ADAPTING INDUSTRY TO WITHSTAND RISING TEMPERATURES AND FUTURE HEATWAVES.

Institution of MECHANICAL ENGINEERS

Summary for policymakers

Improving the world through engineering

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The impacts of a warmer world on industry will be complex and broad, including technical, economic and health related, and the implications of the findings of this report are applicable across the globe. Adapting industries to, and preparing them for, a warmer world will be essential for the future successful functioning of societies of all nations.

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Introduction

The world is already hotter as a result, unequivocally, of greenhouse gas (GHG) emissions from human activity. The global mean temperature is now 1.2ºC above pre-industrial levels, causing climates to change and presenting humanity with substantial challenges. In recent years, temperatures around the globe have reached new record-breaking highs. In 2022, extreme heat events were recorded across the globe. In the UK, temperatures reached 40.3ºC during the driest July in England since 1935, breaking the previous record high of 38.7ºC.[1] The trend is for summers to become drier, with heatwaves becoming more frequent, more intense and of increasing duration, and with a greater, more apparent impact on human health, infrastructure, industrial assets and buildings.

During the extreme heat of July 2022, Luton Airport in the UK saw temporary disruption when a patch repair to the runway became so hot that it de-bonded and began to lift, halting further landings and take offs by aircraft[2]. Train tracks can buckle in the heat, and in the past 40 years, kinks in steel tracks caused by the sun have caused over 2,100 train derailments in the United States[3]. Industrial buildings and assets, such as equipment and plant, are also at risk, as illustrated in France when soaring temperatures threatened to shut down nuclear power plants[4]. Further, heat impacts are magnified in urban areas, both industrial and residential, and these are set to increase as estimates predict that around 70% of the world population will live and work in cities and urban conurbations by 2050[5].

The economies of developed and developing countries worldwide are underpinned by a range of industries that have the heating and cooling of liquids, gases and solid materials at their core. Such industries include the oil, gas and renewable biofuels sectors, chemical and petrochemical processing, industrial gases production, pharmaceuticals, food and drink processing, minerals processing and the production of metals and synthetic materials, amongst others, all of which are sensitive to the temperatures in which they operate.

Consequently, as the world continues to get hotter due to human-induced global warming, and climate change leads to higher seasonal ambient temperatures and more severe heat extremes, their productivity will be impacted, with implications for local, national and international economic well-being.

Industrial processes, assets, buildings and personnel will all be negatively affected by higher temperatures. Indeed, exposure to heat levels beyond those for which designers have allowed can lead to detrimental outcomes for productivity, through reductions in the efficiency and performance of equipment, plant, buildings and people, and in extreme cases, the complete shutdown of operations. To avoid such outcomes, industrial organisations need to plan and implement climate change adaptation measures as well as build internal capacity for resilience to extreme heat events.

The impacts of a warmer world on industry will be complex and broad, including technical, economic and health-related, and the implications of the findings of this report are applicable across the globe. Adapting industries to, and preparing them for, a warmer world will be essential for the future successful functioning of societies of all nations. It is vital that their integrity and productivity are maintained in a future environment characterised by an overall increase in ambient temperatures and intense heat events.

In this report, the IMechE details the engineering challenges presented be a warmer world and describes responses that include: a revision of standards and design codes to ensure industrial assets and buildings are fit for purpose; adopting a 'build back better' rather than a 'like for like' approach when renewing or refurbishing existing assets and buildings; the adoption of sustainable net-zero solutions for cooling provision; and a redesign of curricula at all levels of engineering education and skills training. Industry, governments, the engineering profession, and academia need to collaboratively prepare for, and respond to, this challenge.

