

BuildSim Nordic 2026

Book of Abstracts

12th BuildSim Nordic Conference · 4th IBPSA Nordic Conference

19–21 August 2026 · Umeå University, Sweden

Conference Chair: Prof. Thomas Olofsson

Editor: Dr. Santhan Reddy Penaka



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Title	BuildSim Nordic 2026 – Book of Abstracts
Conference	12th BuildSimNordic Conference & 4th IBPSA Nordic Conference
Date	19–21 August 2026
Location	Umeå, Sweden
Chair	Prof. Thomas Olofsson
Editor	Dr. Santhan Reddy Penaka
Organiser	Umeå University
ISBN	978-91-6850-090-4
Publication date	13/08/2026
Website	https://buildsimnordic2026.ibpsa-nordic.org/

Preface

On behalf of the Organising and Scientific Committee, it is our great pleasure to welcome you to BuildSim Nordic 2026, the 12th BuildSim Nordic conference and the 4th International Nordic Conference of IBPSA, hosted in Umeå, Sweden, from 19 to 21 August 2026.

BuildSim Nordic has grown into the leading Nordic meeting point for researchers, practitioners, educators, and students working in building performance simulation. This year's conference carries the theme Smart and Sustainable Buildings and Cities in the Nordic Countries, with a particular focus on Energy Resilience of Buildings in Cold Climate and Smart and Climate Neutral Buildings, Districts and Cities — two themes that speak directly to the challenges our region faces as we work to decarbonise the built environment while adapting to a changing climate.

Over the coming three days, the programme brings together keynote presentations, technical sessions, and workshops covering topics from building physics and CFD to digital twins, demand-side flexibility, indoor environmental quality, and zero-energy buildings. We are proud of the breadth and quality of the contributions submitted this year, all rigorously reviewed by our Scientific Committee, and we are confident that the abstracts collected in this book reflect the vitality and progress of building simulation research across the Nordic countries and beyond.

Umeå, a lively university city in northern Sweden known for its culture, architecture, and surrounding nature, provides a fitting backdrop for a conference dedicated to smart, sustainable, and resilient buildings. We hope that alongside the scientific programme you will find time to explore the city and enjoy the company of colleagues, old and new.

Umeå University, one of Sweden's largest universities, is a broad university with education and research spanning a wide range of disciplines. The Faculty of Science and Technology is a significant part of the University, with strong research and education relevant to the themes of this conference. We are pleased to host BuildSim Nordic 2026 at Umeå University.

We extend our sincere thanks to the authors, reviewers, session chairs, sponsors, and volunteers whose efforts made this conference possible, and to IBPSA-Nordic for its continued support of this biennial gathering. We hope BuildSim Nordic 2026 provides you with new ideas, valuable connections, and inspiration to take back to your own work.

Welcome to Umeå, and welcome to BuildSim Nordic 2026.

Prof. Thomas Olofsson, Conference Chair
Dr. Santhan Reddy Penaka, Editor

About BuildSim Nordic 2026

BuildSim Nordic is the biennial conference of IBPSA-Nordic, the Nordic regional affiliate of the International Building Performance Simulation Association (IBPSA), covering Denmark, Finland, Norway, and Sweden. IBPSA-Nordic promotes the science and practice of building performance simulation and works to improve the energy, environmental, and economic performance of buildings and their systems across the region.

BuildSim Nordic 2026 marks the 12th edition of the conference and the 4th to be organised as an International Nordic Conference under the IBPSA banner. The conference brings together researchers, practitioners, educators, and students to exchange ideas, share research findings, and discuss emerging challenges in building performance simulation, spanning building physics, energy systems, indoor environmental quality, and digital methods for design and operation.

This year's scientific programme is organised around the theme Smart and Sustainable Buildings and Cities in the Nordic Countries, with dedicated focus areas on Energy Resilience of Buildings in Cold Climate and Smart and Climate Neutral Buildings, Districts and Cities. Contributions span a wide range of topics, including building acoustics, Building Information Modelling (BIM), CFD and air flow, commissioning, daylighting and fenestration, digital twins, demand-side flexibility, education in simulation, hybrid systems, indoor environmental quality, optimisation of system performance, renewable energy and storage, urban-scale simulation, validation and calibration, weather data and climate adaptation, zero-energy buildings, and emissions and life-cycle analysis.

The scope and objectives of the conference reflect the pressing need for the Nordic building sector to decarbonise while maintaining resilience against an increasingly variable climate. By convening the region's simulation community alongside colleagues from the wider IBPSA world, BuildSim Nordic 2026 aims to accelerate the translation of research into practice and to strengthen collaboration across academia, industry, and public authorities working toward smart, sustainable, and climate-neutral buildings and cities.

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Abstracts

Bio-based Phase Change Composites with multi-scale modeling

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Abstract:

The growing demand for sustainable energy solutions has spurred interest in bio-based phase change materials (PCMs) for thermal energy storage applications. This study focuses on the development and characterization of bio-based phase change composites, integrating natural materials with enhanced thermal stability and latent heat capacity. Through a multi-scale modeling approach, we investigate the thermal behavior and phase transition dynamics from the molecular to the macroscopic scale. Molecular dynamics simulations provide insight into the interactions between bio-based polymers and PCM molecules, while finite element models are employed to simulate heat transfer in composite systems. The integration of experimental data with computational models enables accurate prediction of performance under realistic conditions. This research highlights the potential of bio-derived composites as efficient and eco-friendly thermal storage media, paving the way for their application in building energy systems and renewable energy technologies.

