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EVALUATING THE EFFECTIVENESS OF APPROVED DOCUMENT O IN MITIGATING OVERHEATING IN BUILDINGS: A FOCUS ON MODERN METHODS OF CONSTRUCTION

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ABSTRACT

In recent years, the adoption of modern methods of construction (MMC) to help achieve net-zero goals and enhance construction efficiency has risen. However, concerns have emerged regarding its thermal performance and effect on occupant comfort, particularly in an era where building overheating has become an increasing risk. This challenge has drawn stakeholders' attention, including the UK government which has published a regulatory framework to mitigate the adverse effects of building overheating. This study seeks to evaluate the effectiveness of Approved Document O in mitigating overheating in modern buildings. The study employed multiple method qualitative research, including a comprehensive literature review, a desk study of existing regulatory framework and semi-structured interviews among 6 participants to assess the overheating risk in modern buildings and the effectiveness of regulatory frameworks. Findings from the literature review identified key factors contributing to overheating, such as high ambient temperature, solar radiation, design and construction practices, and occupancy behaviours. Thematic analysis of interview data highlighted inappropriate ventilation as the primary cause of overheating, regardless of the construction method, with lightweight materials and energy-efficient building posing additional challenges. The interviewees emphasized the necessity for consistent regulatory frameworks across all construction methods and the importance of passive design strategies. The study contributes to the understanding of regulatory effectiveness of Approved Document O and offers recommendations for improving overheating mitigation in MMC buildings.

Keywords: *Modern Method of Construction; Overheating; Approved Document O; Ventilation Strategies.*

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1. INTRODUCTION

As we stand at the intersection of climate crisis and construction innovation, there is a growing recognition that the way we build, and the materials we use, hold the key to both mitigating the adverse effects of climate change and adapting to its inevitable impacts (Keeffe & McHugh, 2014). These escalating impacts of climate change, such as high temperature, rise in sea level and extreme weather events pose unprecedented challenges to global sustainability and human health (Balogun, et al., 2020; Intergovernmental Panel on Climate Change, 2023). This has necessitated the need for innovative and integrated approaches that will enhance climate change adaptation and mitigation strategies for built environment.

The built environment contributes to environmental degradation and global warming due to high energy consumption and carbon emissions (Sudhakaran et al., 2020; Röck et al., 2020). Adopting sustainable construction methods, such as Modern Methods of Construction (MMC), can mitigate the effects of environmental degradation and global warming by minimizing pollution, reducing energy consumption, and maximizing resource use (Nazir et al., 2020). MMC, which includes prefabrication and modular construction, often enhances construction efficiency and environmental performance (Kaushal et al., 2022). The implementation of MMC has experienced a surge globally, including in the United Kingdom (UK), who aim to deliver high-quality buildings with reduced cost and environmental footprints as outlined in the UK's 2025 construction strategy (Bertram et al., 2019; Buckley et al., 2020; Maqbool et al., 2023a).

While MMC known for lightweight construction have become integral to addressing climate-related issues, which are in alignment with the 'Construction 2025: Strategy', a joint strategy from the UK government and industry for the future of the UK construction industry (Maqbool et al., 2023; Wuni & Shen, 2020), it however, presents the challenge of overheating (Ozarisoy, 2022; Chartered Institution of Building Services Engineers (CIBSE) 2024). The Chartered Institution of Building Services Engineers (CIBSE) offers guidance on managing overheating as outlined in Technical Memorandum 59 (TM59), which should be considered in building development, but factors such as airtightness, high insulation, limited natural ventilation, and lightweight limits the ability for MMC structures to adhere completely to this guidance, and contributing to overheating (Ozarisoy,2022; Gupta & Gregg,2020; Fifield et al., 2018). These unintended impacts necessitate the enactment of a regulatory framework to ensure building standards are compatible with all seasons (Fifield et al., 2018).

Furthermore, different countries have adopted various strategies to address the challenges of environmental degradation and global warming (Howarth et al., 2018; Intergovernmental Panel on Climate Change Technical Support Unit Working Group, 2018). In particular, the UK government inaugurated a committee in 2012 to prepare climate change risk assessment (CCRA) report with a review period of five years. The latest report was published in January 2022, which highlights eight priority risk areas for the government, out of the most significant risk applicable for this research is Priority Risk No. 7, "Risks to human health, wellbeing and productivity from increased exposure to heat in homes and other buildings".