The full report is available alongside this summary on the IMechE website:

https://imeche.org/policy-and-press/reports

Recommendations

The impacts of a warmer world on industrial personnel, buildings and assets, such as equipment and plant, are complex and broad, including technical, socio-economic and health related. Industry, government policymakers, the engineering profession and academia need to come together and act collaboratively to ensure workers and assets are protected against future extreme heat events through adaptation and the building of capacity for resilience. The industries considered in this report underpin the economic well-being of people and nations in the developed and developing world alike. As such, it is vital that their integrity and productivity is maintained during heatwaves, as well as in an environment characterised by an overall increase in seasonal ambient temperatures.

Adapting to, and preparing for, a warmer world will be essential for the future successful functioning of industry and in this regard the Institution of Mechanical Engineers makes the following recommendations:

1. **Industry needs to recognise that in many countries of the world their personnel, buildings and physical assets will be increasingly impacted by higher ambient temperatures and severe long-duration heatwaves, potentially leading to industrial unrest, operational shutdowns and lower levels of economic productivity. To avoid such outcomes, organisations must develop and implement adaptation plans for people, buildings, equipment and plants and invest in increasing their capacity for resilience to extreme heat events. Courses of action should include:**
    - employers and employees, with guidance from relevant health and safety bodies, such as the HSE in the UK, co-designing strategies for dealing with heat stress which are tailored to the specific needs of the different categories of workers and their workplaces. This may include setting a meaningful upper temperature, but the specifics will vary from industry to industry as working conditions, level of PPE and work-load are sector-dependent.
    - senior managers creating an enabling environment in which their engineering and operational teams can develop innovative and timely adaptation solutions for equipment, plant and buildings.
    - managers encouraging engineers to engage with national and international standards writing bodies in the updating of existing standards and design codes to account for higher temperatures and more frequent heat extremes, as well as developing new ones for adaptation and resilience more broadly.
    - organisations implementing ‘build back better’, rather than ‘like for like’, approaches to replacing aged or damaged buildings and assets to ensure that they are fit for future service in a hotter world.

2. **Government policymakers around the world need to recognise the potential productivity impacts of higher ambient temperatures and heat extremes on industries that underpin their national and local economic well-being and support them to adapt by:**
    - raising awareness of the projected heat-related impacts of climate change on industrial assets and buildings and encourage owners, developers, financiers, lenders and those involved in their design and construction to take urgent action on adaptation.
    - ensuring planning policy includes the evaluation of, and changes to, existing planning requirements for new builds and retrofits to reduce exposure to climate change-induced heat impacts.
    - reviewing and updating building codes and regulations to ensure they are relevant to future higher ambient temperatures and more frequent and severe heatwaves of longer duration.
    - ensuring that national net-zero strategies and investment decisions address the threat from higher ambient temperatures and extreme heat events to the performance of the technologies and industries upon which they are based.

- developing an energy policy vision for industrial cooling that is not constrained by defaulting to electricity, but instead is based on the fact that its provision could often be better achieved by "thinking thermally" and utilising available thermal resources.
- encouraging high hazard industry regulators to mandate operator assessments of extreme heat risks alongside other climate threats within their license-to-operate application, as well as to carry out a gap analysis between original design specifications and more recent future climate data. Operators must determine thresholds beyond which operations are no longer sufficiently resilient and establish adaptation plans to create resilience.

3. **The engineering profession worldwide is central to achieving a society well adapted to future climate change and, in this regard, engineers need to help industry prepare for the potential impacts of increased temperatures by:**
   - offering their time and expertise to national and international standards writing bodies, to help accelerate the process of updating existing standards and design codes to account for future heat impacts, as well as develop new ones focused specifically on addressing aspects of adaptation and the building of capacity for resilience.
   - recognising that simply transferring design and operational practice from already hot countries to those that are getting warmer is not necessarily an adaptation solution, due to differences in economies (ie costs of energy, labour, materials, etc.), land-use and GHG emissions policies, and environmental and workplace regulations impacting on the viability of commercial business models.
   - devising, developing and implementing innovative adaptation solutions to future heat impacts on industrial assets and buildings that are based on the principles of net-zero emissions, sustainability and the circular economy.
   - taking a holistic system-of-systems level approach to developing industrial adaptation solutions in which there is consideration and prioritisation of critical interdependencies for establishing failure risk mitigation strategies.

