CRITICAL ERRORS IN BUILDING SIMULATION TO SUPPORT REAL-WORLD ZERO-CARBON ENERGY BUILDINGS: A CRITICAL REFLECTION

Jesus Lizana[1,2]

[1]Department of Engineering Science, University of Oxford, Oxford OX13PJ, United Kingdom

[2]Zero Institute, University of Oxford, Oxford OX2 0ES, United Kingdom

ABSTRACT

Building simulation plays a crucial role in achieving cost-optimal zero-carbon energy buildings. However, several opportunities are frequently overlooked due to incumbent practices rooted in traditional practices, building codes and standards. This article introduces ten common errors in building simulation when designing zero-carbon energy buildings. Key areas of concern include (1) climate data formats and limitations, (2) mischaracterisation of solar properties, (3) missing ventilation strategies, (4) not considering all thermal comfort variables, (5) metrics always focusing on energy systems, (6) unregulated energy uses overlooked, (7) a building-centric focus instead of occupant-centric design, (8) the role of smart control, (9) frequent systems oversizing, and (10) annual carbon emission coefficients overlooking hourly carbon savings. The research explains the relevance and implications of these critical areas and introduces alternatives to overcome them in building simulation. By tackling these challenges, the study offers alternative strategies to enhance building simulations to support net-zero targets. The findings aim to enhance the development of real-world zero-carbon buildings through a better simulation-assisted design, ensuring that building configurations and energy systems are cohesively optimised and integrated following a climate-responsive zero-carbon design.

Keywords: Building simulation; advanced energy modelling; real-world building needs; zero-carbon energy buildings; Climate-responsive design.

INTRODUCTION

Several opportunities in simulation-aided building design are often overlooked due to incumbent practices rooted in traditional routine and building codes, which frequently do not meet the best practices or recommendations. These incumbent traditions can create barriers to innovation and limit the adoption of newer, more efficient techniques, technologies, and methods to achieve net zero. The key reasons creating this incumbency are related to:

- Compatibility Issues: traditional building simulation tools and practices may not be compatible with newer technologies or integrations, making it challenging to analyse and integrate innovative solutions. Constraints on input values, system characterisation, and control limit innovation.
- Lack of knowledge and training: many professionals in the building industry may not be aware of the latest advancements due to a lack of continuous education and training.
- Market dynamics and resistance to change: The building industry is often driven by market demand, which can favour tried-and-tested methods.
- Code compliance focus: Compliance with building codes is a primary concern for many professionals. This focus on meeting minimum standards can limit the exploration of practices that exceed these requirements, even if they offer significant benefits.
- Regulatory constraints: building codes are typically updated slowly and may not keep pace with technological advancements, best practices, or the latest standards or recommendations.

To overcome these challenges, the paper critically discusses 10 common errors in building simulation that lead to significant missed opportunities in the building industry to achieve zero-carbon energy buildings. Addressing these opportunities through knowledge

sharing can maximise best practices for future zero-carbon energy projects. This manuscript is the first analysis of the future ZERO Institute strategy at the University of Oxford to upgrade education and training programs to support adopting the best practices and latest advances in the building sector to net zero.

METHOD

This manuscript compares conventional building simulation approaches with updated building standards and best practices, scientific literature, and recent zero-carbon energy building projects. The aim is to identify the most common critical errors in energy modelling that result in missed opportunities for achieving cost-effective real-world zero-carbon buildings.

Fig. 1 illustrates the traditional workflow for building energy simulation (BES) aimed at regulatory compliance (e.g. UK Part L compliance), which involves three main stages: input data, numerical modelling, and performance reporting (Economidou et al., 2020).

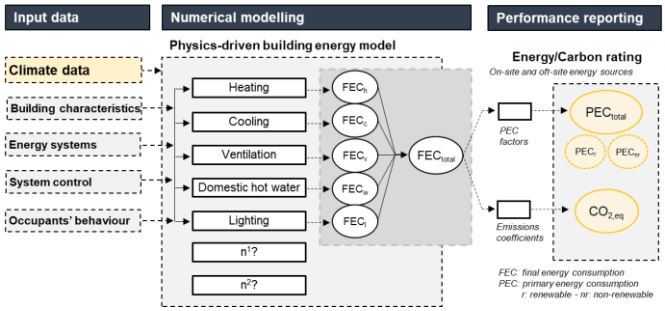

Figure 1: Traditional workflow for BES.