Priority risk -No. 7 of the CCRA report underscores the escalating risks of overheating in buildings, suggesting that policies aimed at achieving Net Zero emissions may inadvertently exacerbate overheating risks. Likewise, Salimi and Al-Ghamdi (2020) proposed that the built environment requires research which should focus on enhancing building codes to address challenges posed by extreme heat waves and power outages. Additionally, Drury and Lomas (2020) as well as Hamdy et al. (2017) delineated various issues relating to building overheating, which include impaired sleep quality, reduced productivity, and health risks. These issues are expected to worsen with the increase in global warming (IPCC, 2018).

Acknowledging the pressing need to combat climate change within the realm of construction, the UK government has implemented a range of policies and regulations with the aim of enhancing thermal comfort and energy efficiency (Howarth et al., 2018). Notable initiatives include the Building Regulations for overheating, detailed in "Approved Document O," alongside the Future Homes Standard and the Clean Growth Strategy, which set forth mandates and objectives for reducing energy consumption and carbon emissions within the built environment. However, an analysis of "Approved Document O" highlights the need for additional clarification, particularly concerning acoustic limits, assessment methodologies for glazing areas, allowances for mechanical cooling, and guidance on selecting suitable sample units (Diamond, 2022). These concerns have identified a notable gap in regulatory guidance for addressing overheating in modern buildings (Jariwala & Taki, 2023).

Given the anticipated rise in both the intensity and frequency of heatwaves in the UK, along with forecasts suggesting a 5.4°C increase in summer temperatures by 2080 (MetOffice, 2018), immediate measures are imperative to prepare ourselves for the present and future alterations in weather conditions. This challenge necessitates effective regulations to address environmental sustainability concerns (Brimicombe et al., 2021; Jariwala & Taki, 2023). While the UK government has enacted policies aimed at facilitating sustainable development, there is a pressing need to assess the effectiveness of the existing regulations in addressing overheating risks in sustainable buildings.

Therefore, this study seeks to evaluate the effectiveness of Approved Document O in regulating overheating in modern buildings. Using the key research question "How effective is Approved Document O in addressing overheating in modern method of construction", the following research objectives: (1) exploring the problem of overheating in buildings, (2) investigate how various MMC techniques susceptible to overheating (3) examining the effectiveness of Approved Document O for mitigating overheating in buildings in England and (4) developing actionable recommendations for policy enhancements for mitigating overheating in modern buildings were explored.

2. LITERATURE REVIEW

2.1 OVERVIEW OF MMC

There has not been a universally accepted definition for Modern Methods of Construction (MMC), as various authors have described the term based on their individual perspectives. According to Nazir et al. (2020), MMC encompasses innovative approaches and procedures that diverge from conventional on-site building practices. Maqbool et al. (2023b) and Saad et al. (2023) broaden this definition to include "panelised frames, volumetric systems, hybrid systems, and modular systems". These methods offer alternatives to the traditional approaches and hold the promise for significantly enhancing productivity, efficiency, and quality in the construction industry and the public sector. Additionally, Maqbool et al. (2023a) highlight the substantial benefits associated with

MMC techniques, emphasizing their pivotal role in achieving the objectives outlined in the 'Construction 2025: Strategy'. Furthermore, Sánchez-Garrido et al. (2022) emphasize the potential MMCs in minimising life cycle impacts by optimising material usage. Taken together, MMC can be described as an innovative technique, which diverges from traditional on-site building methods and creates emphasis on efficiency, sustainability, and precision. Therefore, Table 1 is used to highlight some advantages and disadvantages of MMC as described by various authors.

