



High-Rise and Net-Zero Buildings of Tomorrow: Is the Construction Industry Ready?

Uponor

A research report by Uponor, July 2020



Contents

Abstract	4
Executive summary	6
Contributors	11
Healthy buildings	12
Technology in construction	18
Is net-zero achievable?	22
Conclusions	28
Rethinking water for future generations	30
High-rise case study	31
Further information	33
References and thanks	33

Abstract

At the turn of the 20th century, high rise buildings were not part of the UK skyline; however, shortly after World War 2 this phenomenon gradually became a reality. In the present day, commercial and residential high-rise developments in UK cities constitute a prevalent trend which is expected to surge in the coming years. Despite their increasing popularity, high rise buildings pose a number of challenges to the construction industry. After extensively researching and discussing the main challenges of high rise construction in 2019, this year we shed light on three themes which have made headlines, attracted academic interest and dominated discussion across the industry. Thus, our investigation into healthy buildings, technology in construction and net-zero buildings is expected to provide insights into evergreen challenges of the construction sector and evaluate their feasibility.

Delivering energy efficient, quality buildings faster and at a lower cost whilst ensuring the wellbeing of inhabitants are critical requirements of modern construction; therefore our goal is to assess whether these challenges are realistic and achievable in a constantly evolving industry. Based on a quantitative and qualitative research with industry experts, the current whitepaper discloses some intriguing and compelling findings which are anticipated to spark discussion and debate in the sector and, at the same time, highlight important considerations in the development of multi-use high-rise buildings.

Operating in an industry with a strong influence on sustainable living, Uponor aims to enrich people's wellbeing by offering high quality indoor climate and hygienic water solutions. Water quality and thermal comfort levels play a vital role in delivering sustainable buildings, hence Uponor has been keen to investigate these factors and explore the industry's perspective within this report.



Executive summary

Despite continued market uncertainty due to Brexit and more recently COVID-19, recent research suggests that there are well over 500 tall buildings (20 storeys or above) currently in the pipeline for our capital¹. According to this same research, a record 60 tall buildings were completed in London during 2019, with 88% of these including residential space. This trend is echoed in major cities outside of the capital including Birmingham, Liverpool and Manchester, which have all seen noticeable increases in tall building development, both in the pipeline and in construction, over recent years.

As a London-led but generally nationwide trend, we are likely to see significant changes to the way that we live and work over coming years, with many more people residing closely together in urban hubs instead of dispersed across low rise cities and sprawling suburban areas. As the majority of these new tall structures are mixed-use facilities, incorporating office spaces, shops, cinemas, spas, community centres etc, it could even be that parts of the UK move towards a Hong Kong style of living, where whole communities are entirely catered for 50 storeys in the air.

The planning, design and delivery of these tall buildings present a set of unique challenges, ranging from structural design considerations, cost planning and programming, through to the provision of mechanical and electrical (M&E) systems. With new regulations introduced to make tall buildings safer in the wake of the Grenfell Tower disaster, risk and safety management is also key. There is also more pressure to reduce the impact tall buildings have on the surrounding community and the environment, as well as consider the physical and mental health of those who inhabit these buildings. In addition, energy use and CO₂ emissions are critical factors of the long-term operational management and life cycle costs of high-rise buildings.

It deemed necessary to further understand the current demands on the construction sector concerning the delivery of suitable high-rise buildings and to assess whether the expectations to deliver these demands are realistic in the current climate. Therefore, Uponor undertook comprehensive research and conducted a study among 200 architects, contractors and developers to gather their insights on several key trends and challenges the sector faces on a daily basis.

Based on recent headlines regarding issues facing construction as well as common talking points within the industry, three priority themes were identified for the research.