In the input data stage, detailed information about the local climate, the building's geometry, materials, systems, control, and occupancy patterns is defined. This data forms the foundation for creating an accurate model. During the numerical modelling phase, this data is input into simulation software that applies mathematical models to simulate the building's energy performance under various conditions. This involves complex calculations related to heat and mass transfer, HVAC systems, lighting, and other energy-consuming processes. Finally, in the performance reporting stage, the simulation results are analysed. This typically includes key performance indicators on energy consumption and carbon emissions, providing insights into the building's performance.

This conventional workflow is compared with recent recommended building standards and guidelines from ASHRAE, CIBSE and CEN M/480; the latest scientific literature on building energy modelling (Jesus Lizana et al., 2024; Pan et al., 2023); and recent innovative proposals for zero-carbon energy buildings. The analysis highlights the top ten critical errors in building simulation to support cost-effective real-world zero-carbon buildings.

RESULTS AND DISCUSSION

The results are divided into ten key areas of concern, which include (1) climate data formats and limitations, (2) mischaracterisation of solar properties, (3) missing ventilation strategies, (4) not considering all thermal comfort variables, (5) simulated indicators always focusing on energy systems, (6) unregulated energy uses overlooked, (7) a building-centric focus instead of occupant-centric design, (8) the role of smart control, (9) frequent systems oversizing, and (10) annual carbon emission coefficients overlooking carbon savings.

1-Climate data formats and limitations

Hourly meteorological files encapsulate the climate conditions and facilitate applications in energy simulations and building design. When using hourly meteorological files in building simulations, it is important to understand the application and limitations of each dataset. Understanding these differences is crucial for accurate building energy modelling. Climate data have a tremendous impact on the final building design, system sizing, and energy performance.

Meteorological files for energy simulation can be divided into three main classes depending on the intended application (Herrera et al., 2017):

- Typical years, such as TMY, TRY and IWEC, represent long-term weather compiled from 20-30 years of data. Typical years are widely used for compliance and certification simulations. One of the most popular open-access repositories is "climate.onebuilding.org". Others are Open Climate Analytics (from Design Builder) or Meteonorm. However, many other repositories are available (Table 1). Here, it is important to check the timeframe used to generate these typical year files since most repositories are

based on old climate observations, which may not be representative of the current climate anymore.

- Extreme years or design years often contain a specific year of weather data where the year is selected for some extreme characteristic. Design year data may be used for overheating analyses and heating and cooling system sizing applications. Repositories such as CIBSE, COLBE, Climate Analytics or (Machard et al., 2024) include these extreme weather formats.
- Actual years contain a specific year of climate data. They are often used with calibrated models for post-occupancy evaluation, when we want to match simulated with measured values. NASA POWER and Climate Analytics include access to these data.

Table 1. Popular climate data repositories for BES.

Acronym	Year	Definition	Period	Source
IWEC2	2011	International Weather for Energy Calculation (ASHRAE)	1986-2011	White Box Technologies
TM2	-	Based on weather stations, and geostationary satellites.	-	Meteonorm
CIBSE	2016	TRY and DSY in 14/16 locations in the UK	1984-2013 2011-2040 2041-2070 2071-2100	www.cibse.org/
COLBE	2019	Localised Current and Future Weather for the UK at 5km	1961–1990 2070-2099	colbe.bath.ac.uk/
TMYx	2023	TMY using data from weather stations	2004-2018 2007-2021 2009-2023	climate.onebuilding.org
Climate Analytics	2024	Climate platform from DesignBuilder	-	designbuilder.co.uk
IEA-EBC Annex80	2024	Typical and extreme weather for historical and future weather in 15 locations.	2001–2020 2041–2060 2081–2100	(Machard et al., 2024)
NASA Power	-	Historical observations based on MERRA-2 and GEOS	-	power.larc.nasa.gov

In parallel to this classification, climate data can also represent future climate projections. However, today, no free-access repository is available for future climate files worldwide. Here, morphing techniques have been widely explored to generate typical years for future generations. This consists of generating future climate projections by adding projected monthly changes to typical year weather files. CCWorldWeatherGen (Jentsch et al., 2013) has been the most widely used morphing tool for building simulation, but other morphing methods have been recently proposed, such as the Future Weather Generator (Rodrigues et al., 2023). It should be noted that morphing techniques are applied only to specific variables, climate scenarios are outdated in most tools (even in licenced repositories), and final weather files are based on applying projected monthly changes in climate patterns. This is the reason why today, only licensed repositories (such as Meteonorm or Climate Analytics) are the most used source of future weather files, globally, along with other regional repositories such as CIBSE or COLBE in the UK, or the new future weather repository created by the IEA EBC Annex 80 working group (Machard et al., 2024).