Table 1: Advantages and disadvantages of MMC with emphasis on overheating
Sources: (Gupta & Gregg, 2020; Davenport & Partington, 2021; Ozarisoy, 2022; Maqbool et al., 2023; Jariwala & Taki, 2023)

Advantages	Disadvantages
High thermal insulation properties of MMC systems enhance indoor thermal comfort and energy efficiency.	Low thermal mass in lightweight MMC systems (e.g., steel or timber) can increase the risk of overheating, especially in
Reduced thermal bridging due to precise factory fabrication improves building envelope performance.	High levels of insulation and airtightness can lead to overheating if not paired with adequate ventilation strategies.
Reduction in completion timeframe and environmental impact from construction activities.	Slower establishment of standardised designs, quality assessment systems, and accreditations
Reduced construction waste and environmental impact through off-site manufacturing.	Pre-completed designs limit flexibility, making it harder to adapt thermal strategies
Panelized wood structure provides advantages such as reduced weight, potentially resulting in decreased requirements for foundation design.	Thermal comfort challenges arise from low thermal mass and airtightness, requiring careful passive design integration.

2.2 OVERHEATING RISK

The implementation of MMC known for lightweight construction, has been accompanied by a growing concern over high temperatures in buildings that have adopted MMC techniques (Ozarisoy, 2022; Jariwala, & Taki, 2023; CIBSE 2024). Additionally, CIBSE has described overheating as *"conditions where the indoor temperature surpasses 28°C for more than 1% of the annual occupied hours in the living areas of dwellings without mechanical cooling systems, or when the bedroom temperature exceeds 26°C for more than 1% of the annual occupied hours, unless ceiling fans are present"*. This description along with other criterions formed the basis for which Fifield et al., (2018) identified Bradford Royal Infirmary UK, as being at risk of overheating. Their study highlighted overheating complaints from residents, resulting in discomfort during the summer period. Additionally, the study identified the use of penalized wall as a major contributor to high indoor temperatures in this building.

However, other articles have identified and described various factors contributing to overheating in buildings. The authors have categorized these factors into three categories, as shown in Table 2.

Table 2: Causes of building overheating

Category	Sub-category	Description	Sources
Environmental Drivers	High outdoor temperature Solar radiation Urban heat island Greenhouse gas	Environmental drivers which can include climate related factors, such as high weather temperature, humidity, and wind pattern, affect indoor thermal dynamics. With hot and humid climates, comes the stress of high ambient temperatures and low air movement which hinders natural ventilation and exacerbates heat. Similarly, Urban heat islands, marked by heightened temperatures in densely populated regions, can exacerbate overheating. While MMC offers efficiency and sustainability, its airtight and highly insulated designs can restrict natural ventilation and thermal mass, potentially worsening overheating if not adapted to local climate conditions.	(Hamdy et al., 2017), (Lomas and Porritt, 2017), (Diamond et al., 2019), (Rahif et al.,2022), (Bo et al.,2022), (Chen, 2019), (Alrasheed and Mourshed, 2023), (Jariwala, & Taki, 2023).
Design and Construction	Lack of double-glazed windows High level of insulation Inappropriate ventilation Underperforming insulation Building orientation Reduction in green spaces Increase level of airtightness Lack of external shading	Many newly built energy-efficient homes are designed without fully accounting for future climate warming. Design factors such as orientation, glazing, and insulation, directly affect solar gains, ventilation, and thermal comfort MMC systems, particularly light steel panelised methods, often feature extensive glazing for facades and windows), which, without adequate shading, can lead to excessive solar heat gain. High insulation levels and thermal bridging may further impair heat regulation Additionally, MMC's reliance on lightweight, low-mass materials reduces thermal buffering capacity, increasing overheating risk during high solar exposure	(Fifield et al 2018), (Morgan et al., 2017), (Lomas and Porritt, 2017), (Diamond et al., 2019), (Bo et al.,2022), (Alrasheed and Mourshed, 2023), (Drury et al.,2021) (Mitchell & Natarajan, 2019), (Davenport & Partington, 2021 (Habitzreuter et al, 2020), (Ozarisoy, 2022). (Milovanović et al., 2022). (Rakotonjanahary et al., 2020)
Operational factors	Activities of occupant Level of occupancy Heat gain from boilers Equipment usage	Building operational factors including occupancy patterns and activities, appliance usage, and ventilation practices of the occupants contribute to internal heat gains, this can elevate indoor temperatures, particularly in poorly ventilated spaces with airtight envelopes or limited access to outdoor air.	(Fifield et al.,2018), (Lomas and Porritt ,2017), (Rahif et al.,2022), (Drury and Lomas, 2020), (Chen, 2019), (Habitzreuter et al, 2020), (Mitchell & Natarajan, 2019)