Automated transformation from Parametric BIM Models to Energy Simulations for early design stages

Karim Rezk¹

¹ *AIT*

Abstract:

Building Energy Modelling (BEM) is essential for estimating the heating and cooling loads of buildings. However, the use of BEM presents two challenges: Integration with Building Information modelling (BIM) and application during early design stages. This paper presents a framework that addresses these gaps through applying parametric design using the Dynamo visual scripting tool to generate industry foundation classes (IFC), which are automatically transformed into EnergyPlus simulation models in IDF format using a script leveraging the IfcOpenShell and Eppy Python libraries. This approach enables exploring the impacts of design variables in early stages, such as the dimensions of the building, glass-to-wall ratio, floor height and construction materials on energy performance, ensuring interoperability, reducing manual effort, and minimizing errors due to manual data transformation. A use case involving four building models-varying in geometry and glazing- demonstrates the framework's potential to automate energy simulations in early design stages.

Digital technologies for resilient and safe buildings: a comparative study of state-of-the-art and state-of-practice in fire safety

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¹ SINTEF

Abstract:

Fire safety is a critical, yet often underexplored, component of sustainable and resilient buildings. Recent advances in digital technologies - such as Building Information Modelling (BIM), IoT-based monitoring, AI-driven risk assessment, and digital twins - offer new opportunities for improving fire safety across the building lifecycle. However, the degree to which these innovations are adopted in practice remains limited. This paper presents a comparative study between the state-of-the-art and the state-of-practice in digital fire safety in buildings. Drawing on a comprehensive technology mapping and a nationwide stakeholder survey, the study identifies which digital tools are known and used across five core processes: design and compliance, prevention and risk management, alarm and response activation, evacuation and rescue operations, and reporting and continuous improvement. The results show a clear gap between technological potential and operational realities. While a growing ecosystem of tools exists, adoption is uneven and often constrained by a range of practical, organizational, and regulatory barriers. At the same time, the survey reveals strong motivators and readiness among practitioners to adopt digital solutions - particularly where they support compliance, reduce false alarms, or enhance evacuation safety. This study provides new insight into the conditions under which digital fire safety tools can be successfully implemented and scaled, contributing to the broader goal of integrating safety into smart and sustainable building strategies.

Robustness of Block-Scale Thermal Energy Network Groupings to Future Climate Scenarios

Hossein Bagherzadeh¹, Jenn McArthur¹

¹ *Toronto Metropolitan University*

Abstract:

Fifth generation Thermal Energy Networks seek to meet building energy needs with ambient loops using inter-building heat recovery. While some research has explored how best to evaluate the preferred set of buildings to connect to a TEN or the feasibility of a given building set, there remains a research gap with respect to the sensitivity of such feasibility to climate change. This paper evaluates the robustness of block-scale TENs under future climate scenarios. To investigate this climate sensitivity, a set of EnergyPlus building models for a target region in Toronto, Canada were used to determine the initial TEN feasibility and then re-run using published future climate weather files representing average global temperature rises of 1.0 to 3.5 °C. Results suggest that the thermal balance of feasible TENs is highly sensitive to climate change. Across all methods, climate change eliminates deficits and increases excess heat within the TEN, while reducing the excluded-building load. In addition, buildings excluded under the current climate would thermally match the existing networks under warmer scenarios, even enabling full-block integration. These findings suggest that climate change can improve thermal feasibility of block-scale TENs while also increasing the amount of unmanaged excess heat.

Towards a methodology for quantifying households' thermal comfort elasticities under MPC-based heating optimization

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Abstract:

To better align residential heating demand with renewable energy availability, model predictive controllers (MPC) are increasingly developed. These controllers typically assume fixed thermal comfort requirements, overlooking the flexibility that households may offer. Prior research has examined households' willingness to adjust thermal set points based on stated preferences in surveys or inferred price elasticities from energy demand data. However, stated preferences frequently differ from actual behavior, while price elasticities are difficult to embed in MPCs. Therefore, this pilot study explores how household thermal comfort elasticities can be identified and reflects on methodological lessons learned. A longitudinal case study design was developed in which the daily heating demand of the day zone was optimized based on day-ahead electricity prices, using five to seven comfort-bound scenarios as soft constraints. Each evening, participants selected their preferred option, which was subsequently implemented using smart radiator valves. Results show that, on average, participants were willing to accept a 1 °C temperature deviation for a €1.55 cost reduction. Stronger comfort elasticities were observed during periods of higher price volatility, and option shuffling within the choice set stimulated more deliberate option comparison. These exploratory findings underscore the need for further research on comfort elasticities and their integration into MPC frameworks.