Additionally, specifically for extreme heat, urban overheating is becoming a serious problem affecting building performance. This level of climate observations is vital for understanding localised implications in building design influenced by factors such as urbanisation, land use changes, and topography. In this scale, intra-urban variability emerges as well (Lizana et al., 2022). At this scale, urban meteorological networks stand as the main provider of reliable climatic data, and tools (e.g. *Urban Weather Generator* or Climate Analytics) also enable TMY files to be morphed to represent the urban climate context.

2- Mischaracterisation of solar properties

Solar gains are gaining a significant role in building performance under climate change. The mischaracterisation of solar properties in opaque surfaces (absorption coefficient and emissivity) and openings (e.g. shading reduction factor and g⊥-value) can have a substantial impact on the final performance, which often stems from the simplified or inaccurate characterisation of building materials.

Factors such as indoor or outdoor shading in windows or reflective coatings glazed in the inside or surface position have a completely different impact on internal solar gains and, in most cases, are wrongly characterised in numerical models. In cold countries, the reflective coating is usually placed inside to keep as much heat inside as possible, which also leads to the glass absorbing solar gains in summer and acting as a radiant heating panel. However, in hot climates, this coating is placed outside to reflect as many solar gains as possible. Moreover, many models fail to accurately account for the variability in the seasonal spectrum, leading to errors in predicting thermal loads and energy consumption. For instance, assumptions about the uniform distribution of shading effects and surface reflectivity can result in

significant deviations from actual performance. Additionally, the dynamic nature of solar radiation, influenced by weather conditions, seasonal changes and changeable external obstacles (e.g. trees), is frequently oversimplified. This can lead to underestimations or overestimations of cooling and heating demands, impacting the design and operation of HVAC systems. To improve the accuracy of simulations, it is crucial to ensure accurate solar radiation data and detailed material-specific properties and geometries, ensuring that models reflect the proper interactions between solar heat gains and building components.

3- Unknown effectiveness of ventilation strategies

The most effective alternative to dissipate heat in buildings is by natural/mechanical ventilation (López-García et al., 2022; Mehmood et al., 2022). Natural ventilation is frequently modelled as a constant rate or fixed hourly-based rate profile. However, integrating natural ventilation or hybrid mechanical/natural ventilation is more complex in the reality, and the real-world impact of different solutions can differ significantly. For example, higher ventilation rates can be easily promoted by cross-ventilation. If necessary, this can be achieved by incorporating inner courtyards, which can reduce indoor discomfort hours by up to 26% (Lizana et al., 2022). Additionally, features such as ventilation chimneys or roof vents can be added to assist airflow further (Fig. 2).

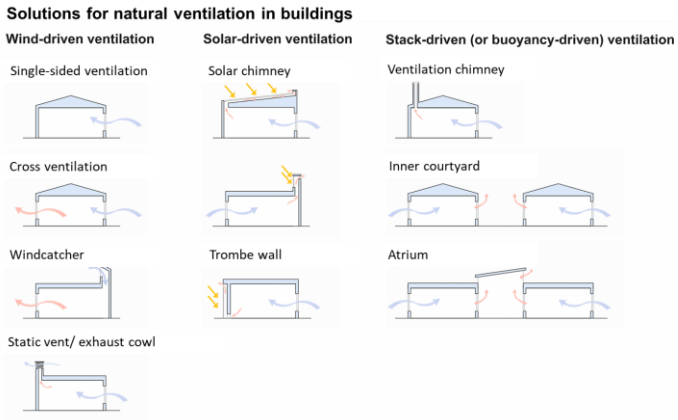

Figure 2: Strategies for natural ventilation in buildings.

Today, there are no guidelines regarding the airflow rate of different natural ventilation strategies in building performance, and many assumptions must be made when no detailed analysis is performed (e.g. CFD).

4- Not considering all thermal comfort variables

Idealised thermal systems are frequently used in BES to size heating and cooling systems, assuming specific temperature set-points of approximately 21°C and 24°C for winter and summer, respectively. This traditional understanding of thermal comfort has overlooked opportunities to reduce system size and energy demand. The main reason is that dry-bulb temperature does not determine our thermal comfort perception. Comfortable environments should be created by controlling temperature, humidity, air velocity and radiant temperature, allowing personal adaptation, and ensuring an adequate supply of fresh air to achieve good indoor air quality (Khovalyg et al., 2020) (Fig. 3).