2.3 OVERHEATING MITIGATION STRATEGIES

Mitigating overheating in contemporary construction necessitates a strategic implementation of passive design techniques, greenery strategy, and innovative technologies. Alrasheed and Mourshed (2023) proposed a classification of passive cooling techniques into three categories: "solar and heat protection, heat modulation, and heat dissipation," providing a systematic approach to alleviate overheating risks in residential structures. Similarly, Gamero-Salinas (2021) underscored the significance of passive cooling design strategies in mitigating overheating in tropical climates like Tegucigalpa (TGU) and San Pedro Sula (SPS). Furthermore, greenery solution such as green roofs emerges as highly effective for cooling and energy savings, particularly in Mediterranean regions, potentially reducing the reliance on cooling systems (Zinzi & Agnoli, 2012). While innovative technologies like mechanical ventilation with heat recovery (MVHR) also play a crucial role by extracting warm and humid air from spaces such as bathrooms and kitchens, recovering waste heat through a heat exchanger, and reintroducing tempered fresh air into living areas, thereby diminishing the need for heating and subsequent energy consumption. However, meticulous planning during the design and construction phases is imperative (Karampour & Burgess, 2022). Implementing these strategies can effectively regulate indoor temperatures and enhance thermal comfort. However, consideration needs to be made on adherence to government regulation like Approved Document O that provides guidelines for assessing overheating in building, when deciding on a mitigation strategy. Figure 1 provides an indicative summary of overheating mitigation strategies.

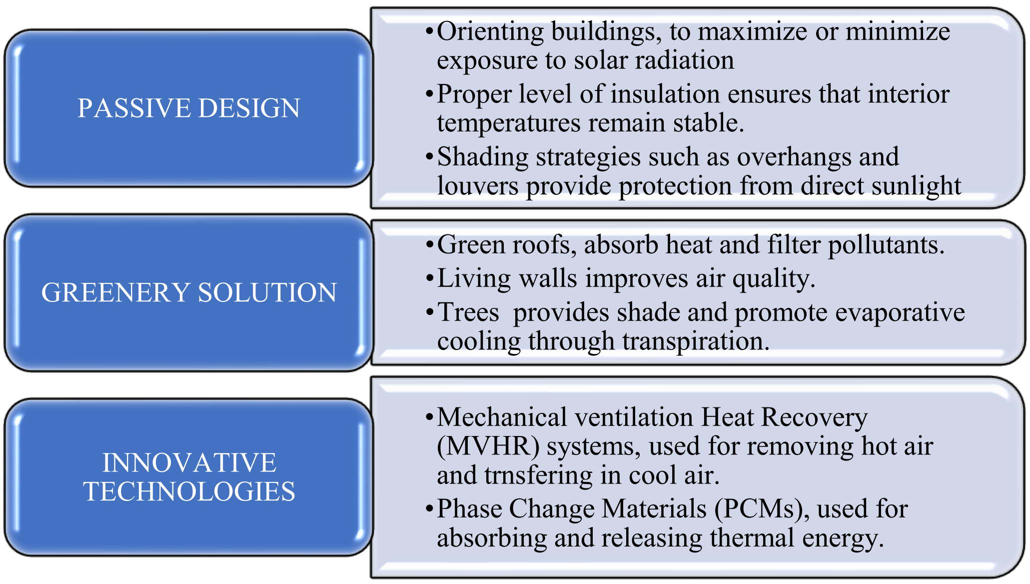


Figure 1: Overheating mitigation strategies
Sources: (Zinzi & Agnoli, 2012; Auzeby, 2017; Hamdy et al., 2017; Diamond et al., 2019; Elaouzy, & Fadar, 2022; Karampour & Burgess, 2022; Alrasheed & Mourshed, 2023)

3. RESEARCH METHODS

The research, which centres on investigating the effectiveness of existing UK government policies on MMC in mitigating overheating risks in buildings and achieving net-zero, adopted an interpretivism approach for its research philosophy. Multiple qualitative research methods were employed. These include secondary data collection from databases such as ScienceDirect, SpringerLink, and the UK Government website, with selection criteria including articles published within the last ten years and a focus on keywords related to MMC buildings in the UK. Additionally, the authors reviewed regulatory publications from the UK government to identify suitable manuscripts for this study, presenting a descriptive desktop study of Approved Document O.