Comparative evaluation of stratified TES models for digital twin applications using real-world operational data

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¹ Universiteit Antwerpen

Abstract:

Thermal energy storage (TES) systems are increasingly used to improve the flexibility of heat pump driven HVAC systems. However, most TES validation studies rely on idealised charging and discharging experiments, neglecting simultaneous primary and secondary flows, and dynamic operating conditions. This study presents a comparative evaluation of three stratified TES modelling approaches for control-oriented digital twin applications under real-world operating conditions. A multi constant size layer model (MCSL), a plug flow model (PF), and an adaptive grid model (AG) are evaluated using measured data from three HVAC systems, represented by five operational profiles. The comparison uses RMSE and MAE metrics for outlet and internal temperatures. The results show that the PF model generally exhibits the largest deviations under highly dynamic operating conditions, while the MCSL and AG models provide lower and more consistent deviations across the evaluated profiles. The largest deviations are observed near the thermocline region, with RMSE values reaching up to 9.68 K for $T_{(tes,top)}$ and $T_{(sec,out)}$. The analysis further indicates that part of the observed deviations are related to local mixing phenomena, hydraulic transport effects, and sensor-related dynamics that are not explicitly represented in the current modelling approaches. The results demonstrate the importance of validation using real operational data for control-oriented TES digital twin applications.

What is a smart building? Insights from the Nordic Smart Building Initiative

Hicham Johra¹, Arianna Fonsati², Silvia Erba³, Wei Luo⁴, Simon Pommerencke Melgaard⁵, Nicholas Swedberg⁶, Kamilla Heimar Johra¹, Aileen Yang¹

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⁶ *Arup*

Abstract:

The concept of Smart buildings has evolved, reflecting a growing focus on digitalization, energy efficiency, user comfort, and interaction with energy and service infrastructures. Many synonyms can be found in literature, such as intelligent, responsive, automated, adaptive, and grid-interactive buildings. Those terms are often used interchangeably, which contributes to conceptual ambiguity. Despite widespread use, no internationally agreed-upon definition or clear set of fundamental characteristics for Smart buildings has yet been established. This paper contributes to clarifying the concept by presenting insights from the Nordic Smart Building Initiative (NSBI), which investigated key functionalities and minimum requirements through a review of academic and stakeholder definitions. A consolidated definition of Smart buildings is proposed, emphasizing their human-centric aspects. Finally, smartness exists on a spectrum and is not defined solely by implemented technologies but by the ability to effectively meet pivotal objectives, such as sensing, interpreting, anticipating, and responding efficiently to user requirements, environmental conditions, and energy grids and infrastructures' needs.

Optimizing Building Retrofits for Energy Efficiency and Climate Resilience Using the ZEBRAFISH Tool: A Case Study in Copenhagen, Denmark

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Abstract:

Building renovation can significantly reduce CO₂ emissions from the building stock; however, the annual renovation rate is only about 1% in the European Union. The revised Energy Performance of Buildings Directive (EPBD) requires upgrading the worst-performing buildings by 2030. Consequently, reliable methods are needed to determine optimum retrofit configurations for energy efficiency, occupant comfort, and resilience. The present study investigated retrofit options for optimizing energy and indoor thermal environment under current and future weather scenarios for an office building in Copenhagen, Denmark. The early-stage design tool, Zero Energy Building Retrofit Assessment – Fabric Intervention and System Honing (ZEBRAFISH), was used which conducts energy and indoor thermal environment analysis. The building energy model was validated using the Energy Performance Certificate of the case study building, while indoor thermal climate was validated using overheating hours from design stage data. The effects of retrofits were then investigated, including improved glazing, upgraded cooling systems, and better-performing ventilation systems using parametric simulations under future weather scenarios. Results indicated that retrofitting window glazing reduced heating and cooling energy use by 8% and 15%, respectively while upgrading the ventilation system fans reduced energy use by up to 28%. Improving the cooling system capacity, combined with upgraded glazing, effectively met future cooling demand, ensuring a comfortable indoor thermal environment up to 2050.

Schema-constrained and Automatically Validated LLM-driven Generation of Symbolic Diagnostic Models for AHUs

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¹ *KU Leuven*

Abstract:

Diagnostic Bayesian networks (DBNs) have been widely used in fault detection and diagnosis (FDD) for HVAC systems due to their ability to explicitly represent causal relationships between faults and symptoms and to handle uncertainty through probabilistic inference. However, the construction of DBNs remains a labor-intensive and knowledge-demanding task. This study proposes a schema-constrained and automatically validated framework for LLM-driven DBN generation, which aims to enable reliable, structured, and executable diagnostic model construction. The approach is evaluated on an air handling unit (AHU) under four representative fault scenarios using diverse LLMs, including general-purpose (GPT-4.1 and DeepSeek-V3) and reasoning-oriented models (GPT-5.2 and DeepSeek-R1). The results demonstrate that all models can generate schema-valid DBNs, but the diagnostic performance still remains limited. A detailed analysis shows that hallucinations occur mainly in symptom level and fault-symptom connection, while parametric hallucinations are less frequent but still observable. These findings confirm the feasibility of LLM-driven DBN generation, while highlighting the need for improved reasoning capabilities and external knowledge integration.

EnergyPlus Simulation of Photovoltaic Systems Using Multi-Year ERA5 Weather Datasets

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Abstract:

Weather-data representation can materially influence the simulation-based assessment of residential photovoltaic (PV) systems with battery storage, particularly when conclusions depend on the timing of generation, household demand, and grid exchange. While previous studies have shown that weather-data choice can affect building and PV simulation outputs, fewer have examined how different representations of the same reanalysis source influence residential PV-battery assessment. This question is particularly relevant for ERA5, which is increasingly used to generate both typical meteorological year (TMY) files and long-term simulation inputs. This study develops a framework for modelling in the whole-building performance EnergyPlus simulation engine using weather data from multiple consecutive years and year-specific load files, processed using Python scripts. This framework is applied to a residential grid-connected PV-battery system, modelled and validated against monitored 2020 data, and compares an ERA5-derived TMY with a 30-year chronological ERA5 sequence (1996-2025) within an EnergyPlus workflow. In comparison to the chronologically ordered multi-year ERA5 weather data, the ERA5-derived TMY overpredicted the annual energy delivered at the inverter output by 3.5% and underpredicted the net grid import by 6.3%, indicating that it provides a less reliable basis for assessing grid dependence.