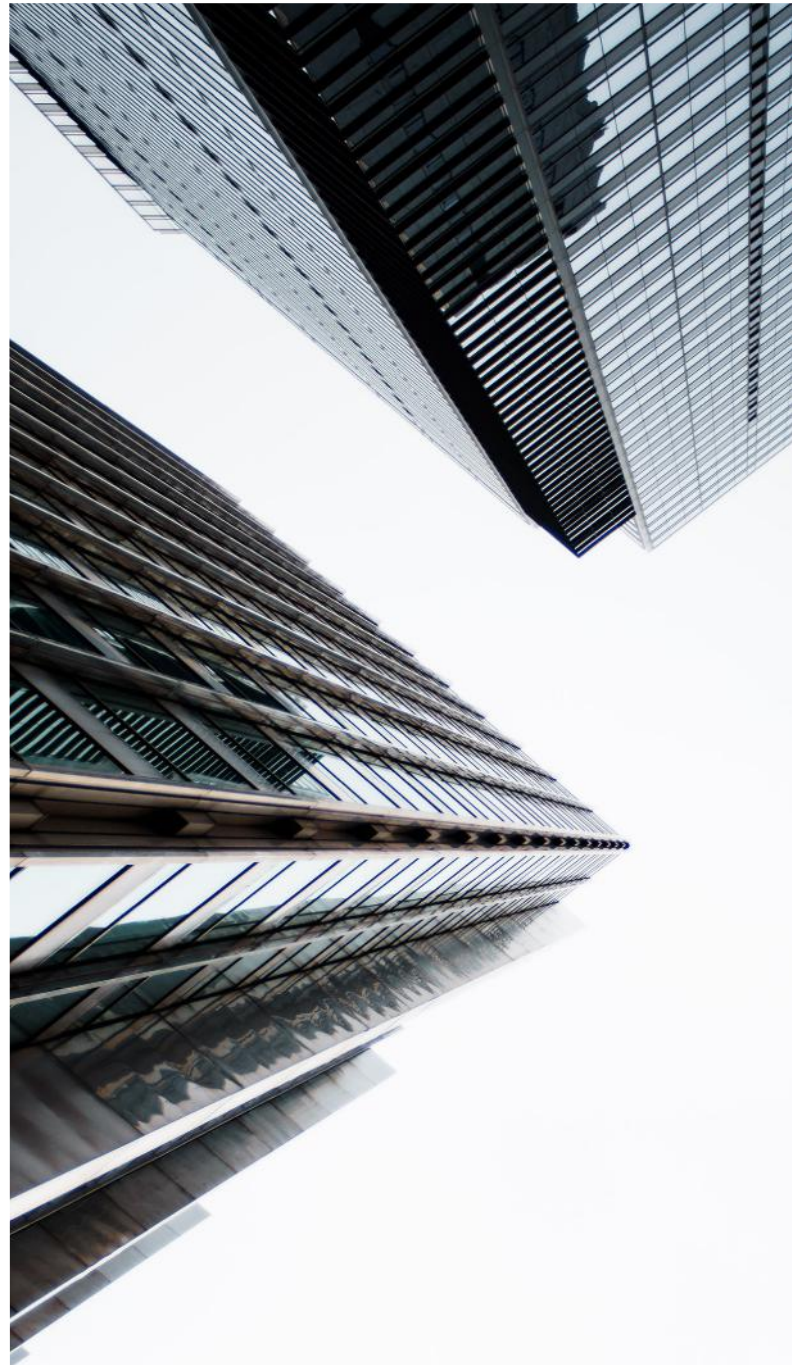




Healthy buildings

The health and wellbeing of a building's inhabitants is a major discussion point on the agenda of developers. The significance of healthy buildings in urban development is also highlighted in United Nations' (UN) Sustainable Development Goals (SDGs) for 2030². According to this resolution, sustainable urban development and management are crucial to the life quality of people. Therefore, the UN is committed towards making cities and human settlements inclusive, safe, resilient and sustainable. The resolution also emphasises the importance of developing healthy buildings and reducing the impact of urban activities on human wellbeing. In addition, research shows that hazards related to low quality buildings can lead to a range of health conditions, including physical diseases and mental health problems³. Due to the increasing demand of delivering healthy developments, several challenges are raised in the construction sector. This report discusses the different aspects of these challenges and identifies their importance considering cost parameters.

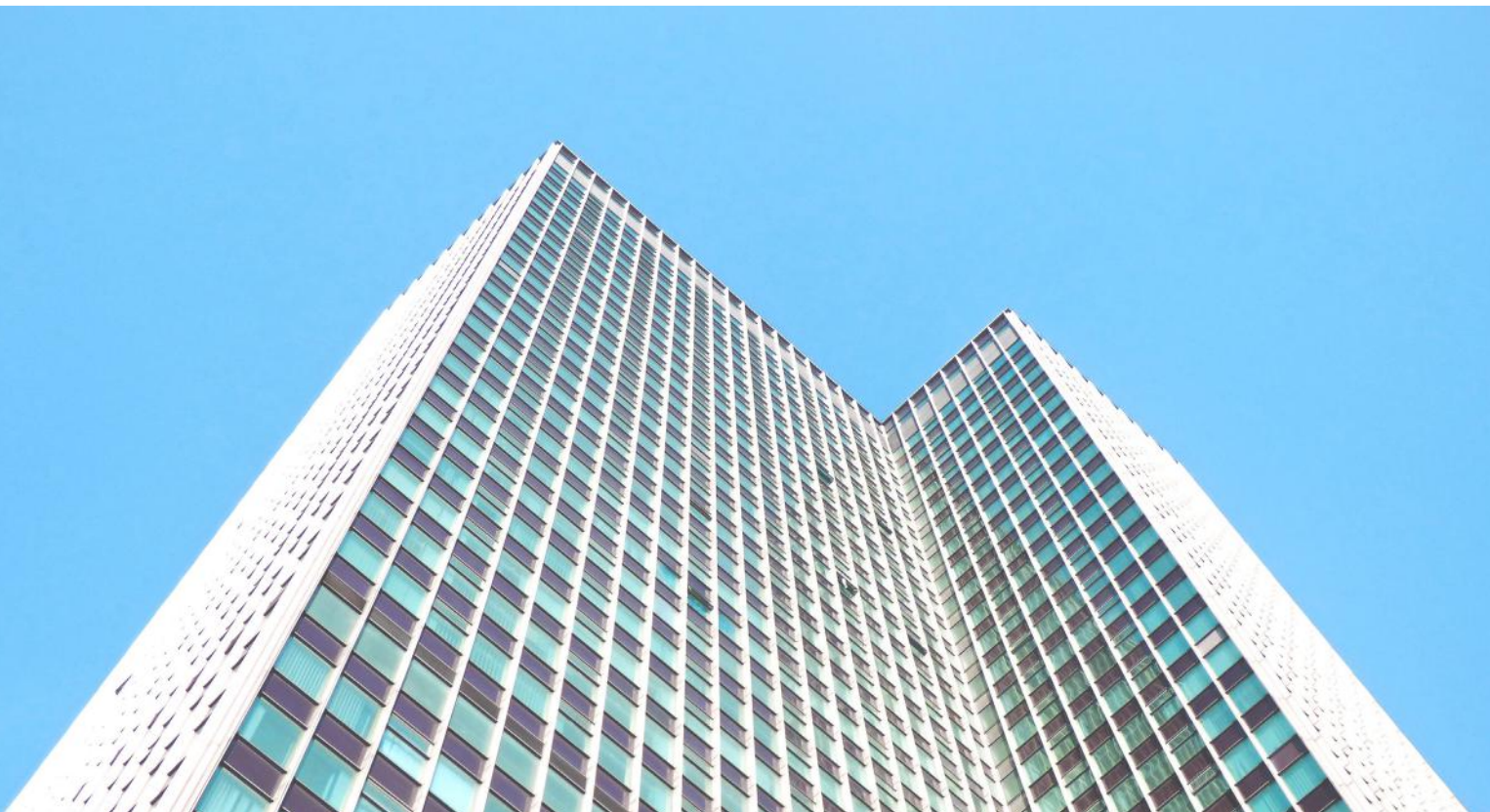
Following the technology boom over recent years, the construction industry has rapidly and efficiently adapted to the new norm. As such, the role of technology in construction has proved a hot topic for discussion and dominated the headlines and attracting academic research interest. Undoubtedly, the implementation of technological advancements throughout any project's life cycle entrains a plethora of benefits, such as improved design, faster procedures, safer working environment and cost efficiencies amongst others. However, there are also a number of perceived barriers including the initial financial investment and the need to upskill and train staff. This report explores the evolving role of technology implementation in the construction sector, investigates its genuine impact in project delivery processes and discusses the different barriers related to technology.



Net-zero buildings

It is estimated that together, the building and construction sectors account for 39% of all carbon emissions globally⁴; a major issue which the construction industry is constantly trying to address. While innovative design approaches and technologies are beginning to be incorporated into tall buildings, sustainability cannot be ensured instantaneously. With new regulations and strict targets in place, it is imperative to examine whether the UK construction industry can realistically achieve net-zero buildings in the future.

