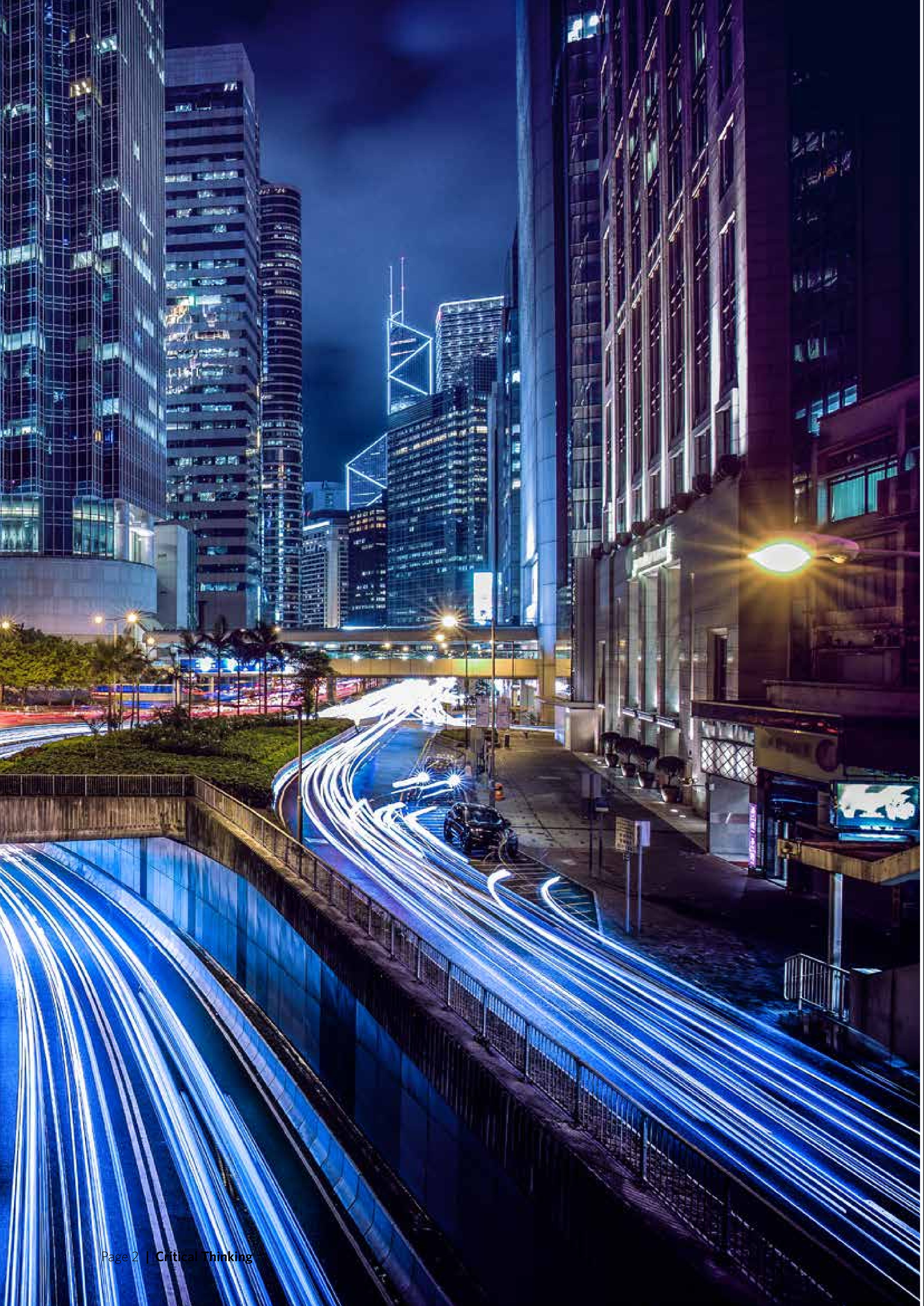
Critical **Thinking**

September 2019

HDR | Hurley Palmer Flatt Group



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Introducing HDR | Hurley Palmer Flatt Group

We are delighted to announce that earlier this year the Hurley Palmer Flatt Group joined HDR, a global firm specialising in architecture, engineering, and consulting. Together, our capabilities span the life cycle of Building Services Engineering, from design, MEP, technology, commissioning and maintenance. Our professionals represent hundreds of disciplines and work on diverse teams to provide a total spectrum of services. Our ability to draw upon company-wide global resources and expertise, is a great strength in meeting and exceeding your expectations.

