A PERFORMANCE BARRIER? CAVITY BARRIER INSTALLATION IN WALL ENVELOPE MAKEUPS

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Fire protection in wall envelope makeups post Grenfell has understandably focused on materials deemed acceptable for use depending on overall building height. Cladding and insulation products have received most attention in the aftermath of the amendment made to Regulation 7 of The Building (Amendment) Regulations 2018 (TSO, 2018). Whilst acknowledging the importance of the amendment to Regulation 7, this paper is suggesting that the area of workmanship related to detail assembly and product or component installation, more specifically cavity barrier installation, deserves equal focus in the drive for improved quality within the sector. The potential for defects in the installation of cavity barriers in ventilated rainscreen envelope makeups has been investigated by employing a mixed method research approach. Qualitative analysis in the form of an exploratory focus group was undertaken with industry professionals to gain a better understanding of potential defects occurring during wall envelope construction. The qualitative data was supplemented by a Failure Mode and Effect Analysis with building control professionals, evaluating the probability of a range of possible defects occurring during installation and the severity of the negative influence of each if they did occur. The results from this study highlight the importance of workmanship in the construction of wall envelope makeups to achieve the requisite standard of fire protection. The paper concludes by highlighting that breaks in the continuity of cavity barriers during on-site installation is an important parameter which requires consideration and proposes a method for assessing the impact of this occurrence in the stated wall envelope makeup.

Keywords: defects, cavity barrier, design management, façade fire, high-rise building

INTRODUCTION

The tragic events at Grenfell Tower in June 2017 led to the publication of The Building (Amendment) Regulations 2018 (TSO, 2018), with a change to Regulation 7, Materials and Workmanship, focusing on material performance classification in relation to fire. This amendment was unsurprising considering the events at Grenfell, and more broadly, the significant fires which have occurred worldwide over the last decade (see Guillaume *et al.,* 2018), many concerning the use of combustible cladding. The amendment to Regulation 7 focused on material performance as opposed to workmanship, with the requirements for the latter clearly stipulated in both the Regulations and Approved Document 7 (HM Government, 2013). For building

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work, the Building Regulations 2010 (TSO, 2010) outline that it should be undertaken "in a workmanlike manner", with Approved Document 7 stating "Workmanship is such that, where relevant, materials are adequately mixed or prepared and applied, used or fixed so as to perform adequately the functions for which they are intended."

There is an expectation that workmanship is viewed as being of equal importance to materials in the delivery of a robust built asset which complies with the legislative requirements. However, it should not be assumed that all workmanship results in compliant building detail assemblies. This paper focuses on one specific intricate detail assembly, namely wall envelope makeup in ventilated rainscreen systems, where there is a potential for issues with the as-constructed assembly due to its complex nature. With a focus on building performance from a passive fire protection, building and life safety perspective, the aim of the paper is to identify potential areas of concern relating to in-situ detail makeups and the possible resulting effects.

Workmanship and Fire Protection
As-constructed detail assemblies deviating from approved technical designs, with inadequate workmanship just one of many possible reasons for this, is an issue which has been well documented within the construction sector (Littlewood *et al.,* 2017; Hackitt, 2017; Comiskey *et al.,* 2018; Daly *et al.,* 2019). Research from the Chartered Institute of Building (CIOB) has illustrated issues with the management of quality in terms of workmanship (CIOB, 2018), with the content of the independent inquiries into the Construction of Edinburgh Schools (City of Edinburgh Council, 2017) and the DG One Complex (Dumfries and Galloway Council, 2018) reinforcing this assertion. The importance of good workmanship is widely acknowledged, especially as it can have a significant impact on protection against fire spread (DCLG, 2008). However, there is potentially a lack of awareness amongst unskilled tradespeople on the importance of specific areas of passive fire protection, namely fire and cavity barriers (DCLG, 2008), which could result in non-compliance of key detail assemblies. Others have made the link between on-site workmanship and the potential impact on fire protection strategies. A paper by Daly *et al. (*2019) alluded to issues with supervision and the seemingly oblivious need for installation of critical components, from a life safety perspective, to be exactly as per manufacturers specification. Littlewood *et al. (*2017) echo the sentiment that detail integrity is not assured, with possible shortcomings in the building fabric potentially contributing to the spread of smoke and fire. Decade long research undertaken by Building Research Establishment (BRE) Global identified that, out of approximately 106 fires investigated, 34 had an aspect related to concealed fire spread, and out of these 34, around half mentioned cavity barrier issues, either solely or along with other issues (Shipp *et al.,* 2015).