Keywords: PV-battery systems; ERA5 reanalysis; ERA5-TMY; Multi-year weather datasets; EnergyPlus; Building performance simulation

Using computer-vision AI for occupant-centric control of solar shading

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Abstract:

Glare is a common local visual discomfort caused by direct sunlight. It often occurs in office buildings, especially in high-latitude regions like Scandinavia, where the sun is low on the horizon. Moreover, glare discomfort is difficult to identify with conventional light sensors. Fortunately, the development of computer vision AI models offers new possibilities for occupant-centric control of building systems and the effective mitigation of local indoor discomforts like glare. This study builds on previous work on glare detection using a computer vision-based AI model capable of identifying visual discomfort caused by direct sunlight and excessive luminosity from video footage of an occupant. This article describes the integration of the computer vision algorithm into a smart solar shading control strategy for office environments. The proposed framework combines real-time occupant-centric visual comfort feedback from the glare-detection AI with a rule-based controller to automatically adjust the position of a venetian blind, balancing daylight availability, view to the outside, and occupant satisfaction. A full-scale experiment was carried out in a single-office test room located in a laboratory environment, and equipped with the intelligent venetian blind system, a single illuminance sensor, and a workstation camera (webcam). Results show that the integrated system responds reliably to changing outdoor light conditions, rapidly eliminating glare discomfort and maximizing daylight and view to the outside. These findings demonstrate the potential of combining computer vision with building automation to enable more responsive facade systems, improving user satisfaction and comfort. This work offers a practical step toward AI-driven solar shading solutions for future smart buildings.

Surrogate modelling for daylighting design: A spatiotemporal approach to optimisation

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Abstract:

Light influences human physiology and psychology through visual and beyond-visual effects. Human responses depend on luminous, spatial, and temporal light factors. Designing lighting systems that effectively support this requires simulating and optimising the combined influences of daylight and electric lighting. Beyond-vision metrics such as melanopic Equivalent Daylight Illuminance have advanced research in recent years. They remain rarely integrated into optimisation due to the computational demands of spectral simulations and the combinatorial growth of design variables. Unlike typical optimisation studies that report only final model equations, this paper presents a stepwise, regression-based surrogate modelling methodology. It predicts spatiotemporal beyond-vision outcomes for use in daylight optimisation. The three-step methodology guided by both statistical reasoning and physical lighting behaviour includes a regression model based on luminous factors for a single point and direction, a spatial generalisation using position-fixed effects, and smooth time functions to capture temporal dynamics. Results demonstrate strong agreement between surrogate predictions and simulation data while reducing optimisation time from hours to minutes. The framework enables rapid exploration of design alternatives and evaluation of beyond-visual performance, supporting practical adoption of daylighting optimisation.

Evaluating Machine Learning Techniques to develop control-oriented models in Positive Energy Districts

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Abstract:

The European Commission formally introduced Positive Energy Districts(PEDs) as a promising solution to support global climate goals in building sector. PED are groups of buildings that achieve an annual positive energy balance by improving energy efficiency, maximizing local renewable energy production, and actively managing energy flows within the district and energy system. Such dynamic management requires advanced tools that enable real-time control. Digital Twin(DT) models support this by simulating PED energy use and informing control decisions. With recent advances in computational intelligence and machine learning(ML), building energy modelling has evolved significantly. This paper analyzes ML techniques for generating predictive models that support advanced PED control. The aim is to identify effective ML approaches and strengthen understanding of ML integration within DT, helping reduce model complexity and enabling the use of data-informed DTs in advanced controllers(MPC). This study adopts a metadata-driven approach combining white-box and black-box methods. White-box models are developed with the openIDEAS library in Modelica, containing detailed physical building properties and generating consistent datasets. These datasets serve as inputs for ML-based black-box models, which are trained and tested to evaluate predictive performance. A simplified virtual PED with nine buildings of varied typologies is used as a case study. The buildings vary in energy performance and incorporate three typical occupancy patterns affecting energy demand across three performance levels, ensuring diverse and representative datasets. ML techniques assessed include Linear Regression, KNN, SVM, Regression Tree, Random Forest, and XGBoost. The framework compares the models using accuracy indicators (e.g., RMSE, peakload day) and computational cost. Considering all, KNN, Regression Trees, and XGBoost show stronger performance, with KNN emerging as a particularly suitable choice.

Energy and climate efficient paint shop – numerical prediction of potential decarbonization pathways

Patrik Rohdin¹

¹ *Energy systems*

Abstract:

An energy and resource efficient industry with low emissions is a key to remain competitive. In the production of construction equipment, painting is an important sub-process as it accounts for a significant part of the total climate impact, energy and resource use. In the painting process of construction equipment, with steel bodies, there is now a combination of opportunities for a technological shift that can drastically reduce energy use, water use and chemicals and thereby improve environmental performance. This opportunity includes a package of measures in the form of (1) changing to a new type of pre-treatment, (2) a transition to low-hardening powder and (3) changing the supply of electricity, heat and fuels. However, this technological shift involves large investments and a deep understanding of the processes, and the necessary decision support is missing. The aim of this paper is to model two of the features in this process, which are ovens and pre-treatment. This is done to better understand the consequences of the different changes in terms of energy and resource use as well as work environment.