HDR is an employee-owned firm who wished to expand their presence and services into the United Kingdom and looked for partners or an acquisition to help facilitate that goal. Hurley Palmer Flatt Group was looking for a U.S. based partner for global growth.

Going forward, the U.K. firm will do business as HDR | Hurley Palmer Flatt Group. The acquired entity comprises all subsidiaries, which will also do business as HDR | Hurley Palmer Flatt; HDR | Andrew Reid; HDR | Bradbrook Consulting; and HDR | Concentre Consulting.

This is a cultural fit of two firms, with the strategic geographic fit of Hurley Palmer Flatt Group in EMEA and APAC to HDR's experience. Together the two firms represent more than 10,000 employees in over 200 locations around the world, and significantly increase our Building Engineering Services to more than 1,200 employees. ◆

Keeping Data Safe with Gas Suppression Systems

Electrical Engineer, Zack Wong, explains how to address the acoustic impact of discharge from a gas suppression system in data centres.

A gas suppression system is a common fire protection system, installed to protect data halls or co-location areas within data centres. They have been used increasingly over the past decade as an alternative to water-based sprinkler protection systems because they don't spray water with potential residues that can damage IT equipment.

However, there have been multiple instances of these systems being triggered accidentally. The sound pressure created during the gas discharge causes vibration, which in turn then damages Hard Disk Drives (HDD) within the room it is trying to protect. This can then result in the potential momentary loss of data or complete loss.

Preventing this is a huge challenge for owners and operators.

How does gas suppression release lead to data loss?

The impact of gas suppression systems on hard drives has been exacerbated by the physical reduction in size and data densification of hard drives, making them more susceptible to vibration at particular frequencies. This impact has been seen on all types of gas suppression system, irrespective of whether chemical or inert gas is used.

The densification of data on hard drives has made them more sensitive to external factors, such as scratches from the spindle motors that read their information, since they need to be positioned closer to the surface. Those scratches – and ultimately the loss of data - can easily occur when the motors are jolted by high frequency sounds, specifically, when gas is released from the pressurised cylinders. The gas moves through and exits the gas nozzles at a very high speed, causing high levels of sound energy to be generated.

According to studies done by Siemens, performance degradation begins when sound levels reach greater than 95 decibels (dB) at a hard disk drive. It should also be noted that gas discharges have no effect on static equipment such as network equipment, servers and solid state hard drives (SSD).

How do you prevent gas suppression discharge?

Our experience in data centre design and commissioning, has given us greater visibility into the most effective prevention for discharge of gas suppression systems and protecting against data loss. Our recommendation is to use a combination of the following measures:

- **Reduce the risk associated with human error**
  Human error is the number one cause of accidental discharge, according to a 2017 Uptime Institute survey. Yet, strict procedures, rules and training imposed by the data centre operators can reduce risks associated with human error greatly.

- **Fit or retrofit 'silencer' nozzles**
  Silencer nozzles are a popular recommendation as they can reduce the sound pressure at the source and be thoroughly tested in a factory before commissioning on site. However, care is needed in the selection of the nozzles, as some units can only silence sound down to around 100 dB and 110 dB at a hard disk, which can still damage certain hard disk drives or increase their failure rate. With careful selection and re-positioning away from hard drive equipment, ensuring that nozzles have been fully tested and certified, it is possible to reduce noise levels down to 95dB at a hard disk.