The primary data collection involved semi-structured interviews with six participants who were selected through purposive sampling based on their experience with MMC and overheating regulatory compliance. Open-ended questions which include seeking interviews opinions on the main strengths and weaknesses of the Approved Document O, were utilized to assess experts' views on the effectiveness of regulatory policy. Thereafter, thematic analysis, was used to analyse qualitative data and identify key themes. These themes are presented in subsequent sections.

4. DESKTOP STUDY OF THE APPROVED DOCUMENT O

The desktop study examines the Approved Document O, which is a part of the Building Regulations in the UK. It is designed specifically to address overheating concerns in residential buildings. This document was introduced in 2021 and came into effect on 15th June 2022. Previous building regulations L and F were used for regulating heat loss in winter. However, with the rising temperatures due to global warming, overheating in urban areas is becoming a bigger problem. Approved Document O now tackles the need to mitigate excessive heat in buildings, to keep buildings from overheating during the warmer months with specific focus on new buildings.

Approved Document O stipulates two core performance objectives:

- Measures should be taken to limit excessive solar heat gain during summer
- Ensure adequate methods to remove heat from indoor spaces with a preference for passive cooling strategies over mechanical cooling systems.

Therefore, Section 3 of the Approved Document O provides passive mitigation strategies that are deemed acceptable for occupant comfort, such as:

- Eliminates noise levels during sleeping hours,
- Minimizes intake of external pollutants,
- Ensures security of ventilation openings,
- Reduces the risk of falls from height,
- Prevents entrapment hazards.

These are not standalone mitigation strategies. However, they provide enabling conditions that support safe and effective implementation of passive ventilation strategies and compliance with the regulatory requirements.

Individuals can demonstrate compliance with Approved Document O using two specific strategies. A simplified method, which uses fixed parameters such as glazing ratios, openable window areas, cross-ventilation, and regional climate zones, offering ease but limited flexibility to accommodate innovative or non-standard construction typologies; and dynamic thermal modelling, which uses CIBSE TM59-based simulations with strict input constraints, allowing greater design adaptability but posing challenges for buildings using mechanical ventilation systems like MVHR. Although MMC is not explicitly referenced, its typical features—lightweight construction, low thermal mass, and airtight envelopes—heighten overheating risks and may conflict with passive cooling assumptions.

4.1 CHALLENGES FOR MMC IN ADHERING TO APPROVED DOCUMENT O

The authors while undertaking this desktop study, have also reviewed various sources of information available on Approved Document O such as (CIBSE 2021: Diamond, 2022). This review has enabled them to identify factors in approved Document O, which may impose a challenge for buildings constructed using MMC techniques. These Factors are described below.

Integration of Mechanical Systems: MMC buildings often incorporate integrated mechanical systems for ventilation and heating. However, the existing standards outlined in Approved Document O do not explicitly specify conditions under which mechanical ventilation is permissible within a building.

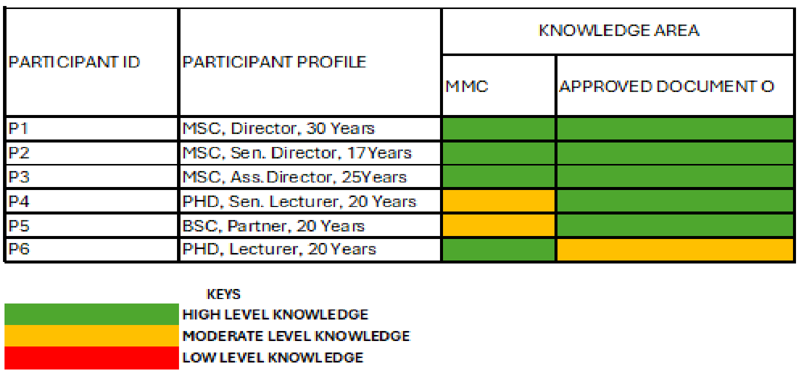
Design Impact on Glazing: Approved Document O mandates higher guarding heights and maximum reach for window handles, impacting glazing design in buildings. This could necessitate raised sill heights and limit the width of opening panes, posing design challenges for MMC projects.