4. **Academia and skills development bodies must recognise that current technical training and education provision for engineers was designed on the assumption of a climate-stable future, in which temperatures are like the recent past, and that there is now a need to:**
   - ensure that basic climate change knowledge is taught throughout all engineering disciplines at every level and curricula considers the impact of higher ambient temperatures and more severe heat extremes, as well as potential approaches to adaptation and the principles of sustainable net-zero design, the circular economy and resilience.
   - make engineering education and skills training more accessible, relevant, responsive and transformative to inspire, attract and retain an expanding and more diverse range of people with non-traditional academic profiles into the profession. Upskilling and continuous professional development also have an essential part to play in allowing greater talent mobility between businesses, academia and other organisations in both the public and private sectors.
   - equip engineers with the knowledge and skills necessary for working collaboratively, particularly in international collaborations.

Heat impacts on people and their places of work

People

Thermal comfort is very important in a workplace and if it is not achieved morale, productivity, health and safety will all likely deteriorate. Poor thermal comfort means colleagues are more likely to behave unsafely and make poor decisions. For example, in hot environments, workers may be tempted to not wear personal protective equipment properly, leading to greater safety risks. Heat may also affect a worker's ability to concentrate on a given task through decreased cognitive function, increasing the chances of errors and accidents, thereby reducing productivity.

Industrial Assets

Industrial assets that use temperature-related processes on materials either in liquid, gaseous, solid or multi-phase form to provide feedstocks or finished products, underpin the economic growth and well-being of developed and developing nations worldwide. Those with intermittent operations offer greater adaptability to extreme heat events as they can be shut down temporarily during periods of extreme heat, though commercial impacts may be severe due to the unpredictable timing and length of these events. However, industrial assets in sectors relying on continuous operations cannot respond with shutdowns. Wide-ranging adaptation is therefore required to ensure the continued performance of these industries that are critical to local, national and global scale economies.

Industrial Buildings

Extreme heat can have widespread and severe effects on buildings and their associated infrastructure. Buildings that were not designed for prolonged periods of high temperatures are often incapable of passively shedding heat and become susceptible to overheating, thermal discomfort and strain on mechanical systems. Industrial buildings are particularly susceptible due to their high internal loads and, in many cases, lack of ceilings and insulation. During the 2022 summer heatwave in the UK, Google and Oracle had issues with data centres overheating because the installed cooling infrastructure was insufficient to expel the additional heat load to the outside ambient environment and maintain the required internal temperature.

With high internal heat gains, industrial spaces have inherently high cooling loads. Combined with the fact that these building types are not typically designed with passive cooling measures in place, this means that industrial buildings are very susceptible to overheating during heatwave events. Overheating can also lead to damage to sensitive equipment or processes that require controlled setpoints (eg sensitive computers, refrigeration equipment etc.) and can increase wear and tear on mechanical equipment. Similarly, excessive heat can limit the building cooling system's ability to reject heat or maintain tight control on humidity levels. As continuity of operation is critical in many industrial buildings, the consequence of system failure within could be severe, with impacts on the productivity and, ultimately, financial health of the businesses that occupy them.

How can engineering respond?

Engineering Design

It will be critical for design engineers and their employers/clients to make use of the available science, engineering knowledge and climate projections, drive research, development and innovation, and ensure that potential future temperatures are accounted for and 'mainstreamed' into the cycle of design, build, operate, maintain and decommission.