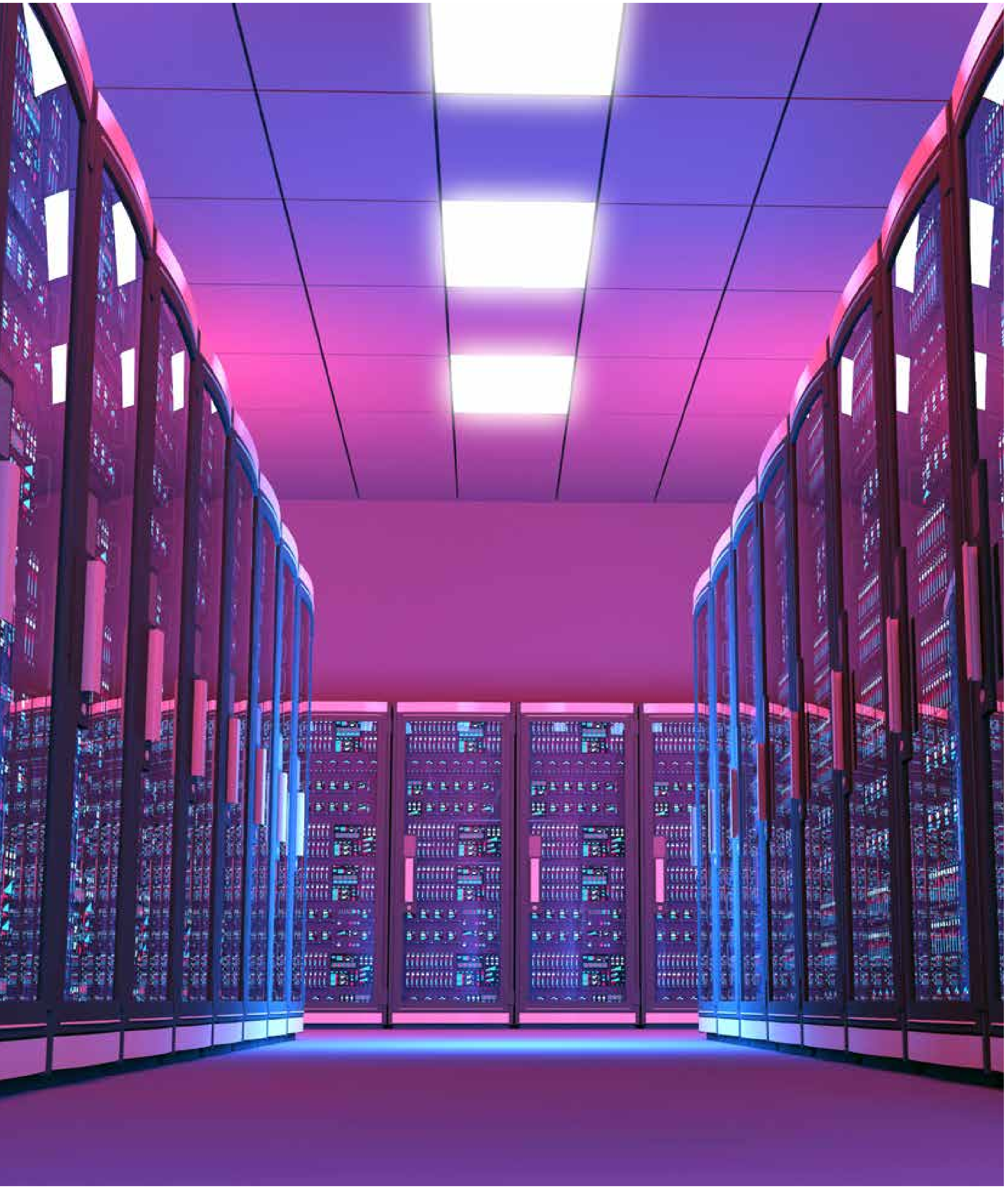
- **Commissioning, testing and maintenance**
  Improper maintenance of gas suppression systems can cause data centre downtime - and ultimately loss of time and money – as a result, it is important to follow manufacturers' recommendations.

  It is also vital to test the gas system during the commissioning stage to ensure it will work as designed. Regularly scheduled maintenance is very important as in some cases, accidental discharge has been due to component failures, such as the solenoid valve not being able to hold the pressurized gas in place. Skipping maintenance prevents the discovery of faults and could lead to failure under uncontrolled scenarios, which will cause more complications over time.

- **Sound muffling materials**
  Sound (and vibration) travels by bouncing off several surfaces before arriving at the HDD. By putting sound muffling material on those surfaces, the sound waves can be absorbed and potentially reduce the end effect. We also recommend soundproofing server racks and doors, as well as isolation mounts on HDDs, particularly for smaller data halls.

- **Improve detection and activation**
  Fire suppression and fire detection go hand-in-hand when it comes to having an effective system. The balance between being able to detect smoke early and being too sensitive is key.

  It is essential to ensure that the installed gas suppression systems are activated via a double-knock system, which means there should be two unrelated systems that can



detect smoke or fire. This could be a conventional smoke detector and an aspirating smoke detector, which constantly tests air samples around the room for smoke particles.