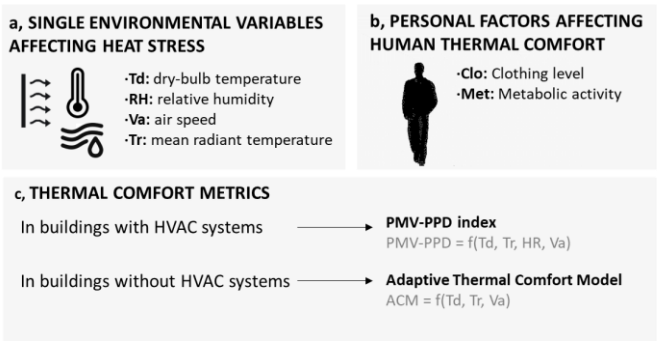

Figure 3. Thermal comfort variables and indices.

The integration of more thermal comfort variables when heating or cooling is also known as the hybrid approach to address thermal comfort (Lizana, et al., 2022) (Fig. 4).

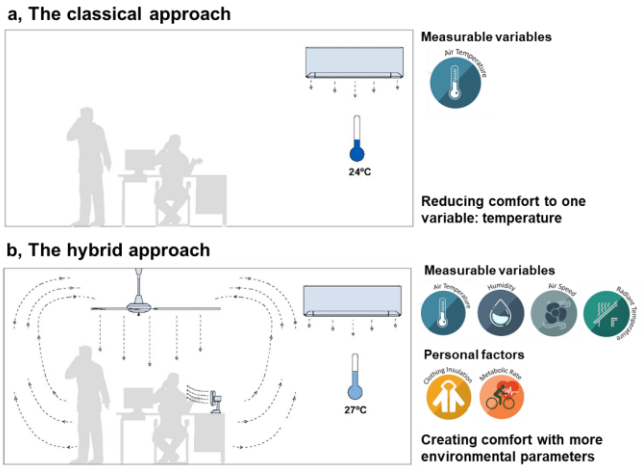

Figure 4. Illustration of the classical and hybrid approaches to promote thermal comfort in buildings.

For example, integrating ceiling fans to increase airspeed can enable to increase the temperature set-point from 24°C to 27°C without sacrificing thermal comfort,

reducing energy consumption by more than 20% or even eliminating the need for an air-conditioner (Hoyt et al., 2015; Zhang et al., 2011).

5-Simulated indicators always focus on energy

A common problem in many new zero-carbon energy buildings is that they frequently overheat due to the lack of heat-resilient metrics and future climate analysis. Specifically, indoor overheating is becoming a critical problem in cold regions, where buildings are traditionally prepared for the cold season (Miranda et al., 2023).

The indicators that guide simulation-assisted building design are critical elements in creating synergies between mitigation and adaptation targets. However, currently, most metrics target mitigation exclusively, calculating energy and carbon emissions assuming all buildings have HVAC systems and fixed set-point air temperatures (Mehmood et al., 2022).

Future building simulation requires the consideration of new metrics to measure passive survivability and/or building resilience (Samuelson et al., 2020). The target would be to maximise synergies between passive and active building performance, reducing trade-offs, and indoor overheating situations. A solution could be the implementation of steady-state models for building analysis with HVAC systems, and adaptive comfort models for building analysis without using the HVAC systems. International thermal comfort standards, such as ASHRAE 55-2020, ISO 7730:2005, EN 16798-1:2019, and other scientific publications provide methods to implement these thermal comfort indices. Some of these thermal comfort can be explored in the CBE Thermal Comfort Tool created by (Tartarini et al., 2020).

Few countries have already implemented new policies in building codes, recognising the importance of the risk of overheating for naturally ventilated and mixed-mode buildings. Some examples are found in Germany, France or the United Kingdom. Moreover, two CIBSE standards already address this problem (TM52 or TM59). However, in most cases, these criteria don't apply to existing buildings, and most importantly, they do not include future climate data in the analysis – we are still using historical climate observations to support the building design that will stand for the next century. All of these factors significantly hinder climate adaptation.

6-Unregulated energy usages overlooked

Over 150 building codes and certification programs are available worldwide to support a sustainable building design (Jesus Lizana et al., 2024). However, most of them only focus on regulated energy usage in buildings associated with heating, cooling, ventilation, hot water and lighting (Fig. 5). They all overlook other energy usages in buildings that will play a crucial role in future zero-carbon energy buildings.