Mitigating Negative Transfer in Cross-Regional PVAC Performance Assessment: An Adaptive Source Selection Approach

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¹ Changsha University of Science and Technology

² KU Leuven/TU Delft

³ City University of Macau

Abstract:

The deployment of photovoltaic air conditioning (PVAC) is pivotal for urban decarbonization, yet its multi-regional performance assessment remains hindered by the scarcity of high-fidelity data in diverse geographical domains. While transfer learning methods are frequently employed to mitigate data scarcity, they are susceptible to negative transfer, where distribution shifts in the joint distribution of solar irradiance and ambient temperature substantially impair predictive fidelity. This paper proposes a physics-guided Cluster-based Adaptive Transfer Learning (CATL) framework. By integrating hierarchical climate clustering with quality-aware adaptive selection, the framework identifies source domains sharing consistent meteorological-to-energy mappings across both supply and demand. Validation across 9 cities demonstrates that the CATL framework maintains high predictive fidelity, yielding R^2 exceeding 0.94 and 0.92 for PV generation and cooling load, respectively, while utilizing as little as 1%–5% of target domain data. The mechanism effectively overcomes geographical proximity biases through structural substitution, establishing a robust foundation for large-scale energy flexibility mapping in data-impovertished scenarios.

Comfort cooling – numerical prediction of energy use in a changing climate

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¹ *Energy Systems*

² *Energy systems*

Abstract:

An increasing demand for energy efficiency indirectly requires that comfort cooling in buildings does not increase uncontrollably. Climate conditions are expected to become more extreme in the future, with longer, hotter periods and a greater demand for cooling. The aim of this paper is to explore the demand for comfort cooling in a residential building using modelling in IDA ICE. In this study, the effects of internal heat gains, different cooling temperature setpoints, and a changing climate outdoors were implemented into the modelling. The future climate is based on the SSPs future climate scenarios. The study found that while the current cooling energy demand is low, it can be significantly affected by lowering the cooling temperature setpoint and increasing internal heat gains. By the mid-century, there will be a gradual increase in cooling demand and maximum cooling power, while by the end of the century, the demand will increase significantly. Therefore, future energy systems must consider this increase in both energy and power demand.

Aftercooling of district heating: performance of substations with cascading concepts

Daniel Rye¹, Liv Lorentzen¹, Christian Anker Hviid¹, Donya Sheikh Khan¹

¹ *DTU Construct*

Abstract:

The use of district heating (DH) is a key technology for a sustainable future, but its efficiency depends on the performance of the local DH substations. Conventional DH substations operate with separate flows for space heating (SH) and domestic hot water (DHW). This study investigates alternative configurations in which SH return flow is cascaded to DHW and vice versa, with the aim of reducing the overall return temperature of the DH flow. Conventional and cascaded substation designs were modelled and simulated using real operational data, and their performances were compared based on their flow-weighted return temperatures. The results show that substations with a single cascade generally performed better than conventional designs, while double-cascade substations provided even greater improvement. Additionally, DHW production efficiency was significantly improved by combining a plate heat exchanger with a single hot water tank. Seasonal variations strongly influenced performance, with return temperature reductions from 1.6 to 3.2 °C in a February week and up to 8.5 to 9.5 °C in a July week (no cascade in July week was possible, since there was no SH demand), compared with conventional DH substations. However, additional cascades result in higher pressure drops, which may pose challenges during peak demand.

Challenges of BIM and BEM integration in different contexts: learnings for IEA Annex 91

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¹ *KTH*

² *LTH*

³ *UCL*

⁴ *RWTH*

Abstract:

Building Energy Modelling (BEM) is key to designing and operating energy-efficient buildings. Its success relies on the modeller's skill in creating trustworthy models through careful choices about geometry, zoning, and assumptions on occupant behaviour and systems. Much of the necessary information resides in Building Information Modelling (BIM) environments, and its use could significantly reduce setup effort and improve access to high-quality simulations. However, linking BIM data to BEM input is challenging due to interoperability issues, semantic gaps, and limited cross-domain expertise. These challenges motivated a workshop held at the Building Simulation 2025 international conference in Brisbane as part of the IEA EBC Annex 91, "openBIM for Energy Efficient Buildings". These workshops collected community feedback on the current state, gaps, and opportunities in BIM-to-BEM workflows. This paper compares the feedback received in this workshop with that from a previous one, conducted in Sweden. The workshop in Brisbane gathered 20 people, researchers from the Building Performance Simulation (BPS) environment. In contrast, the workshop in Sweden involved 15 professionals, including architects, engineers, and software developers, all specialised in BIM and BEM workflows. In both cases, a poll was prepared to gather real-time feedback from participants on the challenges, gaps, and advancements in BIM-to-BEM integration. The results reveal strong alignment across most topics. However, participants in Brisbane expressed lower satisfaction with the current openBIM standards, which could be attributed to a more diverse audience. In Sweden, the lack of knowledge in building physics and BIM-related topics was identified as a significant barrier affecting data exchange challenges. Overall, the outcomes of both workshops highlighted the challenges, barriers, and opportunities in BIM-BEM integration, while also revealing differences on certain specific topics.