- **Replicating data to off-site disk storage**
  Businesses should have appropriate Business Continuity Management Plans that are written, practised and address data recovery. The cost of this should be considered against duplicating data over several sites. In any case, regular backups of data are important.

Alternatives to gas suppression systems

The Uptime Institute states that most data centres would be best served by a combination of pre-action (dry pipe) water-based sprinkler systems and high-sensitivity smoke detection. Most risk managers and insurance companies will support this choice as long as other operating requirements are met, such as having trained staff who understand the building's fire protection system and how to handle an actual fire. However there remains the risk of water penetrating IT equipment, so this needs to be reviewed in conjunction. In the U.S., the insurance company Factory Mutual has now given approval to the use of water mist systems, under FM 5560, for data centres - albeit under very strict conditions particularly in relation to air flow rates - so there are alternatives.

Alternatives to hard disk drives

It is possible to use enterprise-grade hard disk drives, some of which are slightly less prone to vibration effects. However, the most concrete way to reduce the risk of data loss is by using either Solid State Drive (SSD), or tape storage technologies.

SSDs use integrated circuit assemblies as memory with no physical rotating heads. No moving components mean no possibility of pressure waves causing reading errors.

Tape storage technologies hold data in magnetic strips. Data is read as tape is wound between reels. A disadvantage is that this technology is much more sensitive to temperature and humidity than alternatives.

For smaller critical areas protected by gas suppression, the use of SSDs may be a worthwhile investment for risk reduction.

Where to from here?

Every data centre operator should select the fire protection or suppression preference that best suits their data storage environment, budget and customer requirements.

For data centre customers, check with your operator on the gaseous suppression technology they use as well as which hard disk you use and whether these can withstand discharge.

For data centre managers, we recommend putting documentation in place to prevent accidental discharge as well as looking into other potential solutions. It is prudent to understand all the effects and design accordingly.

As with so many design topics, there is no 'one-size-fits-all' solution for data centre fire suppression and it is important to review the method of fire suppression against cost, risk and stakeholder requirements early in any project.

For more information about keeping data safe with gas suppression systems, please contact Robert Thorogood on +44 20 7429 3333.

Seamless Collaboration Delivering The Event Complex Aberdeen

Associate Director, Emma MacLeod, discusses the outcome of seamless collaboration as well as the importance of an innovative solution in terms of both technology selected and a holistic approach.

The Event Complex Aberdeen (TECA) Scotland, U.K. replaces the city's current Aberdeen Exhibition and Conference Centre (AECC). The new £333m development includes a 48,000 sqm Exhibition Centre (P&J Live) and two hotels (Hilton and Aloft), which are served by an on-site low carbon hybrid Energy Centre. The HDR | Hurley Palmer Flatt Glasgow office was responsible for developing the energy strategy for the site and for the engineering design associated with the Energy Centre. The successful delivery of this project illustrates what can be achieved through seamless collaboration with an extensive design and construction team who delivered this landmark project. Our services included;

- **Initial energy strategy development and concept design (to RIBA Stage 2)**
- **Financial modelling and analysis to inform energy strategy**
- **Energy Centre engineering design and specification (to RIBA Stage 4)**
- **Technical Adviser to Aberdeen City Council**
- **BIM (Building Information Management)**
- **BREEAM Assessor**

HDR | Hurley Palmer Flatt developed an energy strategy for the site-wide development, which addresses key issues, such as significant fluctuations in energy demand and meeting the required carbon emission reductions. The energy strategy is centred on the aspiration of Aberdeen City Council to develop the most sustainable venue of its type within the UK. The energy strategy embodies the Scottish Government's "A 2050 Vision for Energy in Scotland" which focuses on three core principles:

- **A whole-system view**
- **An inclusive energy transition**
- **A smarter local energy model**

Our holistic approach allowed external factors to be considered and integrated into the design. As such, the project successfully combines a low carbon heating, cooling

and power network with decarbonised transport fuel, thus embodying the "Smarter Local Energy Model" principle within the 2050 vision. This project is also the first in the U.K. to deliver low carbon trigeneration and renewably produced Hydrogen at the point of demand, thereby demonstrating the viability of such a model. Projects such as this are integral to meeting the 2030 target for 50% of the energy for Scotland's heat, transport and electricity consumption to be supplied from renewable sources.