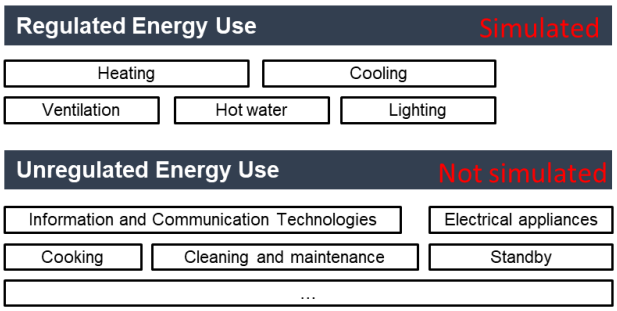

Figure 5. Classification of regulated and unregulated energy usage in buildings.

As an example, Lizana et al. (2024) quantified the impact that background power consumption (e.g. from Information and Communication Technologies) will have in future zero-carbon energy buildings. Using a university building as a case study, the initial baseload for this energy use was responsible for 26 % (28.4 kWh/m^2). However, it will represent 49 % in a future zero-carbon building scenario. This energy use lacks compliance requirements, and it is completely overlooked in building energy modelling. Additional building guidelines should be defined to guarantee that unregulated energy usages are not ignored.

7-The building-centric focus instead of occupants

Recent standards and advances in the building industry suggest that new buildings should include user adaptability with less centralised requirements. Centralised systems have been proven inefficient since, for example, they often cool people down more than necessary, or waste energy by cooling empty rooms. This fact, in combination with the emergence of more hybrid working arrangements in office spaces, has brought forth a new challenge: periods with occupancy close to

zero leading to enormous energy waste. This scenario presents a significant dilemma, as buildings frequently remain fully operational without occupants, resulting in unnecessary energy consumption.

The solution can start from an occupant-centric building design and simulation, combining centralised and personalised environmental control systems (PECS) involving all comfort parameters and allowing adaptability (Fig. 6).

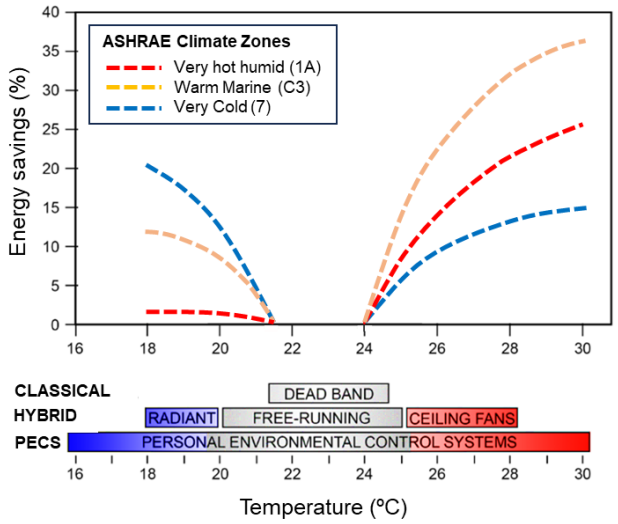

Figure 6. Potential energy savings for different ASHRAE climates by extending the temperature set-points from conventional (21-24°C) to hybrid or PECS approaches. Based on (Hoyt et al., 2015; Zhang et al., 2011).

This requires distinguishing between centralised building configurations and individual adaptive environments for user adaptability according to different occupants' needs. The target is to decrease centralised thermal systems, reducing peak capacity, and energy demand without sacrificing comfort. A growing market of personal heating and cooling devices, involving personal/desk fans, radiant panels, cooled seats or wearable devices is available (Song et al., 2022).

8-The role of smart control

Smart control engineering is another critical aspect frequently overlooked in building simulation. The complexity of operating modes in buildings is increasing drastically, moving from conventional operation modes involving only full-load or partial-load operation to more complex modes considering full occupancy or nearly unoccupied, real-time occupants' preferences, or external signals for energy flexibility (Lizana et al., 2018).

Introducing these operation models in zero-carbon building modelling can help optimise the sizing of thermal systems and improve real-world efficiency. It is common to find new zero-carbon energy proposals where seasonal efficiency is not even close to expected values due to an inappropriate sizing and control strategy, leading to energy waste (Suliman et al., 2023).