Our research findings were presented to a range of M&E experts whose role is integral in delivering and maintaining building-critical systems that cover all three aforementioned subject areas. The purpose of our primary research was to capture their reactions and opinions, and gather insights and suggestions on how the sector can overcome previously identified challenges. This report outlines the collective views of the M&E experts we spoke to, as well as their assessment of the research findings and personal experiences in the delivery of high-rise buildings.



Marc Smith, MD, GHS Group

Marc is the Managing Director of the GHS Group, a full service mechanical and electrical contractor which specialises in providing gas, water and electrical services for projects across the South of England and London. Marc has worked with a number of blue-chip organisations and across a variety of sectors, including residential, education, retail and industrial.

Mike Travis, Regional Director, FutureServ

Mike is the Regional Director of Futureserv, a building services design and consultancy practice which provides mechanical, electrical, public health and vertical transportation advice. Mike has extensive experience working in the high-rise residential sector.

Marjon Van Elk, Project Architect, AWG Architects

Marjon is a Project Architect at AWG Architects and has experience working across a number of European countries as well as multiple market sectors, including education, healthcare and residential.

Kiera Vogel, Company Director, Senate Construction Ltd

Kiera is Joint owner and director of Senate Group Ltd. Senate provides nationwide construction services from its headquarters in Liverpool, including mechanical and electrical engineering, across a variety of market sectors, including education, commercial, healthcare and residential.

Dave Pitt, Consultant, J&D Consultancy Ltd

Dave is currently a Consultant at J&D Consultancy Ltd. Previously an owner of a full service mechanical and electrical contractor, Dave has over 40 years' experience in the domestic and commercial markets working closely with mechanical and electrical consultants and architects.

Building materials can reduce the environmental impact of a development and improve its efficiency. For instance, insulation with higher U-Value, either in new build developments or retrofit applications, can assist in reducing heat loss. In addition, building design significantly affects occupants' wellbeing. Replacing a fan coil unit, which creates uncomfortable streams of air, with a radiant heating system can significantly improve people's thermal comfort levels, minimise dust circulation and reduce costs associated with energy consumption.

In addition, a better considered design can provide improved natural ventilation, and superior equipment can also be used to enhance the overall air quality. With all of this in mind, it is clear that delivering an entirely healthy building is a multifaceted task that challenges the industry. It is especially complex for dynamic high-rise construction, which is characterised by varying demands of inhabitants and diverse design challenges.

“There’s a desperation to create space which can cause problems, such as making the ventilation’s air filters inaccessible. If the design doesn’t give consideration to the maintenance, then two-three years down the road the fans will choke up and burn because nobody has changed the filters. This comes down to costing.”

Marc Smith



The majority of construction industry professionals we spoke with recognised the above and the important role that key systems play in keeping residents both healthy and comfortable.

To what extent do you agree or disagree with the following statement? ‘Buildings shape our health and wellbeing on a daily basis regardless of whether we talk about homes, schools, workplaces, health care facilities, universities, shopping centres etc.’

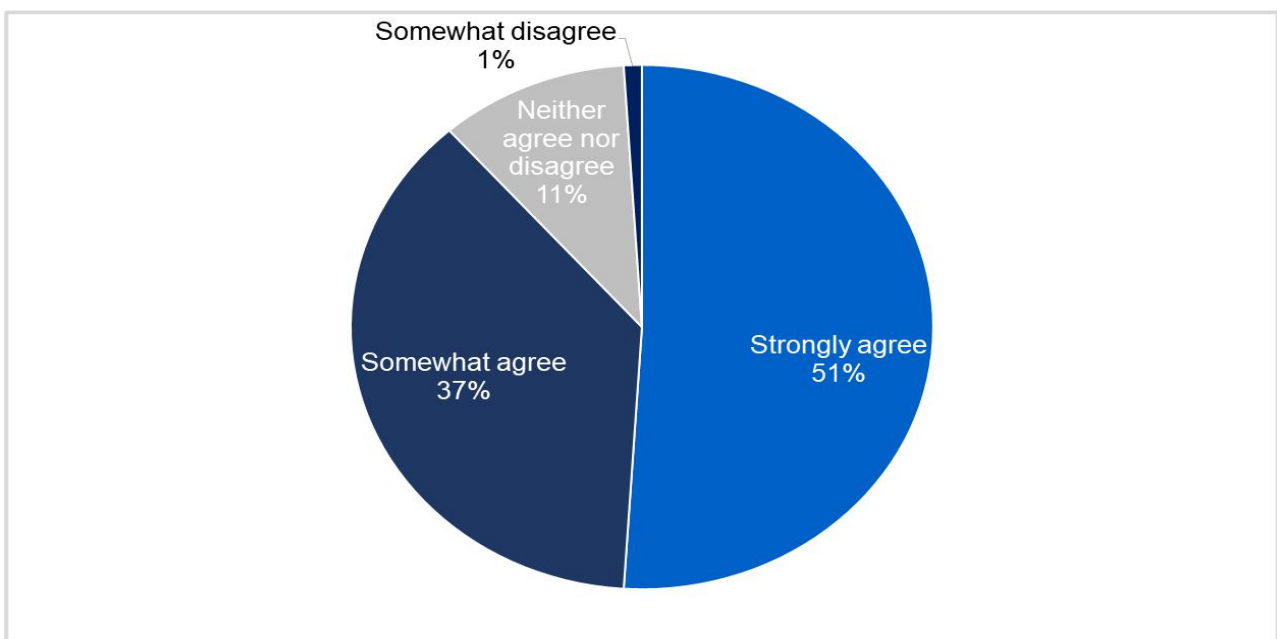


Figure 1

“A lot of high-rise residential buildings are healthier than they used to be. They have green walls, landscaped garden areas, gyms, rooftop running tracks, high speed broadband and every residential building has ventilation, heat recovery and low-flow sanitary water.”

Mike Travis

Which of the following are most important to achieving a healthy building in high-rise construction?