Real-Time 3D Model Collaboration between Remote Desktop and On-Site AR-assisted Operators

Robert Van den Brink¹, Timo Kuula¹, Mika Hakkarainen¹

¹ *VTT Technical Research Centre of Finland*

Abstract:

This article expands upon earlier work done by the authors that provided Augmented Reality (AR) support for construction site operators through path guidance, measuring tools, and virtual notes. However, capabilities for site operators to independently adjust 3D models through the AR interface were thus far missing. Therefore, the objective of this work was to enable real-time 3D model collaboration between remote desktop-based 3D modelling software operators and a mobile AR client operator. This approach applies immersive 3D technologies to support online communication between on-site and remote operators in collaborative use cases, providing augmented information to the on-site operator and a 3D environment to the remote operator. Real-time collaboration between desktop 3D software and mobile AR is achieved through a shared 3D environment managed by NVIDIA Omniverse Nucleus, which provides live access to a centralized scene. Data synchronization and interoperability are enabled via the Universal Scene Description (USD) format, allowing efficient streaming of geometry, materials, and metadata across devices. The system was user-tested and evaluated for feasibility, collaboration and usability. The tests revealed that the system is useable and intuitive but that continued development is necessary for some aspects to improve practical performance of the system.

Barriers and drivers for smart building adoption: A systematic literature review and future research agenda for Nordic contexts

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Abstract:

Smart buildings constitute a critical component to decarbonise the building stock, as they can support energy efficiency, demand-side flexibility, operational optimisation, and the integration of digital and low-carbon technologies. However, their deployment remains uneven and constrained or enabled by multiple interacting technological, economic, organisational, regulatory, social, and informational factors. This paper aims to identify and synthesise the key barriers and drivers for smart building adoption through a systematic literature review with expert-informed categorisation that can support future empirical investigation and prioritisation in the Nordic context. Of the 98 initially identified articles, 87 were selected for the final analysis, with 82 informing the barrier analysis and 81 informing the driver analysis. The synthesis identified 14 barrier categories and 15 driver categories. Key barriers include investment risks, technological maturity, interoperability, occupant acceptance, organisational readiness, skill limitations, regulatory uncertainty, cybersecurity, and limited market evidence. Key drivers include advanced technological infrastructure, energy flexibility, lifecycle value, occupant-centred benefits, operational reliability, regulatory clarity, data-driven intelligence, training, stakeholder collaboration, and demonstrator-based scaling. The resulting categorisation provides a structured basis for future surveys and stakeholder consultation among Nordic building users, policymakers, and industry actors.

Developing Actual Occupancy Profiles for Mosques

Mueez Shemsi¹, Mansour Alhazmi¹, Uthman Baroudi¹, Muhammad Asif¹, Hakim Adiche¹, Yasser El-Alfy¹

¹ KFUPM

Abstract:

Building occupancy profiles are essential for optimizing energy performance, yet standardized data for mosques remains scarce despite their unique, intermittent usage patterns. This study addresses this gap by evaluating a cost-effective, real-time occupancy monitoring system using Raspberry Pi and computer vision. By capturing headcount data at 30-second intervals, the system demonstrated high responsiveness in tracking complex dynamics within a mosque environment. The analysis reveals that weekend attendance generally exceeds weekday levels, with weekdays showing sharper post-prayer declines due to professional and academic obligations. A primary divergence occurs during the Friday Jummah congregation, which reached a peak of 110 occupants, saturating the hall's capacity. This surge exhibited a wider temporal footprint than standard prayers due to the mandatory pre-prayer sermon (Khutbah). Quantitative results show that weekday occupancy peaked at 60 during the Maghrib prayer, while weekend peaks reached 75. On average, worshippers arrived 5 minutes before the prayer and departed 20 minutes after, resulting in a total stay of 25 minutes. These findings validate the system's ability to provide high-resolution, empirical data, offering a foundation for demand-controlled environmental management and more energy-efficient operational strategies in religious facilities.

Towards deployable demand-side management: A reinforcement-learning-enabled digital twin framework for single-family houses

Pengju Liu¹, Chanachok Chokwitthaya¹, Thomas Olofsson¹, Weizhuo Lu¹

¹ *Umeå University*

Abstract:

This paper presents a digital twin-enabled demand-side management framework for single-family houses. The aim is to develop an integrated platform that can systematically coordinate heterogeneous residential energy resources and support real-time optimization of home energy management by responding to dynamic electricity pricing. The digital twin environment (DTE) includes a multi-zone building thermal model, photovoltaic (PV) generation, battery storage system (BSS), electric-vehicle (EV) model, and schedulable electric appliances. The Soft Actor-Critic (SAC) algorithm is adopted as the embedded reinforcement learning optimizer in the DTE to determine optimal control actions for these resources by minimizing cost and comfort deviation. The framework is linked to a Modelica-based high-fidelity building emulator for data generation and subsequent validation. Compared with a rule-based strategy, the results demonstrate that the proposed RL-digital twin framework can effectively manage flexible resources while saving the electricity cost. In addition, the RL-digital twin efficiently satisfies occupants' needs on thermal comfort and domestic hot water, which are significantly compromised under the rule-based strategy. The obtained results demonstrate the RL-digital twin framework potential for real-world deployment in residential demand-side management.