The ability to combine Anaerobic Digestion (AD) and Hydrogen Generation allows for both, a carbon reduction and revenue generation/cost reduction. This was demonstrated by financial modelling throughout the various stages of the project. The use of AD also provides a cost effective output for household waste and organic waste from adjacent farmland, with green hydrogen produced by electrolysis providing load balancing services for excess onsite electrical generation.

HDR | Hurley Palmer Flatt provided the detailed design of the Energy Centre, which included the UK's largest static Fuel Cell installation, Combined Heat and Power (CHP) technologies and electrolysers. These produce green Hydrogen gas for use within the city's Hydrogen bus network. The project was delivered using 3D Revit modelling to allow full coordination of the sizeable items of plant and the complex integration of multiple systems.

In order to facilitate the inclusion of multiple, complementary sources of generation within an energy system, it is necessary to define and understand how the technologies in question will work together (i.e. in 'hybrid' operation). This is in order to meet demand, generate revenue and satisfy client priorities. Such a change away from more traditional approaches, has significant implications for the role of designers throughout the design process. This creates a need for decision support early in the design process and effectively brings forward the need for detailed modelling. The HDR | Hurley Palmer Flatt modelling and design approach used for the Energy Centre, was developed in conjunction with the University of Strathclyde. It caters for this additional complexity in the design by providing a structured approach, which uses a range of software tools and modelling techniques to reduce uncertainty through a detail-driven solution. Our energy modelling approach enabled demand profiling to be carried out for the site. New modelling techniques were developed to model the performance of the Energy Centre systems, enabling it to be reviewed at sub-hourly intervals across an entire year of operation. We could demonstrate, test and optimise the control strategy, thereby removing the traditional design bias and enabling designers to optimise the design and specification of the Energy Centre for the varying demands of the site. The introduction of a high temporal resolution model also allows designers to test and interrogate alternative solutions and operational scenarios. This reduces the uncertainty associated with the system and allows resilience testing and optimisation to be undertaken quickly and accurately.

The new modelling techniques allowed plant sizing to be optimised to avoid costly oversizing. We could also test the sequencing of different items of the plant to effectively match energy demand and supply. Large peak demand and low baseload is managed with the use of energy storage in the form of hot and cold thermal stores, hydrogen production, and grid export for excess production. Resilience and virtual storage is provided by utilising both electricity and gas grid for export and supply. The AD system provides both gas to the grid and also private pipe to the Energy Centre. This maximises the direct use of low carbon green gas, while also providing carbon offset for the gas delivered through the gas grid and means that the design achieves an Good Quality CHP (GQCHP) index of over 113 at design stage.

An optimised control strategy was developed to maximise the use of the embedded energy systems and minimise grid dependency.

Our Technical Adviser role provided an opportunity to help secure the legacy of the Energy Centre, through developing the technical specification of the Energy Centre operation and maintenance, as well as defining the roles, responsibilities and key performance indicators to be delivered by the successful contractor.

The Exhibition Centre and Hilton Hotel are both on track to receive BREEAM Excellent which was delivered through our role as BREEAM assessor during the development. The low carbon performance of the Energy Centre enabled the Exhibition Centre and hotels to comply with Section 6 of the Technical Handbook and Building (Scotland) regulations 2004. The carbon reductions were further improved beyond regulations in order to achieve the BREEAM excellent rating for both the Exhibition Centre and Hilton Hotel.

This project is innovative in both the technology selected and the holistic approach. It also addresses local issues such as waste management and provides a clean transport fuel. Each element is fundamental to the feasibility of the overall strategy which considers finance, energy, efficiency, carbon footprint, local employment, local environment, sustainability and establishing Aberdeen as Europe's Energy Capital.

For more information please contact Mark Arthur, Neil Hadden and Emma MacLeod on +44 141 465 1440. ◆

Are you prepared for Whole Life Carbon Emission Assessments?

Energy and Sustainability Divisional Director, Paul Scriven, and Associate, Jordan Kirrane, explore the effect of climate change and the impacts for companies at all stages of the building life cycle.

Whether we choose to agree with, or be cynical of 'Climate Change' we all have a responsibility to the asset(s) we contribute to, own, occupy, deliver and manage. As such, the choices we've made and will make today, are impacting tomorrow and future generations.