Cavity Barrier Installation
The potential for in-situ issues with cavity barriers in refurbishment projects was illustrated in expert reports as part of the Grenfell Inquiry (Bisby, 2018; Lane, 2018). Notable observations included some cavity barriers not being fitted as per the manufacturers specification and examples of breaks in the continuity of cavity barriers resulting in what was described as an "interconnected network of connected cladding cavities" (Bisby, 2018). This paper is not speculating on cause, rather, highlighting challenges which can be encountered with in-situ cavity barriers generally, acknowledging that even perfect installation which follows the specification of the manufacturer is not a panacea in all situations. It is recognised that cavity barrier performance in the event of a fire which bypasses the cavity barrier via a combustible

external surface is somewhat irrelevant (Lane, 2018) and in the case of Grenfell, it is unlikely that even if all cavity barriers had been installed exactly as per the manufacturer specification, that this "would have been effective in preventing lateral spread of fire or smoke" (Bisby, 2018). A study by Guillaume *et al. (*2018) further illustrated the ineffectiveness of cavity barriers when the fire is driven by combustible materials as the cavity integrity is not ensured. However, it is important to stress the importance of cavity barriers as part of a well-considered passive fire protection strategy. Colic and Pecur (2020) emphasise their significance in the event of a fire, something illustrated in a study by Giraldo *et al. (*2013), and that on-site installation is critical. In the event of a fire, on-site workmanship and material installation related to key details can play a significant part in helping to reduce the overall impact on the building structure, delaying potentially disastrous situations and providing a window of opportunity for fire and rescue services to intervene.

Workmanship and Inspection

Improving workmanship quality is one area addressed by the CIOB in their 'Code of Quality Management' (CIOB, 2019), with suggestions made in relation to training, incentivisation, supervision and a greater emphasis being placed on those constructing buildings to produce good workmanship. However, this is not a magic bullet. The nature of the industry means there is always the potential for human error during construction resulting in as-constructed detail assemblies not meeting the required regulatory standards. It is also important to acknowledge that, with the majority of buildings which will be around in 2050 having already been constructed (Ford and Gillich, 2018), this means that even with exemplary workmanship standards over the next three decades, there will still be uncertainty over the quality of many built assets. Mindful of this, the focus of this study is to identify potential defects and discuss possible resulting effects in the area of greatest significance, that being already constructed buildings including those which have been refurbished.

Workmanship, inspection, and quality are interlinked and there is huge scope for advances in inspection techniques for quality checking, both during and after construction. Such advances are already taking place in the form of the development of inspection apps (Siderise, 2020), which could be supplemented by the application of existing technologies, such as infrared photogrammetry, or via innovative digital solutions. Daly *et al. (*2019) have already highlighted the potential for inspection of cavity barrier positioning, prior to encapsulation within the building fabric, using point cloud overlay on a project Building Information Model. However, this is a separate area of investigation which is outside of the scope of this paper.

Ventilated Rainscreen Systems

A deficiency in an as-constructed detail assembly poses a concern in any building type, with the significance exacerbated in complex medium and higher rise residential schemes due to the level of human occupancy. Ventilated rainscreen systems are a popular choice of external wall envelope for such buildings, used in both new build and refurbishment settings (Guillaume *et al.,* 2018; Asimakopoulou *et al.,* 2016; Giraldo *et al.,* 2013). A ventilated rainscreen system is essentially a façade assembly made up of an outer panel, a ventilated cavity and an inner leaf. The air flow in the cavity provides several advantages both from an energy and moisture prevention perspective. A process of natural convection can take place in the cavity resulting in a chimney effect. Should a fire occur in the cavity, flame extension can be excessive and become elongated, to between five and ten times the original length (Colwell and Baker, 2013; Asimakopoulou *et al.,* 2016), as oxygen is sought to sustain combustion, facilitating rapid fire spread through the hidden cavity if the barriers to prevent this are not in place (Colwell and Baker, 2013; Asimakopoulou *et al.,* 2016). The design of the cavity, a concealed space, is considered as a critical detail assembly from both a fire and life safety perspective, with the role of cavity barriers in this assembly playing an important part in the passive fire protection strategy. Workmanship detailing is therefore key in ensuring the cavity has a clear ventilation and drainage channel which, should a fire occur, fully fills to act as a seal, preventing the spread of smoke and fire. Asimakopoulou *et al. (*2016) outlined that much of the literature related to ventilated façade systems has focused on energy performance as opposed to their behaviour in relation to fire, but that in the event of a fire, such systems may contribute to fire spread. As such, additional research is required to fill this knowledge gap.