A SegFormer-based model for spatial Daylight Factor prediction with comprehensive obstruction encoding and regulatory validation

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Abstract:

Daylight compliance assessment in residential buildings currently requires time-consuming raytracing simulations and specialist model preparation, limiting its integration into iterative architectural design. This paper presents a machine learning-based methodology for predicting the spatial distribution of the Daylight Factor (DF) directly within Building Information Modelling (BIM) environments, delivering results in seconds without model export or manual curation. The approach addresses five gaps not simultaneously covered by any existing model: comprehensive external obstruction encoding including balconies, own building height, variable material reflectances, non-orthogonal room geometries, and explicit regulatory validation. Two models are developed and validated: a default-materials model using fixed reflectances for preliminary design checks, and a custom-materials model with variable project-specific reflectances targeting final design verification. Both are trained on approximately 20,000 synthetic Radiance-simulated rooms and validated against a held-out synthetic dataset and 102 rooms from 18 real building models. The default-materials model achieves MAE = 0.11% DF on the synthetic dataset, predicting BBR (Swedish) compliance area within 4.85 pp MAE and TEK17 (Norwegian) mean room DF within 0.304% DF MAE on real buildings. The custom-materials variant shows 1.7–2.4× higher error across all metrics. Both models are deliberately designed to concentrate accuracy in the BBR compliance-critical zone (DF < 1%), achieving a sub-1% DF MAE of 0.105%. All cases where the model overestimates compliance are genuinely borderline, within 10.7 pp of the BBR threshold (median 3.2 pp) and 0.36% DF of the TEK17 threshold (median 0.10% DF). The default-materials model is recommended as a replacement for preliminary daylight simulations; the custom-materials variant needs to be further developed before it can be used for final compliance verification.

A scenario-approach optimization with output-side uncertainty for frequency control with aggregated heat pumps

Manuel Koch¹, Colin N. Jones¹

¹ EPFL

Abstract:

As the share of electricity generation from non-dispatchable sources like wind and photovoltaics grows, so does the need for active grid stabilization. For this purpose, we use aggregated heat pumps in buildings as a virtual power plant. Previous work has shown good performance in frequency control with 1000 simulated buildings using a comparatively simple control framework. In this paper, we extend this framework by replacing some heuristics in its planning process with a robust optimization, based on the scenario-approach. While this would be straight-forward with direct control of the heat pumps, we rely on indirect control through thermostats for reasons of practicality. However, this places the scenarios, i.e. the uncertainty, on the output-side of the system, which makes it more difficult to ensure feasibility. We reformulate the optimization problem accordingly and show good performance over a two-month simulation period, increasing the amount of flexibility provided by 39 % and decreasing the cumulative tracking error by 25 %, compared to the simpler reference method. Since the estimated implementation cost of the extended methodology is only marginally higher than that of the simpler reference, we expect it to be more financially viable, especially with smaller buildings.

The effect of ventilation system demand response and unobtained comfort cooling on indoor temperatures in office buildings

Sandra Boström¹, Annica Nilsson², Samuel Wennlund¹, Tobias Bergman¹

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² *Uppsala University*

Abstract:

More intermittent energy production and increasing electricity demand poses new challenges for the power grid. Demand response, DR, in buildings has the potential to be part of the solution. This study investigates the potential of using the ventilation system in a timber-framed office building to contribute to DR by reducing airflow during selected periods. Using building energy simulations, three ventilation reduction scenarios were analyzed in varying weather conditions. The results show that even short reductions of 15 minutes can lead to uncomfortable temperatures, especially in sun-exposed or densely occupied areas. With a seasonally adapted ventilation reduction strategy, up to one hour ventilation reductions are generally possible while still maintaining an acceptable indoor climate. The power-saving potential varies between 0 and 15 kW for the scenarios that meet the European indoor-climate standards. The study concludes, that the thermal indoor environments of office buildings are sensitive to ventilation reductions. Additionally, the benefits to the power grid of ventilation-based DR are modest.

LCA of smart building energy systems and installations from a Nordic perspective

Bojana Petrovic¹, Marianne Kjendseth Wiik², Lina Morkunaite³, Susana G. Sanfelix⁴, Shahab Zangi⁵, Andrea Ferrantelli⁵, Eduard Petlenkov⁶, Ali Reza Yaghoubi⁷, Rongling Li⁷, Amin Hajizadeh⁸, Georgios Pardalis⁹, Hicham Johra²

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Abstract:

The upcoming revision of the Energy Performance of Buildings Directive (EPBD) will require reporting of the whole life-cycle global warming potential (GWP) for new buildings from 2028 at the European level. In the Nordic countries, several frontrunners have already introduced national climate declaration requirements for new buildings. The focus was primarily on embodied emissions from building materials. However, buildings also comprise a wide range of building energy systems (BES) and technical installations, which contribute to the overall impact. Despite their importance, there is currently a lack of research regarding these building components. Therefore, this paper presents greenhouse gas (GHG) emissions of BES and technical installations by using GWP-total climate data. The embodied GHG emissions from the production of air handling units (AHU), lighting systems, cables, cable joints/connectors, LED kits, panel radiators, and transformers are presented as minimum, median, mean, and maximum values. The analysis is based on a dataset of 1,622 environmental product declarations (EPDs) collected across the Nordic countries. The dataset is largely composed of products manufactured in Sweden (44%), followed by Norway (22%) and Estonia (19%), with smaller shares from Finland (7%), Denmark (6%), and Lithuania (2%). The mean values can be used by building designers and environmental consultants as generic climate data to support early-stage sustainable building design and to address data gaps where product-specific information is unavailable.