Integration of Noise Mitigation Measures: Implementing noise mitigation measures within MMC components can present a complex challenge for professionals.

Limited Flexibility during Construction: MMC processes typically follow standardized manufacturing techniques, leaving limited room for on-site adjustments or modifications to address noise-related issues as they arise. This lack of flexibility can hinder the ability to tailor noise control measures to specific site conditions, potentially affecting compliance with Approved Document O.

5. DATA ANALYSIS AND DISCUSSION

The authors have used Figure 2 to provide an overview of participants' profiles and their knowledge levels in two domains MMC and ADO. Participants' profiles column details



PARTICIPANT ID	PARTICIPANT PROFILE	KNOWLEDGE AREA	
		MMC	APPROVED DOCUMENT O
P1	MSC, Director, 30 Years		
P2	MSC, Sen. Director, 17Years		
P3	MSC, Ass.Director, 25Years		
P4	PHD, Sen. Lecturer, 20 Years		
P5	BSC, Partner, 20 Years		
P6	PHD, Lecturer, 20 Years		

Figure 2: Overview of participants information and knowledge

their academic qualifications, job roles, and years of experience. Knowledge levels are color-coded: green for high (≥7 years), yellow for moderate (4–6 years), and red for low (1–3 years). All participants show high knowledge in MMC, whereas only half show high knowledge in Approved Document O. The table offers a clear visual summary of participant expertise and familiarity with key subject areas.

From Figure 2, it is visible that all participants have a significant level of knowledge of the subject area to enable them to make effective contribution to the existing body of knowledge.

5.1 PRIMARY FACTORS ENHANCING BUILDING OVERHEATING

The participants highlighted several factors contributing to overheating, such as inadequate ventilation, large glazing area solar heat gains, limited green spaces, and occupant density. From the interviews conducted, ventilation emerged as a major concern for all participants with P1 further emphasizing that flats are at a higher risk of overheating: "*Yes, there were many examples of people at that time living in flats where the internal environment just became untenable from a living perspective".* -P1. Therefore, there is a need for flats to be designed with the right ventilation strategy. Additionally, the participants debated on how design and construction materials contributed to building overheating, P2 stated that building materials with low U-values trap heat and lack the ability to disseminate the heat once absorbed. However, P1 and P6 argued that lightweight materials do not significantly impact overheating. With P6 further describes the challenge of building overheating as design related, stating that the increased reliance on floor to ceiling glass ratio has impacted the level of heat gains into the building. These findings are consistent with those reported by researchers (Alrasheed & Mourshed, 2023; Drury et al.,2021; Habitzreuter et al, 2020; Mitchell & Natarajan, 2019; Diamond et al., 2019).

5.2 MMC TECHNIQUES SUSCEPTIBLE TO OVERHEATING RISK

The participants were asked which MMC techniques are more likely to bring about high temperatures in buildings. This aims to gather insights from individuals on their experience with techniques they have adopted to help mitigate building overheating, specifically in response to rising temperatures caused by climate change. It is important to know which MMC techniques are more likely to be susceptible to overheating. The interviewees expressed diverse opinions on the susceptibility of techniques to overheating, where three participants, namely P1, P2 and P5, did not agree that any single technique significantly increases a building's likelihood of overheating when compared to other techniques. Moreover, P5 was very assertive that neither the thermal mass nor the energy efficiency of the building or its component can make it susceptible to overheating. Two key themes namely energy efficient buildings and Lightweight materials were derived from participants' response. Moreover, the discourse surrounding the correlation between a building's energy efficiency and its susceptibility to overheating has garnered varied perspectives. While certain researchers, such as Bo et al. (2022) and Fifield et al. (2018), have suggested that highly energy-efficient buildings are prone to overheating, contrasting viewpoints have been presented by scholars like Lomas et al. (2024), who argues that because a building is energy efficient, does not necessarily make the building vulnerable to overheating.