Our awareness and consideration of climate change is in part due to the growing concern around climate change, the mounting pressures younger generations are putting on us, and the call for industry to react faster to secure a more sustainable future.

Irrespective of what our personal thoughts are, this movement is influencing our industry. Simply look at the proposed changes to London (United Kingdom) planning requirements considering whole life carbon assessments (primarily led by the Greater London Authority) and the developed versions of sustainable building assessment methods, such as BREEAM.

For years now, industry has recognised that one of the missing links in our fight to reduce carbon is 'whole life carbon emissions'. Over recent years, research, standards and tools have been developed to address this missing jigsaw piece. As such, is should be of no surprise to hear whole life carbon assessments are already being targeted and implemented in our industry.

Our specialist in-house Energy and Sustainability team is seeing a refreshing and growing movement of corporate clients taking ownership in their whole life carbon emissions. This welcomed uptake is seeing companies either looking to review their stock to set targets or deliver already established whole life carbon reduction targets for 2030 and 2050.

"Seamless collaboration"

Whilst a number of clients are looking for leadership in developing their 'best-fit' company and operational sustainability metrics, others have already set ambitious targets such as:

- Zero waste to landfill by 2025
- A reduction in carbon emissions across a value chain of 50% by 2030
- 35% reduction in carbon emissions from construction by 2030
- 80% reduction in emissions from operations by 2030
- Reporting on the carbon emissions associated with all supply chain activities by 2030
- Net zero carbon operational emissions from all their directly managed buildings, including listed buildings by 2030
- Carbon positive across business activities by 2050
- Water neutral by 2050
- Be a net biodiversity contributor by 2050

Currently, we are mainly seeing a spike in interest from companies holding medium to large scale asset portfolios, wanting to better understand the overall impact of their activities. In particular; how much carbon is associated with an individual asset and how the asset then compares to other assets in the portfolio, enabling them to more generally benchmark current and future ratings. An example of this is where we have recently engaged with a global commercial real estate company, international property group and London property developer to provide tailored whole life carbon assessments and briefing documents for their existing and new assets.

Whole life carbon assessments typically include the following, but are not limited to:

- Embodied carbon from building materials (Life Cycle Carbon Assessment (LCA))
- Carbon associated with replacement cycles (LCA)
- Regulated and unregulated building consumption (real life consumption data and/or enhanced industry best practice design assessment)
- Carbon associated with operations (e.g. water consumption, transport, waste) scoped to enable comparison between portfolio assets.

These assessments typically result in a single carbon profile value for each of the assets' which is typically reported in CO2e/kg/m2. This value can then be translated into a portfolio average, or various metrics, to inform progression of the corporate strategy and plan.

Once the single carbon profile value(s) has been measured the 'carbon optioneering analysis' can begin. Such an analysis would typically consist of;

- Material optioneering (LCA – Software)
- Replacement and maintenance plan testing (LCA – Software)
- Best practice operations transfer / interventions
- Modelled regulated and unregulated energy reductions (Digital Twin)
- Life Cycle Costing (LCC)

This analysis would result in a series of costed interventions showing how the asset or asset portfolio could be altered to meet the clients corporate carbon reduction targets over time. This would typically be presented as a 'roadmap' to a particular target.

Part of our process and strategic approach to carbon reduction is to also consider potential synergies with established sustainability assessment methodologies. This can identify potential additional benefit(s) and added value. An approach such as this, strives to align with our client's current and future planned maintenance / design workstreams. For example:

- ISO 14001
- ISO 50001 (ESOS)
- BREEAM In Use
- BREEAM New Construction
- BREEAM Refurbishment and Fit Out
- LEED Operations & Maintenance
- LEED Interior Design + Construction
- LEED Building Design + Construction
- Home Quality Mark

Through the life of the 'roadmap' the interventions undertaken would be measured and assessed against the 'roadmap' model, therefore creating a benchmark to test the proposed interventions. For example, if the installation of LED lighting was predicted to reduce carbon emissions by 15%, however, the resulting analysis only showed a reduction of 11%, this would need to be reviewed for the quality of installation and/or commissioning and controls. The resulting outcome would need to be re-entered in the 'roadmap' model to enable informed decisions to be made elsewhere in the carbon reduction chain. Left unmonitored to later years, the only way of achieving the planned whole life carbon reduction target may be a net zero solution(s).