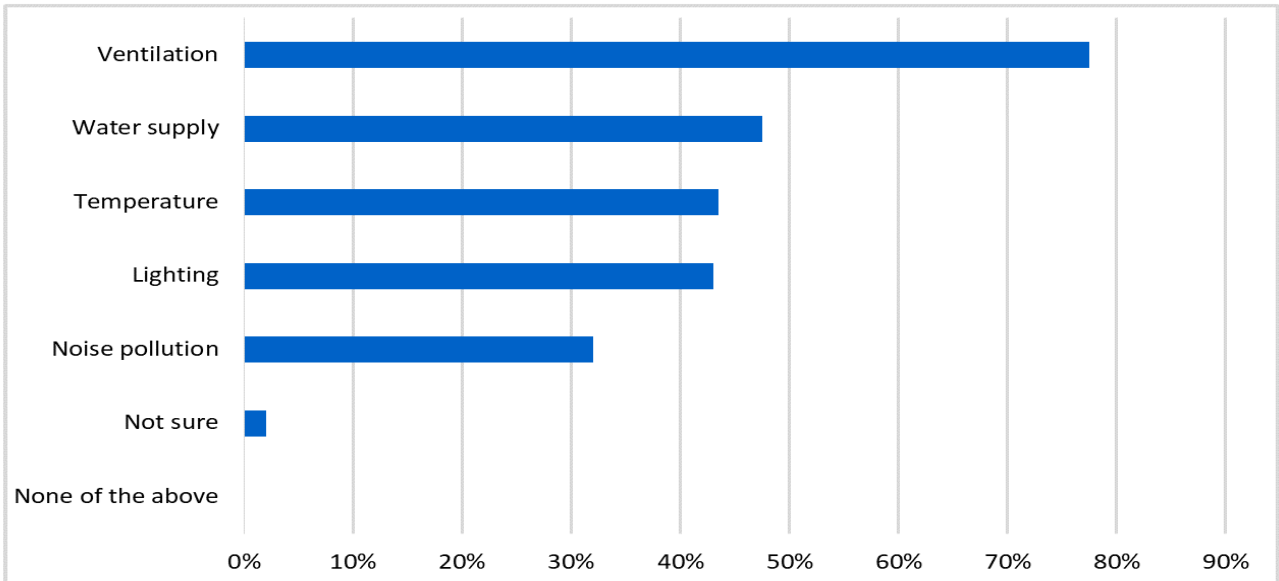


Figure 2



The research found that:

- 90% of participants agree that healthy buildings are essential in shaping our health and wellbeing, but just 5% of them think the M&E sector is able to deliver this without significant challenges
- Almost two thirds of respondents admit compromise of some kind is needed to create truly healthy buildings in the current sector climate (see Figure 3)
- 77.5% of respondents believe that ventilation is the most critical building system to achieve a healthy high-rise building. This was followed by water supply (47.5%) and temperature (43.5%)
- Despite almost half of our research participants citing temperature control as one of the most important factors when creating a healthy building, over 20% admitted they'd compromise on this if cost was an issue

To what extent do you agree or disagree with the following statement? 'In the current climate, creating a truly healthy building isn't possible without compromise.'

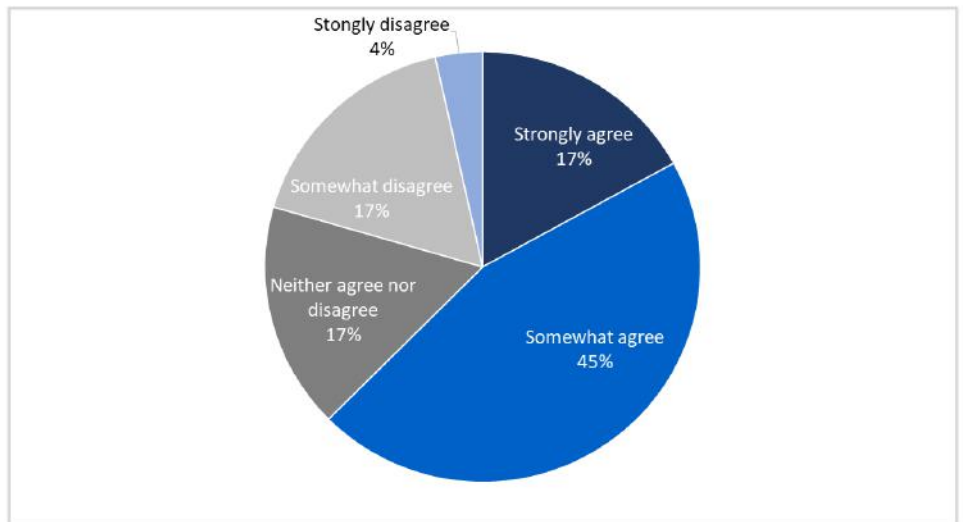


Figure 3

However, despite acknowledging that systems such as ventilation, water supply and heating are all critical to maintaining a healthy environment, many respondents admitted that these would be compromised if cost was an issue.

“I don't agree that creating truly healthy buildings is not possible without compromise, there is always a way for water to be bacteria free, whether it's from the mains or sealed storage tanks where water is pumped from a sealed hot water cylinder, combined with regular testing of water by specialists.”

Dave Pitt

While hidden from view, cutting back on the water distribution system design could have significant long-term implications. In specific, the process of designing and installing the water distribution system in a building is particularly important for the prevention of water stagnation. Stagnation, in water temperatures between 20°C and 45°C, can lead to the growth of harmful bacteria such as Legionella. Therefore, it is critical to specify and install the correct size of pipes and fittings to prevent stagnation. In addition, pipes and fittings with smoother internal bore can reduce the risk of calcification (limescale) on the internal wall of pipes/fittings. If allowed to accumulate, limescale can reduce the overall performance of the system and contribute to the formation of bio-films and bacterial growth, including Legionella.

Following smart design principles and correct procedures when specifying systems and products at conceptual stage might seemingly increase the initial cost of the project, however, it is very likely to lead to reduced operational costs and lessened health risks for the occupants.

The gravity of selecting and employing the right solutions, has led to the creation of several guidelines and norms developed by European Workgroups, CIBSE and the UK government amongst others⁵⁶⁷.

“The M&E aspects of a building are the most important parts to making it healthy, especially by providing the comfort, heating and ventilation, so it is important that it’s done well.”

Marjon Van Elk

“There is more of a conversation at the design stage now around how the building performs, what offer that building is going to give to either its residents or the people using it, and the reason for that is - why not? It’s just as easy to design something in as it is to then have to retrospectively add it in.”

Kiera Vogel

In addition, it is widely accepted that thermal comfort is vital to creating a pleasant environment. In one of their recent reports, the Institute of Chartered Accountants for England and Wales highlighted the importance of thermal comfort in workplaces. One of the key suggestions of its summary stresses that a 'well-lit environment with suitable ventilation is imperative⁸. Moreover, research has shown that the annual increase in productivity is worth at least 10 times as much as the increase in annual energy and maintenance costs when improving the perceived air quality of an office building⁹.