Furthermore, two participants P2 and P6 associated susceptibility to lightweight construction material. P2 pointed out that lightweight construction techniques, such as light steel gauge construction, are particularly vulnerable to overheating due to their inherent characteristics. P6 further pointed out that, unlike heavier materials with greater thermal mass, which can absorb and store heat during the day and release it slowly at night, lightweight materials lack this capacity.

The assertions that lightweight buildings are susceptible to overheat, are corroborated by existing literature, where researchers such as Mavrogianni (CIBSE, 2024) and Milovanović et al. (2022) stated that lightweight buildings are more likely to overheat compared to their heavier counterparts. This susceptibility is attributed to factors such as thermal bridging, which presents challenges in achieving a stable and comfortable indoor environment, necessitating increased energy consumption by heating and cooling systems to effectively regulate temperatures.

5.3 STRENGTHS AND CHALLENGES OF APPROVED DOCUMENT O FOR BUILDING OVERHEATING

To assess the third and fourth objectives of the research, participants were asked about their perceptions on the influence of Document O on design and construction stage of a project. Four participants stated that Document O would have some level of influence on these stages. However, one participant described that the level of influence depends on project location. Finally, the last participant expressed a differing view but provided statements indicating that the design stages are indeed influenced by Document O. Consequently, it can be inferred that the document does impact the design stage.

Three key themes, which include awareness of regulatory requirements, positive health and safety impact, and climate variability, are used to highlight the strength of Approved Document O on building overheating, and the challenges associated with the same.

Regulatory Requirement awareness: The transition of Approved Document O from a mere appendix to a mandatory regulation underscores the government's pivotal role in addressing overheating concerns within the construction industry. This statement was further highlighted by the interviewees who noted that this has compelled stakeholders to consider overheating mitigation strategies at project design stage.

Positive Health and Safety Impact: The interviewees highlighted that raising awareness of overheating among all stakeholders early in a project's life cycle would reduce the risk to occupants. This factor was highlighted in the CCRA 2022 Report, where it noted that public awareness regarding protective measures during heatwaves is crucial. Therefore, through the adoption of suitable design strategies outlined in the Approved Document O, this risk can be further mitigated.

Regional and Climate Variability: Section 1.1 of the Approved Document O acknowledges regional variability by emphasizing the importance of considering local climatic conditions when assessing overheating risks in buildings. While the influence of regional climate conditions on overheating risks and the efficacy of regulatory frameworks was recognised by P3 and P5, P3 emphasized the importance of continuous refinement and updates to accommodate regional variability and evolving construction techniques. Similarly, P5 highlighted concerns about the document's applicability in low-risk regions and suggested the need for a simpler compliance method tailored to regional climate conditions.

With respect to the challenges of Approved Document O, two themes were determined. Which includes compliance challenges and MMC specific considerations.

Compliance Challenge: Some interviewees expressed concerns about the complexity and stringency of compliance methods outlined in Approved Document O. P4 commended the document's two-tiered approach, which offers simplified compliance checks for straightforward buildings and dynamic thermal simulation for complex structures. However, the interviewee also noted the challenges associated with dynamic simulation, such as the need for extensive input assumptions, stating, "*if you use dynamic thermal modelling, you have to have an assumption for all these things, because it is a required input into the model*." These observations underscore the need for a balanced approach to compliance that accounts for building complexity while ensuring feasibility and cost-effectiveness.

MMC Specific Considerations: The interviewees had varying opinions on this, with P5 stated that it would not be necessary for Approved Document O to differentiate between traditional and MMC buildings. However, all participants recognized the unique challenges associated with MMC construction. P2 noted that MMC buildings, with their superior airtightness and insulation, may be more prone to overheating due to limited natural ventilation opportunities. P3 echoed these concerns, emphasizing the need for tailored guidelines to address MMC-specific challenges, such as lightweight construction materials and sealed building envelopes.

5.4 RECOMMENDATIONS FOR ENHANCING OVERHEATING MITIGATION STRATEGY IN APPROVED DOCUMENT O

The interviewees were asked to provide recommendations they believed could enhance the effectiveness of Approved Document O in mitigating overheating in modern buildings. From their responses, four key themes were identified, as illustrated in Figure 3 and discussed below.