Therefore, it is essential that the 'roadmap' model is kept up to date with planned maintenance and design development, on a periodical basis, to provide the client with an up to date and meaningful carbon profile. This integral process enables client reporting of progression on the journey to meeting their corporate carbon reduction target, associated Corporate Social Responsibility and carbon taxes.

Looking forward, maybe one day well see the introduction of Whole life Carbon Certificates, or similar, as we expect to see Energy Performance Certificates on buildings and white goods today. Ideally this will be applied to construction products and materials first. Watch this space!

We welcome this gear change in the industry to capture one of the missing links and enable us to provide a more holistically informed carbon approach and decision-making process to our clients on the journey to a more sustainable world.

How we can help?

We currently provide whole life carbon assessments, including value carbon optioneering analyses for top international clients. We see great potential in driving significant carbon reductions and values through our developed process.

Led by our dedicated in-house energy and sustainability development, operations and compliance teams we can engage with our clients from conception, to effectively integrate their strategies and targets into implementation, as well as monitor the delivery of their whole life carbon plan.

Further supported by our multidisciplinary capability, specialist divisions and technical board, we are able to engage with clients and provide a class-leading services in the field of whole life carbon assessments.

Should you wish to find out more about whole life carbon assessments, how it may impact your business, or our developed service line, please contact Paul Scriven on +44 20 7429 3333. ◆

The Challenges in the Structural Design of Tall Buildings

Mustafa Al-Rikabi, Divisional Director, discusses the various structural challenges that tall buildings present, ahead of the Council on Tall Buildings and Urban Habitat's World Congress in Chicago in October 2019.

Challenges in tall buildings' design are associated with their height to width ratio. Any building with height to the least plan dimension ratio of 5:1 could be considered as a tall building. The Council on Tall Buildings and Urban Habitat (CTBUH), which is holding its World Congress in October in Chicago, sub categorises tall buildings into: tall buildings and super tall buildings, with a benchmark of 300m height being the marker for the difference between the two, where any building with more than 300m height is categorised as a super tall building.

The construction of high-rise buildings started at the end of the 19th century in Chicago. This was made possible because of new inventions such as the safe elevator in 1853 and the telephone in 1876, that enabled transport of building materials and the ability to communicate to higher levels. In addition, the building materials changed as they transformed from wood and masonry to using steel frames with lighter masonry walls. Earlier buildings that were built with heavy masonry walls was limited to certain heights by its own self-weight. With steel frames the masonry could be thinner and act only as façade for weather protection and taller buildings could be constructed.

In tall buildings, the horizontal loads from wind and/or seismic activities imposes a substantial significance on the structural design, where the lateral stability system becomes a major element, which in turn, depending on its severity, influences the structural system required to resist these forces.

Vertical loads are typically calculated based on the building self weight, live loads, and finishes. These are transferred to the foundation through columns, load-bearing walls

and cores. The live load depends on the type of usage in the building and on the standard used for designing. The building façade will distribute the wind forces to the supporting slabs. The slabs are working as diaphragms and provides the lateral transfer of the resulting shear forces to the vertical lateral stability elements.

The seismic force, unlike the wind, is an excitation that starts from the building base at its foundation level, resulting in lateral forces imposed on each level, as a function of height and mass, in direct proportion, the heavier the level or the higher it is will attract higher forces. The most challenging aspect in designing high rise, slender buildings, is to overcome the buildings' destabilising overturning forces that are subjected on it from the various types of imposed lateral forces. These overturning forces becomes more significant the more slender the building is.

Various structural systems have developed throughout the years, however the selection of the most appropriate structural system for tall buildings depends on many factors including, but not limited to, geographical location, construction skills, building height, plan dimensions and intended use, as well as preferred visual appearance and architectural requirements.

The concept differentiating all these various structural systems could be reduced into three categories: the integrated lateral stability system, the dedicated lateral stability system and a hybrid system, where the shear walls or the vertical bracings are working together with the building columns to achieve the building overall stability, vertical and lateral, as in the shear wall frame structure. All the other structural systems are a variant of one of these three concepts.

What really makes it standout when compared to a low-rise building design, in structural design terms only, could be reduced to the following two fundamental tall buildings design considerations: dynamic behaviour and elastic and long-term creep and shrinkage.