The survey's findings reveal a disconnect between the ideal of a healthy building and the reality of creating such a structure given the pressures the industry is currently facing. If the wellbeing of residents and building's users is second place to budget, then it is vital that the industry assesses its priorities and finds ways to balance health and cost concerns.



Historically, the construction sector has been driven forward by technological advancements, from the introduction of elevators which enabled the sector to build taller buildings, to modern construction tools that replaced manual activities. Following the technological boom over recent years, new information management and 3D visualisation software have been implemented in project life cycle, meaning the role of new technology has been a common topic of discussion which dominated many headlines and influenced regulations.

“The use of tech is good and it’s that which is going to assist us in achieving climate reduction targets. The developers of high-rise residential buildings are adopting technology which is a lot better than what’s going into the general housing market.”

Mike Travis

The construction world widely acknowledges the fact that technology has enormous potential to develop cost-effective, faster and safer processes within the industry. This optimism, however, is tempered by a belief that there is a long list of barriers to the effective implementation of modern technology.

Such barriers include additional investment costs, training required to upskill the workforce, as well as scepticism as to whether technology utilised will actually provide added value to the project’s life cycle.

“Clients might want to adopt new technologies for tech’s sake, just because they have read up on something that could give them better performance, but in reality, it just won’t perform.”

Kiera Vogel

What do you think might be the main barrier to the adoption of new technology?

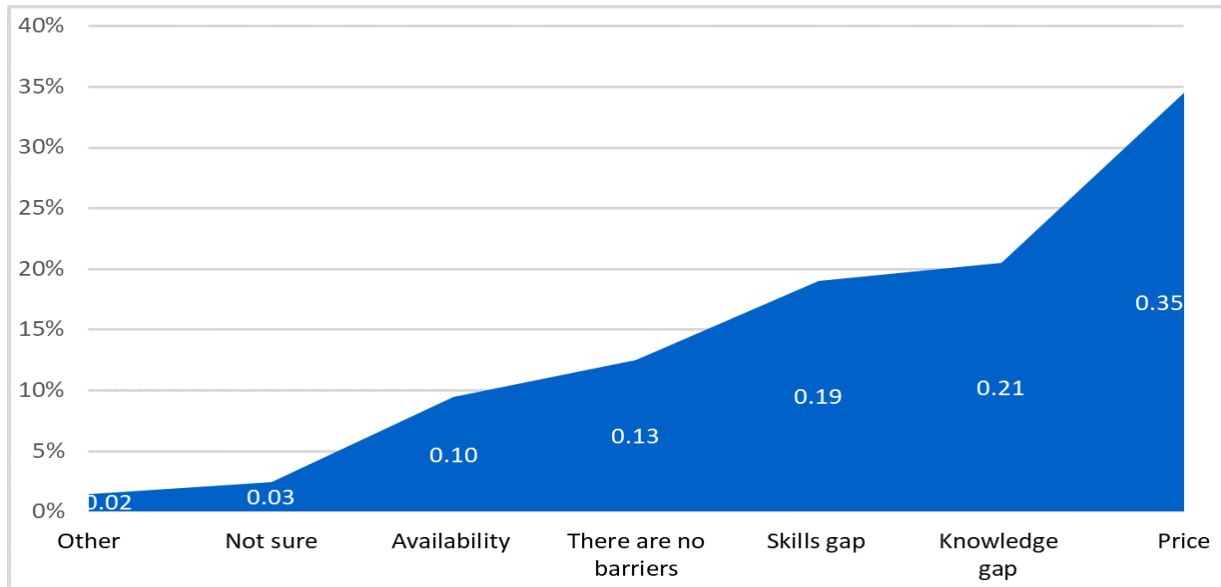


Figure 4



To what extent do you agree or disagree with the following statement? The use of BIM (Building Information Modeling) is essential in helping M&E contractors to deliver projects on time, within budget and to agreed specification.

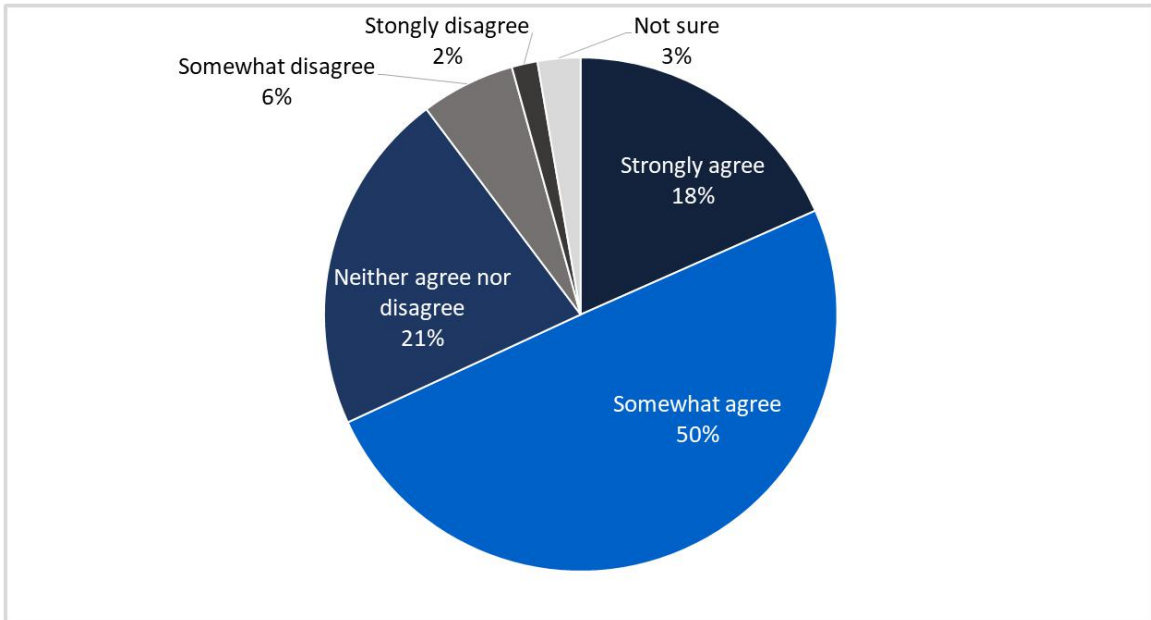


Figure 5

The research found that:

- The majority of respondents agree that technology will have a strong impact on the ability of contractors to deliver construction projects faster, at a lower cost, to a higher standard of quality and accuracy and with fewer resourcing issues
- Almost half of those surveyed think the industry is at risk of implementing technology for tech's sake
- 35% say budget restrictions are hampering the adoption of technology within construction
- A knowledge and skills gap is affecting technology uptake in the construction sector according to 40% of respondents
- 70% of respondents say BIM is essential in helping M&E contractors to deliver projects on time, within budget and to agreed specification, however on average only 30% of projects implement it

This dichotomy is represented by the implementation of BIM (Building Information Modeling), with close to three quarters of the industry saying that adopting BIM is critical for M&E contractors who wish to deliver projects efficiently and effectively. Yet despite this, more than two thirds of projects are not implementing BIM. The results of the current report correspond with the National BIM Report 2019, which stated that BIM awareness and adoption has grown from 10% in 2011 to around 70% in 2019¹⁰.