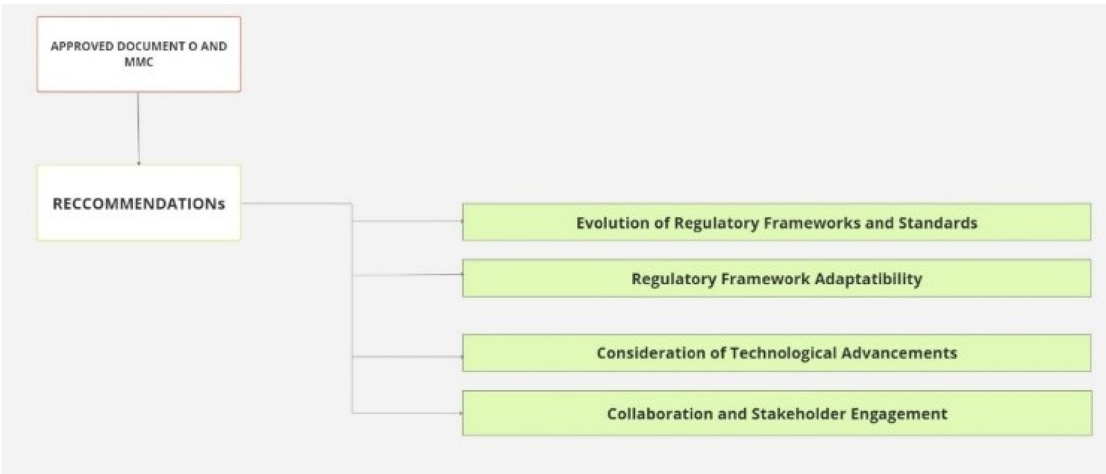


Figure 3: Overview of key themes derived for enhancing Approved Document O.

Evolution of Regulatory Framework and Standard: some interviewees advocated for flexibility and agility in regulatory frameworks to accommodate emerging trends and technologies. Furthermore, P4 highlighted the need to align regulatory frameworks with future climate projections, to create a better understanding for designers.

Regulatory Framework Adaptability: Several interviewees P2, P4 and P5 emphasized the necessity for a regulatory framework to remains consistent across different construction methods. However, they describe the need for specific adaptability consideration for lightweight structure. This emphasizes the importance of adaptability and effectiveness in regulatory standards.

Consideration of Technological Advancement: Some interviewees discussed the need for consideration of technological advancements, such as intelligent MVHR systems, to be included in regulatory frameworks.

Collaboration and Stakeholders Engagement: P6 emphasized the importance of collaboration between industry stakeholders and policymakers for the practical implementation of regulatory frameworks, this interviewee describes the struggles of stakeholders in complying with different aspect of design regulations. This aligns with P3 recommendation for enhanced collaboration to ensure the practical implementation of regulatory measures.

6. CONCLUSIONS

This study evaluated the current regulatory framework and its effectiveness in addressing overheating in buildings, especially those constructed using MMC. It began with reviewing the literature and identifying factors contributing to building overheating. These factors were categorized into climatic, design and construction., and occupancy. Furthermore, overheating mitigation strategies were examined using literature and interviews, revealing the use passive design, green solution and innovative technologies such as MVHR as effective mitigation strategies. The interviewees also highlighted that lightweight construction has a significant risk of overheating due to low thermal mass. Additionally, the assessment of Approved Document O identifying its positive impacts and challenges in terms of compliance, due to large assumptions in the dynamic thermal modelling standard and absence of consideration for MMC buildings. The study also proposed policy enhancements, emphasizing regulatory evolution, technological advancement and stakeholders' collaboration to improve overheating mitigation standards in modern buildings, contributing to occupant wellbeing and economic development. Finally, the research demonstrates the need for a comparative large-scale study between MMC and traditional construction methods to identify any significant differences in overheating risks and mitigation effectiveness, seeking to explore how the Approved Document O has addressed this risk. Limitations of the study include the small sample size of interview participants and the focus on a single regulatory document (Approved Document O). Future research should consider comparative studies across different regions and regulatory frameworks.

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