In terms of mathematical modelling, tall buildings are, in effect, vertical cantilever beams, which will exhibit dynamic excitation when subjected to lateral wind and seismic forces, and move either in the direction of the force, or even perpendicular to the force direction, as in the cross-wind effect. The resultant movement direction and magnitude will depend on the building's lateral elements stiffness, arrangement, layout and of course the magnitude of force applied.

Depending on the building's height, stiffness, mass, and material damping characteristics, tall buildings will exhibit different dynamic responses, however it is quite important in terms of a building serviceability limit state design, to aim for a resulting transitional sway for the first two modes in the building excitation, and a rotational mode for the third. The lowest natural frequency (f) of vibration of a structure corresponds to the longest time period (T) of vibration, as frequency and time period are inversely proportional ($T=1/f$, $T=1/f$). The natural frequency (f) of a building can be calculated using the simple formula $f = \sqrt{(k/m)}$, where k is the overall building stiffness, and m is the mass. It is evident that the building's natural frequency is a function of its stiffness and mass, and for a given building mass the natural frequency is directly proportionate to its stiffness, where the higher frequency means the stiffer the building is.

Taller and more slender buildings present a unique situation in relation to the occupants' perception of the building's lateral motion. This is related to the movement acceleration of the floors, which is more of an issue at the higher floors. For super-tall buildings above 300 metres, it is quite likely that this 'habitability' limit state may become a governing limit state in the structural design of the building.

For preliminary design purposes, the targeted fundamental building period in design can be estimated to be as equal to the height of the building divided by '46' or - following a UBC (universal building code) rule of thumb - equal to the number of storeys divided by 10.

There are no clear code limitations on the acceptable total peak acceleration values for buildings. However, some recommendations for the comfort criteria are identified in ISO 10137 2007 for a 1-year return period, National Building Code of Canada NBC 2010 which adopts the ISO limits, and industry suggested limits for total peak acceleration for a 10-year return period. Assessing the appropriate acceleration limit to adopt is based on experience, as the perception of its effects varies from one person to another and depends on the duration of the vibration and the position a person is during the vibration incident.

The other major aspect governing a tall building design process, is the tendency of elastic shortening in its supporting vertical elements, and in concrete structures, this gets more complex due to the nonlinear behaviour of concrete with a long-term creep and shrinkage effect resulting in additional shortening with age. The shortening of the various vertical structural elements depends on multiple factors, such as the construction material, age, size, outside humidity and temperature, and more significantly the stress level imposed on them. The adverse effect of this behaviour is what a differential shortening in the various vertical elements of a building would cause to the overall structure, and specifically to the slabs, inducing additional internal forces within the slabs that may have not been designed for.

The building's columns are usually the elements subject to the most stress, due to their confined section sizes when compared to usually a bulky core size needed in a tall building. This size variance results in columns being subjected to higher stresses and subsequently higher shortening values to what the building core will exhibit. This effect is known as the 'umbrella effect', where the building perimeter (supported by columns) settles down more than its central core, forming a shape similar to an umbrella. To avoid this, height corrections of the columns should be carried out during construction, to compensate for their anticipated shortening values. To accurately estimate these values, a complex nonlinear sequential structural analysis is required, to simulate the actual construction progress of the building. However, as the core area is the heaviest part of the building, piles under the core will settle more than the piles at the building perimeter, in a counter effect to the umbrella effect, known as the foundation (raft) dishing effect. Therefore, this should be taken in consideration when estimating the columns' correcting length values, simulating piles as spring constants in the analysis with their relevant actual pile stiffness. During construction, foundation's settlement monitoring survey should be constantly carried out as the building's height build's up, monitoring at the same time the elastic shortening in the various vertical elements (cores, walls and columns), and calibrate the analytical values with the actual values obtained by the survey, and apply the required equivalent columns' height correction. This correction is summed up to a group of several levels and applied to columns usually at every 5 – 10 storeys.

In conclusion, tall buildings structural design is an exciting, complex, and challenging process, influenced by several aspects, with unique design solution to each. An early structural advice during the initial architectural development of the scheme, will enable the production of a cost-efficient design, by coordinating the best position and orientation of the core, column grid layout, and even façade shape and arrangement.

For more information please contact Mustafa Al-Rikabi on +44 20 8763 5900. ◆

HDR | Hurley Palmer Flatt Group

HDR | Andrew Reid

HDR | Bradbrook Consulting

HDR | Concentre Consulting

HDR | Hurley Palmer Flatt Group Companies

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