There are many advantages to adopting a policy of adaptation at the renewal and/or refurbishment stage for existing assets – replacing life-expired buildings or installations with designs that are 'future-proof'. Furthermore, a policy of 'build back better' after weather damage can be beneficial – rather than one of replacing 'like-for-like' – where industrial assets and buildings are designed with future hazards in mind. For example, in the case of public infrastructure, this concept is part of Network Rail's strategy: "when weather events cause catastrophic asset failure such as collapse of a sea wall or scour damage to a bridge, [Network Rail] commit[s] to replacing like for better rather than like for like"[6].

Engineers should think about 'entry points' for adaptation. Each stage of a project carries considerable scope for reviewing decisions, as well as workflows, and thoughtfully linking to relevant standards and guidelines at appropriate stages (the entry points) throughout the process. Clients have considerable leverage and can push the 'line of sight' concept so that what is seen as necessary at the outset of a discussion about a project translates to fruition during and after the delivery phase.

To ensure that engineering design of industrial assets and buildings is 'fit-for-purpose' in a world that is becoming warmer, the profession needs to develop sector-specific adaptation guides which clearly communicate that designing new assets and buildings, or assessing those existing assets for refurbishments or modifications, using current standards (or worse, using standards applicable at original build) will potentially fail to identify longer term vulnerabilities to heat impacts.

This is due to the fact that most current standards, engineering design codes and building codes are based on the use of historical climate data and do not therefore account for future changes in climate, or incorporate methodologies that enable engineers to allow for such changes in design.

High hazard industry regulators should mandate operator assessments of extreme heat risks alongside other climate threats within their license-to-operate application, as well as carry out gap analysis between original design specifications and more recent future climate data. Operators must determine thresholds beyond which operations are no longer sufficiently resilient and establish adaption plans to create resilience.

Sustainable Net-Zero Cooling in Practice

Work to increase the sustainability of cooling today is primarily focused on improving individual technologies. More specifically, it is focused on transitioning away from high global warming potential (GWP) refrigerants to natural or ultra-low variants and increasing equipment efficiency. In the case of the former, a significant scale-up is required in the roll-out of cooling units using alternative refrigerants, thereby reducing the direct emissions resulting from leakage and/or spillage during use and end-of-life disposal.

The principal challenge in improving energy efficiency is the pace required to make improvements, which is far beyond what has been historically achieved by cooling technology and equipment developers through a 'business as usual' approach. In this regard, overcoming technical constraints to the speed at which efficiency is improved is essential if real, tangible progress is to be made against a background of rapidly growing global demand for cooling equipment. The Global Cooling Prize has recently illustrated what, given appropriate incentivisation and a concerted effort, can be achieved in overcoming such technical constraints in the case of room air conditioners[7].

One key barrier to the uptake of 'best available', highly energy efficient technologies is the fact that they often require a greater upfront capital investment cost when compared to incumbent cooling options. While per unit manufacturing costs and market prices may be higher, however, economic cost savings are often possible from new equipment that meets higher energy efficiency standards, but the principal issue is that these cost savings are typically realised over a relatively long time frame.

The latter can discourage investment, especially in countries which have a high cost of capital and less developed economies, where quick returns are expected to drive growth.

These barriers need to be addressed through market interventions, such as awareness raising, approaches to procurement practices that are tailored to individual countries, financial levers for manufacturers, increased price transparency and innovative business models.

In the case of industrial assets and buildings, however, the anticipated future demand for cooling will not be met sustainably by simply transitioning to new refrigerants and installing higher-efficiency Heating, Ventilation and Air Conditioning (HVAC) systems and process cooling equipment in plants and premises. Instead, a new approach based on the efficient use of energy resources will be needed and this will involve:

- reducing the need for active cooling in the first place through encouraging behavioural change and deploying nature-based and passive solutions, such as leveraging natural ventilation, tree shading and bodies of water in close proximity, etc.
- aggregating multiple demands for efficient use of supply, by, for example, using district cooling network infrastructure.
- harnessing available thermal energy resources to meet thermal services, many of which are present in the local natural environs and can often be sustainably utilised. For example, by making use of 'free' cooling resources, such as cold water from local rivers, lakes, underground aquifers or ocean sources which can be passed through a building to provide cooling.
- harnessing thermal energy resources rejected by other human processes and therefore currently regarded as 'waste' – waste thermal streams from one process can be used to provide valuable thermal services to another process, thereby replacing primary energy consumption (for example, see the case studies in the main report on; the use of industrial waste cooling from LNG regasification; and cooling water heat recovery use for district heating).
- using thermal methods of storage and the utilisation of thermal energy carriers instead of electricity and (chemical) batteries, thereby unlocking otherwise redundant resources of renewable or waste energy and boosting system flexibility by enabling cold and heat to be used where and when needed.

A whole systems approach is needed that considers the full range of drivers and feedback loops within a system and in the case of cooling specifically:

- aims to minimise the demand for active cooling via integration of passive cooling techniques and approaches as well as behavioural change;
- helps make sure individual cooling technologies are supported by the broader infrastructural landscape in which they are embedded (such as manufacturing, energy, transport, waste management etc), interdependencies are understood and managed and components work synergistically together, and;
- helps governments/policymakers/financiers to identify where current policy and regulations, alongside monetary and fiscal interventions, perform well, as well as where barriers exist that require intervention or need to be redefined, realigned to the goal of net-zero and/or improved to enable the uptake of sustainable net-zero cooling solutions and accelerate transition.

This approach also supports the wider energy system decarbonisation by reducing the investment need for increased power grid and generation capacity, freeing up limited renewables capacity for other uses, reducing peak energy demand and creating more room for intermittent renewable and waste thermal energy sources through thermal energy storage systems.

Education and Training

Engineers who are innovative, resilient and socially adept with good communication skills to respond to the challenges of a warmer world are vital to ensure industry, politicians, policymakers and the public understand the broader societal impact of increased heat and the direct implications on productivity levels and the broader economy.

The current technical training and education systems were designed to operate in a climate-stable, cooler world. It is essential that not only basic climate change knowledge is taught throughout all the engineering disciplines, but considerations of the impact of a warmer climate, adaptation measures and sustainable design are included to ensure the basic working knowledge of graduates is 'fit-for-purpose' to address the substantial global challenges faced by society. Curriculums should be linked to the United Nations Sustainable Development Goals and the Paris Agreement.

Beyond the traditional academic training routes, the engineering profession must rapidly inspire, attract and retain an expanding and more diverse range of people with non-traditional academic profiles to develop engineers in the timescale needed to meet the challenge. This means making education and skills training more accessible, relevant, responsive and transformative to new cohorts. Upskilling and continuous professional development also have an essential part to play in redefining the role of the profession and allowing greater talent mobility between businesses, academia and other organisations in both the public and private sectors.

In addition to closing the skill gaps at all technical levels and attracting new engineers and technicians into the sector, broader training is also needed to create a better prepared market for absorbing new technologies and ensuring the associated economic, social and environmental benefits are realised. In this regard, continuous education and training provision is needed for all stakeholders, including project developers, contractors and end users, to raise awareness of the benefits of sustainable and resilient cooling access, facilitate behavioural change and increase the uptake of systems thinking, best-in-class technologies and best professional practice.

Conclusion

It is critical that humanity begins to prepare for the future through the adaptation of domestic life, public services, businesses and industry to climates with higher ambient temperatures across the seasons and more frequent and extreme high temperature events. This will entail changes to the design of buildings, infrastructure and other physical assets and systems, both regarding those that already exist and those that are yet to be built or manufactured, as well as the work, educational, leisure and other activities that humans undertake. Without such change, economic productivity will be reduced, learning will be impaired, human well-being will be degraded and, ultimately, mortality will increase[8].

There is a public health and economic impact associated with rising temperatures and extreme heat events that governments and industries must prepare for through adaptation and the building of capacity for resilience.

A society that is failing to plan for extreme heat is planning to fail.

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