“Once people use BIM they rarely go back as it does so much of the work for you, as well as speeding up the communication and allowing you to see where the clashes might be.”

Marjon Van Elk

However, it was reported that adoption levels were relatively stagnant during the last round of data collection.

“BIM can be used for costing and efficiency services, but should be kept within the confines of a private room where a specialist company can analyse it.”

Dave Pitt

“Over the next five years everyone will know how to do it, but at the moment BIM is quite a specialist area.”

Marc Smith

With growing populations requiring large-scale housing developments and high-rise commercial and residential buildings, BIM is becoming an imperative necessity. BIM is likely to be a crucial piece of technology to streamline, simplify and speed up the design of increasingly complex developments. In order to meet its requirements, the industry must invest in people, equipment and software, which will, in turn, ensure that technological advances are fully embraced and utilised.



Sustainability is never far from any debate in the construction industry, particularly when discussions revolve around large developments that consume an abundance of materials and resources. In the current climate, those involved in planning have to pay particular attention to aligning with the new sustainability focused norms, which have become more stringent in recent years.

In its 2019 report, the Climate Change's Mitigation and Adaptation Committee outlined a number of targets suggesting, amongst others, that by 2025 no new homes should be connected to the gas grid and should instead utilise developments in low carbon products¹¹. This would mean that all heating and domestic hot water (DHW) distribution systems should be provided by efficient, sustainable alternatives to today's gas-reliant status quo. Some of the alternative technologies that are very likely to flourish in the near future may include district heating networks and renewable energy sources.



In fact, research has shown that the replacement of conventional heating sources with district heating networks or renewable energy sources, can significantly improve the energy efficiency levels of a development. Consequently, greenhouse gas (GHG) emissions and energy consumption costs will diminish¹².

In addition, the overall energy efficiency of a development can improve even more by implementing alternative heating solutions which operate at lower water temperatures compared to conventional systems^{13,14}. Such alternative solutions encompass radiant heating systems and more specifically, radiant panels and underfloor heating. Finally, the overall energy efficiency levels of a development can be further improved when smart energy management technology, such as smart controls, is applied, for instance, on heating systems¹⁵.

“The equipment is there to be carbon zero. The major things to get right are making sure the building is well insulated and that it also has a good heat recovery system. In fact, it’s frightening how little heat is actually needed when something’s well insulated and has reached its core temperature.”

Marc Smith

However, only half of our study’s participants accept that the disconnect of new homes from the gas grid is a realistic target, with more than 10% of all participants supporting that the UK will never be able to reach a state where no new homes are connected to the gas grid, let alone by 2025.

This inability to foresee a genuinely sustainable future for construction is also confirmed by a small percentage of people working in the construction sector, who think that the UK will never be able to build net-zero homes as standard. This is concerning, given the fact that the Energy Saving Trust is certain that all new homes should be net-zero by 2050, an objective that the government endorses, too¹⁶.

To what extent do you agree or disagree with the following statement: ‘There are plans for 1.5 million new UK homes by 2022. These new homes must be built to be low-carbon, energy and water efficient and climate resilient. Support to train designers, builders, contractors and installers is needed to deliver this, in areas such as low-carbon heating, energy and water efficiency, ventilation and thermal comfort.

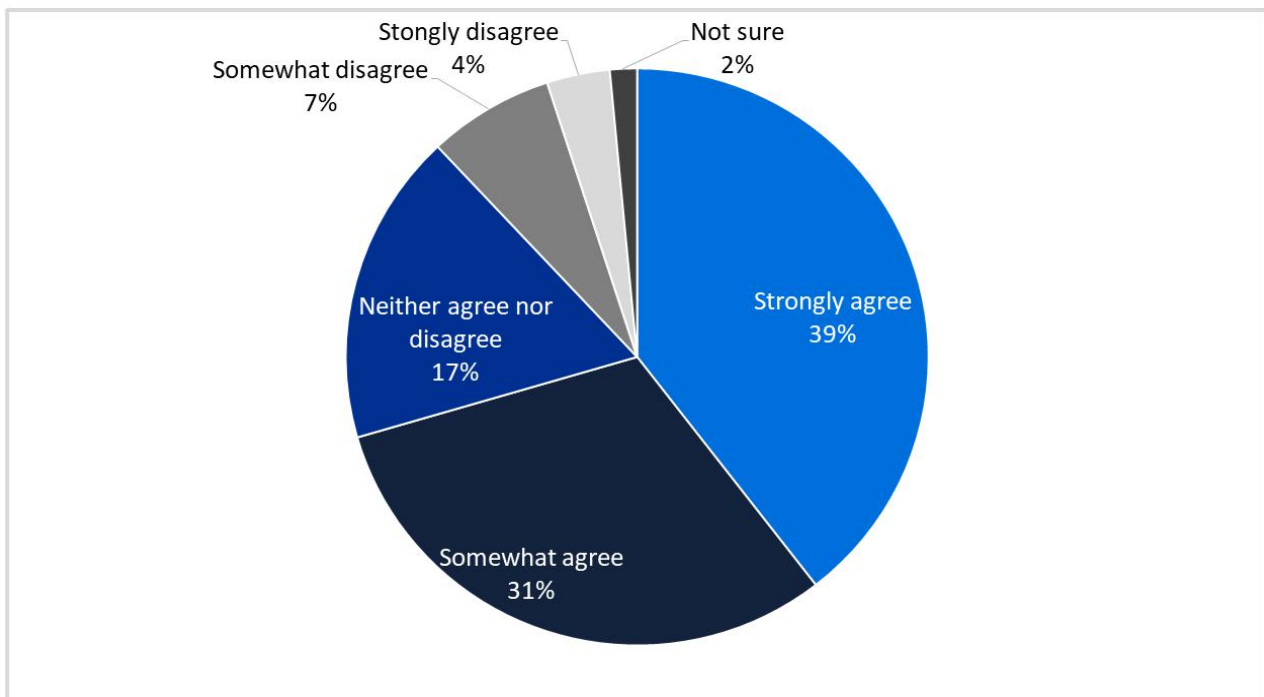


Figure 6

The research found that:

- Of the research respondents, only 4% think the UK construction industry can meet climate objectives without a major change to the approach to retrofitting existing homes and building new homes
- Net-zero homes as standard will not be a reality until 2040 say a third of the industry, while 5% don't think the UK can ever deliver net-zero homes as standard
- Only 10% of respondents think the construction sector workforce is fully equipped to deliver the sustainable houses we need
- More than 10% of the industry think the UK will never be able to take all new homes off the gas grid and replace the grid with low-carbon heating systems such as heat pumps or heat networks
- Two thirds of respondents feel more investment in NPD is needed from manufacturers for the enhancement of water delivery efficiency which will, in turn, improve the building design

“For some old buildings it's practically impossible to achieve carbon zero. The timescales it would take, the logistics are just not realistic.”

Kiera Vogel

A combination of high standards, low training levels and lack of awareness regarding the right solutions has made the industry very skeptical about a truly sustainable future in construction. According to our findings, it unanimously appears that major change to the approach of constructing new homes and retrofitting existing ones will be required for the UK industry to meet its climate objectives.

Our findings also highlight that compulsory metering is seen as 'enough' when it comes to improving water efficiency. In reality, water metering is an integral part of an efficient water distribution system; using innovative solutions, such as smart water leak detectors can lead to significant reduction of water wastage.

Moreover, occupants can gain considerable financial benefits from smart water control. For example, modern smart leak detectors can address leaks before incurring unexpected costs. In that way, people can save money by preventing a disastrous pipe burst or by reducing their home insurance costs. Furthermore, based on our research findings there is a disconnect between the necessity to improve on water saving applications and the expectations of occupants to be provided with

high performance outlets. Hence, designing a water distribution system that meets the needs of the building's users while simultaneously reducing water and energy wastage, ought to be a priority in the industry's agenda.

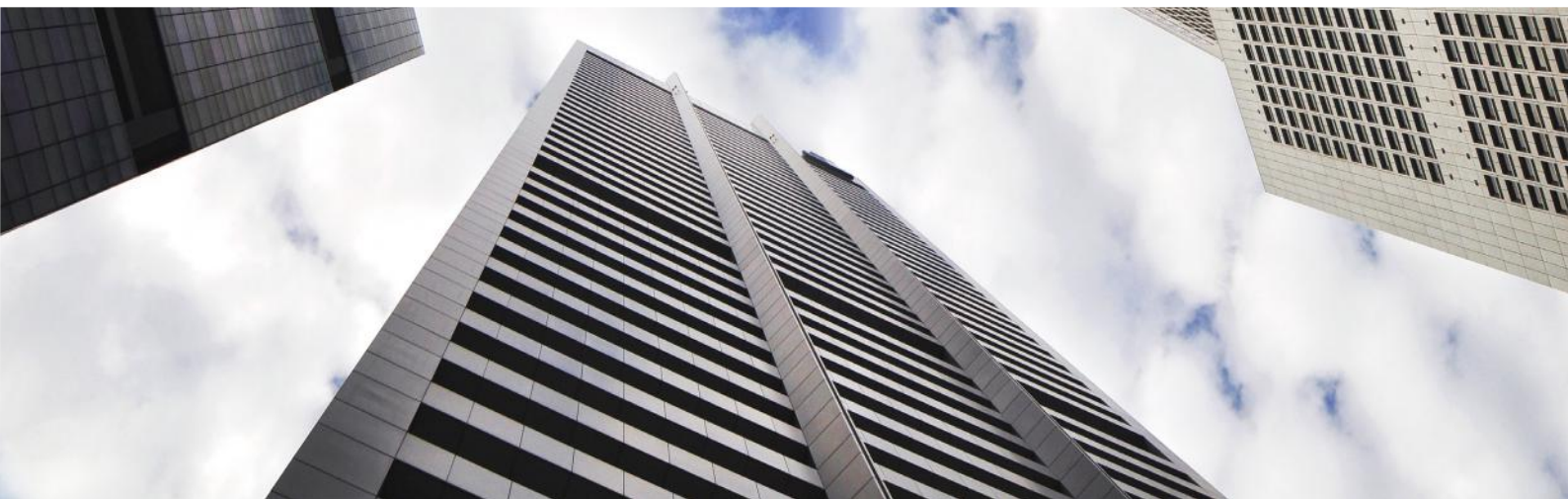
The ambitious environmental targets, which governments and organisations are calling for, emphasise the importance for the construction industry to get ready now for the demands of the future. The profile of products and services that will facilitate this new generation of construction needs to be of primary focus for people who are involved in the design and delivery of tomorrow's buildings.

“With water efficiency we try to reduce water consumption with low-flow taps, etc. but what we don't do is reuse water - we find people tend to lean away from that sort of system. There aren't many technologies that I'm aware of that would further improve water efficiencies in a high-rise building that are viable.”

Mike Travis

“There's a big drive for controls to make buildings more efficient but they are only as good as the operator using them. Someone can come along and turn up the controller, so if you can override the system then it makes it pointless.”

Marc Smith





On the whole, the results of the current report reveal an interesting paradox. Evidently, the construction industry is fully aware of the requirements, and their significance, in delivering healthy, sustainable and modern high-rise buildings. On the contrary, however, there is a number of challenges that render the above standards unrealistic and give rise to pessimism among industry professionals.

Moreover, our research brought to light an intriguing trend; when cost is a factor, people are willing to compromise on systems which are critical to all the topics discussed in this report. For instance, cutting back on systems, such as water supply and heating, may prove problematic; this action might have a knock-on effect on delivering high quality, healthy and sustainable buildings. Otherwise stated, opting for inferior products in a water supply system not only jeopardises the system's efficiency levels required by modern standards, but it is also more likely that the building's occupants are exposed to unhygienic water.