9-Frequent systems oversizing or undersized, overlooking real-world needs and future climates

Traditionally, design load has been calculated using specific outdoor conditions based on climate percentiles. For the cold season, 99.0 and 99.6 percentile values are used. During the warm season, the values are 0.4, 1.0, 2.0, and 5.0. These criteria guarantee that the designed thermal system can meet peak load based on these requirements. However, these conditions frequently result in the oversizing of thermal systems, with industry engineers reporting variations by factors of 1.5 to 2.0. These sizing errors stem from a failure to account for all variables affecting the load.

Fig. 7 illustrates an example of a load duration curve for heating, selecting a heating system to cover more than 99.6th of heating needs (peak load of 102kW). Oversizing or system redundancy is never a problem in the building industry – this would only affect the investment cost. The main problem appears when the thermal system is configured exclusively to work close to peak load. As a result, the thermal system operation will be inefficient, drastically decreasing seasonal efficiency, leading to unnecessary energy consumption and higher operational costs.

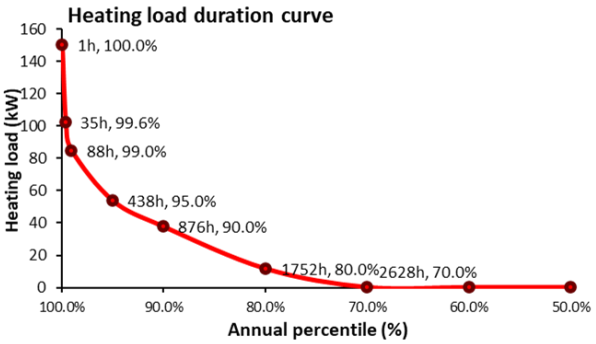

Figure 7: Example of load duration curve of heating.

The second problem arises from this design failing to recognize opportunities for peak load reduction, for example, decreasing (or increasing) the set-point temperature (1), non-simultaneous building demand when using smart control or during non-occupancy periods (2), or the integration of thermal energy storage to buffer peak load (3) (Lizana et al., 2024; 2017). A detailed analysis must be always integrated with additional variables affecting thermal sizing for optimal configuration and control. Zero-carbon energy buildings should ensure that thermal systems are adequate, efficient, and resilient.

10-Constant carbon emission coefficients overlooking carbon savings

Annual carbon emission coefficients, frequently used in emission calculations for compliance, drastically overlook the potential carbon savings that result from improved efficiency and renewable energy adoption. These coefficients typically assume a static annual rate of emissions per unit of energy consumption ($kgCO_{2eq}$ per kWh), failing to account for technological advancements in control engineering that can reduce the carbon footprint over time. By relying on static or outdated coefficients, we may underestimate the positive impact of innovations and miss opportunities.

First, it is important to admit that only electrifying thermal systems can continuously decrease annual carbon emissions due to the projected changes in the power system's annual emission coefficients (Fig. 8).

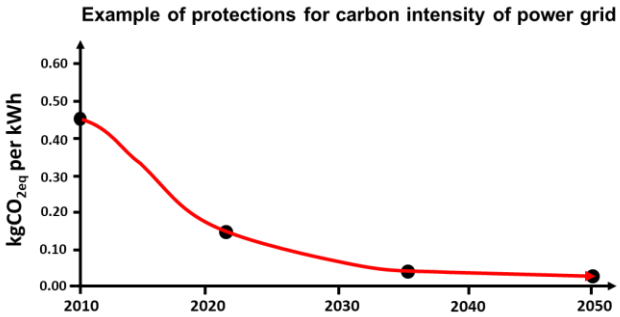

Figure 8: Example of projected annual carbon intensity rates.

Second, it is critical to recognise that carbon intensity rates are not constant over time, and thermal system sizing and system control can be further optimised to maximise real-time usage of renewable energy from the power grid (Franken et al., 2025; Lizana et al., 2018, 2023). Here, an optimal control can also lead to a further increase in the efficiency of thermal systems (e.g., when operating chillers at night, combining lower outdoor temperatures with low carbon intensity rates). To address this, it is essential to use dynamic coefficients that reflect the evolving energy landscape and the benefits of global sustainability efforts.