Cavity Barrier Requirements

This paper focuses on the design requirements of cavity barriers in medium and high-rise residential schemes, more specifically ventilated rainscreen systems. It will refer to Approved Document B Volume 2: Buildings other than dwellings (HM Government, 2019), referred to as ADB in the remainder of this paper, as the reference document providing practical guidance in terms of meeting the requirements of The Building Regulations 2010 (TSO, 2010) and subsequent amendments. It is acknowledged that the devolved regions of the United Kingdom (UK) have their own technical guidance documents related to fire safety; Technical Booklet E in Northern Ireland (DFP, 2012), Building standards technical handbook 2019: non-domestic in Scotland (Scottish Government, 2019) and Approved Document B Volume 2: Buildings other than dwelling houses in Wales (Welsh Government, 2015), and that separate guidance on fire safety is provided by the Centre for Window and Cladding Technology (CWCT) in their Standards for Systemised Building Envelopes publication (CWCT, 2005) and the more recent Technical Note 98 (CWCT, 2017). However, the sole focus of this paper is ADB in England.

Regulation and Technical Guidance Requirements

To comply with the legal requirements of the building regulations, B3 (4) (Building regulations, 2010) states that "The building shall be designed and constructed so that the unseen spread of fire and smoke within concealed spaces in its structure and fabric is inhibited." Cavity barriers are key in this regard in ventilated rainscreen makeups. For clarity, the definition of a cavity barrier as provided in ADB is a construction within a cavity, other than a smoke curtain, to perform either of the following functions.

- Close a cavity to stop smoke or flame entering
- Restrict the movement of smoke or flame within a cavity

The term should not be confused with similar phrases used in relation to passive fire protection such as cavity closer, fire barrier and fire stopping. In simple terms, in the event of a fire in a ventilated rainscreen makeup the purpose of a cavity barrier is to cut off the supply of oxygen to prevent the chimney effect. It also cuts off potential fuel supplies to a fire in the form of materials above and below, so the fire is contained within a compartment for a time period in accordance with the regulations. In ventilated rainscreen systems, vertical barriers are installed to fully fill the cavity. Due to the need for ventilation, horizontal barriers do not fully fill the cavity. Instead, an intumescent strip is placed on the outer face of the cavity barrier, which, under normal conditions facilitates the required ventilation gap to be achieved. In the event of a fire, and when a critical temperature is achieved, the intumescent strip activates, expands and fully fills the cavity. Section 12.8 of ADB states that cavity barriers should be provided as set out in Section 9 of the same guidance document, with the key requirements for the area of focus for this study including:

- The provision of cavity barriers around openings and junctions between external cavity walls and compartment floors and walls
- Maximum dimensions of cavities as per Table 9.1 of ADB
- The requirement to provide 30 minutes integrity and 15 minutes insulation
- Acceptable materials for use specified
- The requirement for adequate fixing, with the term "tightly fitted" used
- Guidance on allowable openings, which are limited to few scenarios

With the regulations and technical guidance setting out clear requirements for the performance of cavity barriers and the review of literature highlighting potential workmanship and installation concerns more generally, a research methodology was developed to further investigate the likelihood of deficiencies and their impact.

RESEARCH METHODOLOGY AND DATA COLLECTION

This study is an example of real-world research, as discussed by Robson and McCartan (2016), in so far as it is identifying a current problem and seeking to progress research into the area. To further explore the findings emerging from the review of literature a mixed-method approach was deemed most suitable. This consisted of a two-stage approach, a qualitative analysis in the form of an exploratory group interview, with the findings from this forming the basis for a Failure Mode and Effect Analysis (FMEA) undertaken as part of a focus group. The group interview was undertaken for exploratory purposes, to allow for a better understanding of the topic area, ascertain the feasibility of follow on work and methodological techniques, identify nuances and add precision (Frey and Fontana, 1991 citing Babbie, 1989).