In addition, low-carbon systems ought to be promptly embraced by the industry in order to maximise the likelihood of meeting the sustainability targets that have been set. It's important to note that, presently, there are available solutions which can start to move the industry towards a more sustainable direction; nevertheless, as this research has indicated, a more holistic understanding of these solutions should be reinforced.

A need for greater awareness and more training, as well as comprehensive technology implementation, more modern designs and new product innovations were recurring themes throughout all the answers and discussions. The general consensus is that the industry as a whole is not yet fully equipped with the knowledge and tools to meet the scale and complexities of the challenges it faces.

To support these issues, Uponor will be partnering with M&E specialists and applying expertise to ensure that sustainable indoor climate solutions and efficient water solutions are specified at the concept stage of new high-rise projects. Thus, forming such strong partnerships can ensure that tomorrow's high-rise buildings are well-planned, healthy and environmentally friendly.



Rethinking water for future generations

Uponor is a leading global solutions provider for the delivery of safe drinking water as well as energy efficient heating and cooling systems. We support our customers across different industries, such as residential and commercial construction, in working efficiently and developing a more sustainable living environment.

We are committed to addressing the key issues of our time through innovative solutions with minimal environmental impact, whilst shaping healthy and comfortable built environments.

Our radiant heating and cooling solutions ameliorate energy efficiency levels of buildings, whilst creating a thermally comfortable indoor climate. Implementing our novel water hygiene solutions ensures continuous water flow at the correct water temperatures and consequently prevents water stagnation. Hence, adopting these hygienic systems within a design will help prevent the growth of unwanted bacteria and micro-organisms.

With over 100 years of experience in the construction industry, we are capable of providing expert advice and suitable solutions for large scale projects, including the most complex high-rise developments.



High-rise case study: Madison Residential Tower

Uponor's team is well versed in the intricacies and difficulties of high-rise construction and also with the topics that have been discussed in this whitepaper. This experience was demonstrated at The Madison residential tower in Canary Wharf, which is still under construction and is scheduled for completion later this year (2020). This development is a 53-storey landmark feature in the Canary Wharf skyline and comprises both affordable apartments and high-end luxury homes. The development also boasts an impressive set of amenities for the residents that includes public gardens, common areas, a bar, a gym, terraces, swimming pool and spa.

Using manifold plumbing schemes, over 70,000 metres of our Pre-insulated multi-layer composite (MLC) pipes have currently been installed to create a high-performance water system, feeding the potable water outlets and the heating systems. Each affordable apartment is heated using a traditional radiator system, whilst the high-end homes are fitted with an efficient fan-coil unit to provide both heating and cooling.

Potable water for the domestic outlets is supplied via 16mm and 20mm multi-layer pipes which are pre-insulated with a special fire-resistant class of insulation. With the manifolds connected directly to the HIUs (Heat Interface Units), they distribute the water to the outlets via the pipes which are connected from source to outlet with virtually no connections other than the ones at the termination points. It was important to the client that all connections are at accessible points and not within the ceilings or walls, and that the number of connections should be kept to a bare minimum.

The Uponor multi-layer pipes have been designed to combine the benefits of both a metal and plastic pipe in one. The pipe is based around an aluminium core which is then layered inside and outside with a high-performance polyethylene. The combination of the two materials means that the pipe is highly flexible allowing it to be quickly and easily routed through the apartment

without compromising the space that is needed for the other services. The insulation prevents thermal transfer between the different services and each pipe has a continuous vapour barrier which is colour coded to identify the different hot and cold pipes. The 75m long pipes come as coils which makes them a convenient size to store and easy to move around the construction site.

Full training installation for every engineer has been provided by Uponor, and regular on-site consultations have taken place along with regular installation reviews and observation reports. Commissioning of the apartments is well underway and the team hopes to complete the project soon, but the impact of Covid-19 has delayed progress slightly.

The specification of this project posed many challenges, but thanks to the combination of the right products and expertise, Uponor was able to ensure that the high-rise apartments could be provided with a state-of-the-art water delivery system.



To discuss the information contained within this report further, or comment on the findings, please get in touch by emailing marketing.uk@uponor.com or calling 01923 927 000. You can visit our website (www.uponor.co.uk) for more information on our services, systems and solutions.

References and thanks

With special thanks to all the research participants for discussing our survey results with us.

Please note that this report does not express the personal views of each practice.

Where interviewees are quoted, views represented are those of the individual, not the practice as a whole.

Resources:

1. <https://nla-production.s3.amazonaws.com/9430/Londons-Tall-Buildings-Survey-2020---NLA-download.pdf>
2. <https://sustainabledevelopment.un.org/post2015/transformingourworld>
3. Healthy buildings for a healthy city: Is the public health evidence base informing current building policies? *Science of the Total Environment* 719 (2020) 137-146
4. <https://www.worldgbc.org/news-media/WorldGBC-embodied-carbon-report-published>
5. <https://www.ecdc.europa.eu/sites/portal/files/documents/Legionella%20GuidelinesFinal%20updated%20for%20ECDC%20corrections.pdf>
6. <https://www.hse.gov.uk/pubns/priced/l8.pdf>
7. <http://www.pendred.com/wp-content/uploads/CIBSE-TM13-Minimising-the-Risk-of-Legionnaires-Disease-NEW-2013-3.pdf>
8. <https://www.uponor.co.uk/company/news/news-items-south-west/comfort-should-not-be-a-secondary-consideration>
9. 'Cost-benefit analysis of improved air quality in an office building'. In: Proceedings of Indoor Air 2002, Monterey, The 9th International Conference on Indoor Air Quality and Climate, Vol. 1, pp. 808-813
10. <https://www.thenbs.com/knowledge/national-bim-report-2019>
11. <https://www.theccc.org.uk/2019/02/21/uk-homes-unfit-for-the-challenges-of-climate-change-ccc-says/>
12. Super-insulate or use renewable technology? Life cycle cost, energy and global warming potential analysis of nearly zero energy buildings (NZEB) in a temperate oceanic climate. *Energy and Buildings* 139 (2017) 590–607
13. A comparison of heating terminal units: Fan-coil versus radiant floor, and the combination of both. *Energy and Buildings* 138 (2017) 621–629
14. Low-energy guide. Underfloor heating and cooling in low-energy buildings. Uponor
15. Categories and functionality of smart home technology for energy Management. *Building and Environment* 123 (2017) 543-554
16. <https://energysavingtrust.org.uk/clean-growth-plan-2050-ready-new-build-homes-policy>

uponor