CONCLUSIONS

This paper discusses ten common critical errors in building simulation that can hinder the design of cost-effective zero-carbon energy buildings. Addressing these opportunities are crucial for advancing both the design and implementation of sustainable, zero-carbon building projects. By selecting accurate climate data (1), correcting mischaracterizations of solar properties (2), incorporating effective ventilation strategies (3), and considering a full range of thermal comfort variables (4), designers can achieve more precise and effective interventions. Additionally, expanding the scope of simulation indicators to include heat resilience metrics (5), including unregulated energy uses (6), adopting a holistic, occupant-centric design (7), integrating advanced smart control strategies (8), and avoiding systems oversizing (9) are essential for creating energy-efficient and climate-responsive buildings. By focusing on these elements and enhancing the temporal resolution and projection of carbon intensity rates (10), this paper offers a pathway to successfully realising zero-carbon climate-responsive buildings.

FUTURE WORK

This work is part of a new research and training programme in the ZERO Institute at the University of Oxford, aimed at promoting the adoption of best practices in building services engineering. Future efforts will incorporate these principles into a cutting-edge educational curriculum, ensuring that future engineers and practitioners are equipped with a deep understanding of cost-efficient zero-carbon energy principles for building energy simulation and design.

ACKNOWLEDGEMENTS

Research supported by the ZERO Institute at Oxford.

NOMENCLATURE (IF NEEDED)

BES	Building energy simulation
CFD	Computational fluid dynamics
HVAC	Heating, ventilation and air conditioning
PECS	Personalised environmental control system
TMY	Typical meteorological year

REFERENCES

Economidou, M., Todeschi, V., Bertoldi, P., D'Agostino, D., Zangheri, P., & Castellazzi, L. (2020). Review of 50 years of EU energy efficiency policies for buildings. *Energy and Buildings*, *225*, 110322. https://doi.org/10.1016/j.enbuild.2020.110322

Franken, L., Hackett, A., Lizana, J., Riepin, I., Jenkinson, R., Lyden, A., Yu, L., & Friedrich, D. (2025). Power system benefits of simultaneous domestic transport and heating demand flexibility in Great Britain's energy transition. *Applied Energy*, *377*(PB), 124522. https://doi.org/10.1016/j.apenergy.2024.124522

Herrera, M., Natarajan, S., Coley, D. A., Kershaw, T., Ramallo-González, A. P., Eames, M., Fosas, D., & Wood, M. (2017). A review of current and future weather data for building simulation. *Building Services Engineering Research and Technology*, *38*(5), 602–627. https://doi.org/10.1177/0143624417705937

Hoyt, T., Arens, E., & Zhang, H. (2015). Extending air temperature setpoints: Simulated energy savings and design considerations for new and retrofit buildings. *Building and Environment*, *88*, 89–96. https://doi.org/10.1016/j.buildenv.2014.09.010

Jentsch, M. F., James, P. A. B., Bourikas, L., & Bahaj, A. B. S. (2013). Transforming existing weather data for worldwide locations to enable energy and building performance simulation under future climates. *Renewable Energy*, *55*, 514–524. https://doi.org/10.1016/j.renene.2012.12.049

Khovalyg, D., Kazanci, O. B., Halvorsen, H., Gundlach, I., Bahnfleth, W. P., Toftum, J., & Olesen, B. W. (2020). Critical review of standards for indoor thermal environment and air quality. *Energy and Buildings*, *213*, 109819. https://doi.org/10.1016/j.enbuild.2020.109819

Lizana, Jesús, Chacartegui, R., Barrios-Padura, A., & Valverde, J. M. (2017). Advances in thermal energy storage materials and their applications towards zero energy buildings: A critical review. *Applied Energy*, *203*, 219–239. https://doi.org/10.1016/j.apenergy.2017.06.008

Lizana, Jesus, Friedrich, D., Renaldi, R., & Chacartegui, R. (2018). Energy flexible building through smart demand-side management and latent heat storage. *Applied Energy*, *230*, 471–485. https://doi.org/10.1016/j.apenergy.2018.08.065

Lizana, Jesus, Halloran, C. E., Wheeler, S., Amghar, N., Renaldi, R., Killendahl, M., Perez-Maqueda, L. A., McCulloch, M., & Chacartegui, R. (2023). A national data-based energy modelling to identify optimal heat storage capacity to support heating electrification. *Energy*, *262*, 125298. https://doi.org/10.1016/j.energy.2022.125298

Lizana, Jesus, López-Cabeza, V. P., Renaldi, R., Diz-Mellado, E., Rivera-Gómez, C., & Galán-Marín, C. (2022). Integrating courtyard microclimate in building performance to mitigate extreme urban heat impacts. *Sustainable Cities and Society*, *78*(December 2021), 103590. https://doi.org/10.1016/j.scs.2021.103590

