performance of the adhered brick slips where Target ‘A’ scored medium overall hazard but Target ‘I’ was given a high hazard score. On closer investigation, the difference between the scores is behind the brick slips and

can be attributed to how they were fixed to the studwork. Target A used a flexible scrim sheet to which the brick slips were adhered to, whilst Target I used a steel mesh with circular metal fixing discs to hold it onto timber battens. The lack of ductility in this system and the metal discs punched brick fragments out of the wall that were projected up to 5 m from the front of the wall as shown in Figure 13. This example highlighted that the wall must be tested as a system rather than assuming that similar external systems would perform in the same way.



Figure 13 Pictures of target A and I with a close up of the fixing discs

A major limitation with the case study results was the lack of wall displacement data due to the failure of the wooden rods to accurately measure the deflection of the wall. It is recommended that alternative sensors such as laser sensors, Linear Variable Displacement Transducers (LVDTs) or string potentiometers should be used in future testing (Chester et al., 2018). This correction would enable the calculation of end rotation and enable further analysis of the wall performance. The adapted test standard would also benefit from specifying a way of fixing the walls into the cassettes. Targets had different fixing methods connecting the C-channels at the top and bottom of the walls to the cassettes which may have affected performance. A specified type and number of fixings would allow more accurate comparisons of the targets. The case study and adapted standard also only looked at the hazards from walls, when buildings typically also have doors and windows. While separate test standards exist for these, what is lacking is one that represents the full modules as they would be constructed in a building. Further adaptation of the standard could be a combination of the standards to address the wall, glazing and framing elements.

The main limitation with both the existing curtain walling standard (National Protective Security Authority, 2024a, 2024b) and adapted standard is that it only represents large far-field blast hazards. In reality, an explosive event is likely to contain or create

fragmentation or potentially be smaller and closer in the form of a personnel-borne IED (Mellen et al., 2019; Sielicki et al., 2021; Studziński et al., 2024). It is acknowledged by Joint Research Centre et al. (2013) that existing standards and certification tests focus on arena or shock-tube testing to re-create far-field blast and close-in detonations have significant differences in compression wave characteristics. It is also recommended by Larcher et al., (2016) that standardization of numerical simulations and validation is required for glazing and glazed facades and for international standard technical committees to further discuss this. However, the adapted test standard scoring system used in this case study could be applied to many situations, regardless of the threat size and proximity. This example reinforces the requirement to be able to quickly adapt test standards to enable decision making when a specific standard does not exist.

Conclusions and future work

The hazard assessment case study highlights the requirement to be able to adapt and apply a standard when one does not exist for that specific product or application. This finding is especially true in the construction industry where materials, building techniques and designs are rapidly changing in reaction to drivers such as climate change, cost and speed of construction. The adapted test standard can be used to assess both internal and external hazards to compare the performance of wall systems against a large free-field blast. The study showed that the results can also be used to aid material selection by using heat maps comparing the materials against metrics such as GWP and thermal transmittance.

While the adapted standard only covers wall cladding materials and the test standard is focused on large, free-field blast, this study shows that the scoring system descriptions can easily be adapted to suit other building elements. Further work should be completed on the combined blast and fragmentation effects on wall cladding materials and the variations found in close-in blast testing. This would enable the testing and standards community to better understand how test standards need to be adapted to incorporate the additional fragmentation hazard and differences in charge proximity.

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