The FMEA was influenced by the work of Dubas and Paslawski (2018) and a combination of the nominal and interacting group models, as described in Adams (2006), was used along with a vignette technique, that being eleven construction defects related to cavity barriers visually represented. Each scenario was presented to members of a focus group, consisting of eight building control professionals, with each member given time to record their individual observations for each scenario should they so wish. This was followed by a group discussion before figures were agreed to give an overall value for which a risk level could be attributed (Table 1). In the case were there was no unanimous agreement, an average figure was taken. The FMEA approach was selected as it collects numerical data which can be analysed, allowing for identification of critical junctures in ventilated rainscreen makeups where risk is greatest. Ethical approval was sought and obtained for the study.

Professional Insight and Analysis

An initial exploratory group interview took place with two industry professionals, both from a leading fire safety engineering consultancy, and focused primarily on on-site inspection processes. This exploratory work was aimed at identifying common defects which had the potential to occur in the construction of ventilated rainscreen makeups, specifically in relation to cavity barriers, based on the industry experience of those being interviewed. The discussion suggested that the potential for incorrect and substandard quality installation of cavity barriers was higher in commercial and larger scale projects. As highlighted earlier in this paper, reference was made to tradespeople, as opposed to specialist installers, installing cavity barriers on projects, with issues arising requiring the work to be redone several times before installation was deemed as being satisfactory. It was stated that, due to the rapid erection of many larger scale projects, aspects such as this can be easily missed, especially if frequent inspections are not undertaken. The findings from the exploratory group interview formed the basis for the FMEA (Table 1).

Table 1: Failure Mode and Effect Analysis

Probability: 1-extremely unlikely, 2-remote, 3-occasionsal, 4-reasonably possible, 5-frequent
Severity: 1-no effect, 2-very minor effect, 3-minor effect, 4-critical, 5-catastrophic
Risk Level: < 9 Low, < 12 Moderate, < 15 High, ≥ 15 Unacceptable

Description of Defect	Probability (P)	Severity (S)	Risk (P x S)	Risk Level (RL)
Inadequate installation of fixing brackets, either the number of brackets used not being in accordance with manufacturers recommendations or the installation being defective	3	3.5	10.5	Moderate
Missing cavity barrier, either vertical or horizontal	3	4	12	High
Cavity barrier in place but sagging in the cavity due to issues with the fixing brackets	3	3.5	10.5	Moderate
Vertical cavity barrier installed in a horizontal position	2	4	8	Low
Horizontal cavity barrier installed in a vertical position	2	1	2	Low
Horizontal cavity barrier installed with the wrong orientation i.e. upside down	2	3	6	Low
Gaps between cavity barriers	4	3	12	High
Cavity barrier connection joints not taped in accordance with manufacturers recommendations	4.2	2	8.4	Low
Cavity barrier placed in front of insulation i.e. insulation placed first which is not in accordance with manufacturers recommendations	2.2	4	8.8	Low
Incorrect dimensional gap between the rear of the cladding panel and the cavity barrier	2	4	8	Low
Cavity barrier material substitution	2.8	4.2	11.8	Moderate

DISCUSSION

The findings highlight that in terms of risk level, missing cavity barriers and gaps between cavity barriers have the highest ranking. Perhaps more importantly, in terms of probability of occurrence, gaps between cavity barriers and joints not being taped were ranked the highest. The requirement for taping of the joints is something highlighted by certain manufacturers of cavity barriers in their installation guidance documents (Siderise, 2019). The findings from this study are in broad alignment with a study by Comiskey *et al. (*2019) which also highlighted potential inadequacies in relation to gaps between cavity barriers in ventilated façade makeups. Note that whilst Comiskey *et al. (*2019) use the term ‘fire barriers’, its scope and the vignette clearly illustrated this was in relation to an enclosed cavity in a wall envelope makeup. The findings would suggest that there is a genuine potential for breaks in the continuity of cavity barriers when installed on-site.