Lizana, Jesus, Miranda, N. D., Gross, L., Mazzone, A., Cohen, F., Palafox-Alcantar, G., Fahr, P., Jani, A., Renaldi, R., McCulloch, M., & Khosla, R. (2022). Overcoming the incumbency and barriers to sustainable cooling. *Buildings and Cities*, *3*(1), 1075–1097. https://doi.org/10.5334/bc.255

Lizana, Jesus, Wheeler, S., Azizi, E., Halloran, C., Wheeler, J., Wallom, D. C. H., & Mcculloch, M. (2024). Integrated post-occupancy evaluation and intervention that achieve real-world zero-carbon buildings. *Energy & Buildings*, *303*(July 2023), 113766. https://doi.org/10.1016/j.enbuild.2023.113766

López-García, E., Lizana, J., Serrano-Jiménez, A., Díaz-López, C., & Ángela Barrios-Padura. (2022). Monitoring and analytics to measure heat resilience of buildings and support retrofitting by passive cooling. *Journal of Building Engineering*, *57*(July), 104985. https://doi.org/10.1016/j.jobe.2022.104985

Machard, A., Salvati, A., P. Tootkaboni, M., Gaur, A., Zou, J., Wang, L. L., Baba, F., Ge, H., Bre, F., Bozonnet, E., Corrado, V., Luo, X., Levinson, R., Lee, S. H., Hong, T., Salles Olinger, M., Machado, R. M. e S., da Guarda, E. L. A., Veiga, R. K., … Holzer, P. (2024). Typical and extreme weather datasets for studying the resilience of buildings to climate change and heatwaves. *Scientific Data*, *11*(1), 531. https://doi.org/10.1038/s41597-024-03319-8

Mehmood, S., Lizana, J., Núñez-Peiró, M., Maximov, S. A., & Friedrich, D. (2022). Resilient cooling pathway for extremely hot climates in southern Asia. *Applied Energy*, *325*, 119811. https://doi.org/10.1016/j.apenergy.2022.119811

Miranda, N. D., Lizana, J., Sparrow, S. N., Zachau-Walker, M., Watson, P. A. G., Wallom, D. C. H., Khosla, R., & McCulloch, M. (2023). Change in cooling degree days with global mean temperature rise increasing from 1.5 °C to 2.0 °C. *Nature Sustainability*, *6*(11), 1326–1330. https://doi.org/10.1038/s41893-023-01155-z

Pan, Y., Zhu, M., Lv, Y., Yang, Y., Liang, Y., Yin, R., Yang, Y., Jia, X., Wang, X., Zeng, F., Huang, S., Hou, D., Xu, L., Yin, R., & Yuan, X. (2023). Building energy simulation and its application for building performance optimization: A review of methods, tools, and case studies. *Advances in Applied Energy*, *10*(March), 100135. https://doi.org/10.1016/j.adapen.2023.100135

Rodrigues, E., Fernandes, M. S., & Carvalho, D. (2023). Future weather generator for building performance research: An open-source morphing tool and an application. *Building and Environment*, *233*(February). https://doi.org/10.1016/j.buildenv.2023.110104

Samuelson, H. W., Baniassadi, A., & Izaga Gonzalez, P. (2020). Beyond energy savings: Investigating the co-benefits of heat resilient architecture. *Energy*, *204*, 117886. https://doi.org/10.1016/j.energy.2020.117886

Song, W., Zhang, Z., Chen, Z., Wang, F., & Yang, B. (2022). Thermal comfort and energy performance of personal comfort systems (PCS): A systematic review and meta-analysis. *Energy and Buildings*, *256*, 111747. https://doi.org/10.1016/j.enbuild.2021.111747

Suliman, A., Wheeler, S., Topouzi, M., & Lizana, J. (2023). Energy Waste: The Challenge of Decarbonising Office Buildings. *The 1st International Conference of Net Zero Carbon Built Environment*.

Tartarini, F., Schiavon, S., Cheung, T., & Hoyt, T. (2020). CBE Thermal Comfort Tool: Online tool for thermal comfort calculations and visualizations. *SoftwareX*, *12*, 100563. https://doi.org/10.1016/j.softx.2020.100563

Zhang, H., Arens, E., & Pasut, W. (2011). Air temperature thresholds for indoor comfort and perceived air quality. *Building Research and Information*, *39*(2), 134–144. https://doi.org/10.1080/09613218.2011.552703