Impact of Cavity Barrier Gap

It is reasonable to assume that a break in the continuity of a cavity barrier caused by a gap could provide a passage for the movement of smoke from one compartment to an adjoining compartment and would therefore be in contravention of the building regulations. A gap could potentially occur where two cavity barriers abut, perhaps most critically at external or internal corner junctions with mitred edges or around doors and windows. Additionally, where vertical penetrations sometimes occur through horizontal cavity barriers, such as with rainscreen support rails. Consideration of the movement of smoke is important due to suggestions that a major cause of fatalities in a fire is due to spread of smoke and its inhalation (Cheung *et al.,* 2006), with smoke gases being ranked as more dangerous than heat or particulate matter by respondents in a paper by Littlewood *et al. (*2017). Whilst acknowledging their scope and focus is not the same as what has been identified for this paper, several authors have highlighted the possibility of unwanted spread of smoke if there are potential issues with construction. Cheung *et al. (*2016) discussed the impact of gap size around fire-rated doors on smoke spread. Littlewood and Smallwood (2017), in a study which included both a dwelling and flats, demonstrated the effect of potential failings in the building fabric in relation to the spread of smoke. They concluded by suggesting that compartmentation between dwellings within the UK context is potentially not working in relation to smoke and fire spread, with a high likelihood of injury or death in the event of a real fire.

There is a need to discuss and highlight the potential consequences in higher rise projects which have different, and could be argued more complex, wall envelope makeups and detail assemblies. With added complexity comes the greater risk of workmanship or product installation issues. It is therefore important to have an awareness and understanding of what these are and their potential significance. The FMEA has begun to address the former, but the impact of such failings also needs to be investigated. Should gaps exist between compartments in a ventilated rainscreen makeup, what is the likelihood of smoke not only spreading between compartments but making its way into a building and the potentially serious consequences this presents in relation to life safety. A speculative analysis would suggest that such a likelihood is minimal as the smoke would need to find a pathway through various layers of the wall envelope makeup. However, analysis of as-constructed detail assemblies identified in this paper would suggest that it is a possibility and thus needs to be considered further, along with the impact of the dimensional tolerances of any gaps.

Methods of Analysis

The only way of understanding the true impact of gaps between cavity barriers is via the results of experimental testing or simulation. Full scale fire tests which align with the area under investigation as described in BS 8414-2:2015+A1:2017 (BSI, 2017) and supporting document BR135 (Colwell and Baker, 2013), and intermediate scale fire tests as per ISO 13785-1 (ISO, 2002), are all undertaken in a laboratory and therefore assume "perfect and controlled conditions" (Colic and Pecur, 2020). This is echoed by Littlewood at al. (2017) who caution that testing of products does not account for in-built performance, with the potential for components and products not being installed as specified. Colic and Pecur (2020) acknowledge "detailing is difficult to evaluate." These tests are unlikely to provide the data required, not to mention the considerable cost associated with them.

Computational Fluid Dynamics (CFD) simulation is also often used to predict the likely consequence of a fire (Drean *et al.,* 2019), but for this to be accurately modelled a detailed understanding of the materials and their performance under simulated real-world conditions is required. In the case of ventilated rainscreen makeups, an understanding of the impact the intumescent strip has on the gap between cavity barriers would be beneficial before such analysis takes place. For instance, what impact does the intumescent strip have in the event of a fire, does it potentially close any gap between the cavity barriers and thus negate the impact of the gap. There are other related questions such as what impact the size of the gap has on the performance of the intumescent strip. With this in mind, this paper is proposing that a logical first step could be to adapt the fire test identified in the Association for Specialist Fire Protection (ASFP) (ASFP, 2014) which is designed to evaluate the fire resistance of open state cavity barriers in ventilated rainscreen systems, specifically focusing on the upward spread of fire. Whilst this test is focused on the intumescent strip and the time from ignition until the cavity barrier is sealed, this test could be adapted, with a gap left between cavity barriers to evaluate the impact of the intumescent strip under test conditions. This would provide an insight into the potential effect of the gaps.

CONCLUSION

This paper has highlighted the potential for deficiencies in the installation of cavity barriers during on-site operations, with gaps or breaks in the continuity of cavity barriers posing a high risk and having a high probability of occurrence, along with joints not being taped. Such occurrences, certainly gaps between cavity barriers, could be considered as being in contravention of the building regulations. To evaluate the impact of this occurrence this paper is suggesting that the fire test identified in ASFP (2014) could be adapted to evaluate the effect the intumescent strip has on gaps between cavity barriers under differing dimensional tolerances. This would provide a better understanding of the likely gaps being present in the event of a fire, after the intumescent strip has been activated, and allow for CFD analysis to predict the severity of consequence in terms of smoke movement between compartments. Once a fuller understanding is developed, medium and large-scale testing could be undertaken to evaluate the likelihood of smoke not only moving between compartments but finding a path into the inside of a building.

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