Emissions and Efficiency in Passenger Transport: A Quantitative Assessment of Modal and Technological Shift Scenarios Using Statistical Agent Simulations

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¹ *Lucerne University of Applied Sciences and Arts (HSLU)*

Abstract:

Please note that the abstract is provided in the attachment (submission file).

Keywords: Decarbonisation; Energy Consumption; Agent-Based Modeling; Mobility Demand; Travel Behavior; Life-Cycle Assessment (LCA); Climate Policy

Performance Evaluation of a Novel Automatic Shading Control System for High-Rise Buildings Using Simulation Techniques

Ernest Tsang¹, Shuyang Li¹, Kevin Kwok¹, Stephen Lam¹, Roger Ng²

¹ *Hong Kong Metropolitan University*

² *Hong Kong Institute of Vocational Education*

Abstract:

Please refer to the attached file.

Digital Twins for indoor environmental quality optimisation: Insights from two case studies

Myriam Aries¹, Alyaá Tabbah¹, Thomas Olsson¹

¹ *Jönköping University*

Abstract:

Digital Twin (DT) technology links physical and virtual building environments, offering opportunities to improve indoor environmental quality (IEQ). This paper synthesises insights from two applied DT case studies: an educational classroom with occupancy and environmental sensing, and a residential living lab for data-driven lighting optimisation. BIM based models were coupled with measured data to support DT analysis at the Digital Shadow level. Results show that integrating BIM with IoT data improves situational awareness, while purpose driven geometric simplification enhances simulation efficiency and agreement with measurements. Persistent challenges include interoperability gaps, limited analytics in visualisation platforms, and communication constraints. The study highlights lighting as a practical entry point for scalable IEQ oriented DT deployment.

Sensitivity Analysis of Input Data in Demand-Side Flexibility Assessments in Multi-Family Residential Buildings: An IDA ICE Simulation Case Study

Antti Mäkinen¹, Kari Kallioharju¹, Aki Kortetmäki¹

¹ *Tampere University of Applied Sciences*

Abstract:

Demand-side flexibility in buildings equipped with heat pumps is becoming increasingly important as the share of variable renewable electricity grows. The robustness of flexibility assessments depends on the modelling assumptions and input data used in building simulations. This paper investigates how selected input-data choices influence the estimated demand response potential of apartment buildings with centralized heat pump systems. A systematic sensitivity analysis is carried out using the IDA ICE simulation environment, focusing on the impact of (1) interannual variability in paired weather and electricity spot-price data, (2) the representation of DHW consumption profiles (constant, representative 24 h cycle, and measured 8760 h profile), and (3) the representation of occupancy-related internal electricity loads (constant vs. representative 24 h cycle). Simulation results quantify the relative importance of these input domains for annual heat-pump operating-cost savings under spot-price-based control. The findings show that reference-year selection is the dominant source of variation in annual cost outcomes, whereas DHW and occupancy profile resolution has a smaller effect when annual totals are preserved. The study provides guidance for researchers and practitioners on which modelling assumptions should be prioritised in cost-focused flexibility analyses.

Sensitivity of collective thermal systems to control strategy selection

Stef Jacobs¹, Houssam Matbouli¹, Alexander De Santis¹, Ilya T'Jollyn¹, Ivan Verhaert¹

¹ *University of Antwerp*

Abstract:

The design of collective thermal systems for multi-family buildings aims to balance operational costs and thermal comfort. However, the performance of these systems depends not only on their physical configuration but also on the implemented control strategy, which may differ between design assumptions and real-world operation. This introduces uncertainty in system performance and complicates robust decision-making during the early design phase. This study compares two low-temperature heating concepts with a central heat pump: (i) a two-pipe system with decentralized domestic hot water (DHW) storage and centralized high-temperature production, and (ii) a system with decentralized booster heat pumps for DHW production. Both concepts are evaluated under a range of price-based control strategies for DHW production. Dynamic simulations are performed in Python, accounting for occupant behavior and variations in control settings. Results show that system performance can be highly sensitive to control strategy selection. The decentralized storage systems exhibit high variability, with cost differences up to 31% and DHW discomfort ranging from 0,4% to 3,28% of tapping time. In contrast, decentralized booster heat pumps show limited cost reduction potential (up to 5%), with discomfort ranging from 0,72% to 2,36%. These findings highlight the need to incorporate control sensitivity and associated risk into designs tools for energy systems.

The complexity of hybrid residential ventilation design: towards a systematic optimisation approach

Jitse Van Thillo¹, Houssam Matbouli¹, Zakarya Kabbara¹, Sandy Jorens¹, Kenneth Sörensen¹, Ivan Verhaert¹

¹ *UAntwerp*

Abstract:

Residential ventilation design is shaped by two converging pressures: the need to improve indoor air quality (IAQ) for occupant health and the imperative to reduce operational energy use in support of building-sector decarbonisation. At the same time, homeowners and developers seek to limit installation and maintenance costs. These drivers often conflict, especially in dwellings with weak or variable natural driving forces. Hybrid ventilation offers a potential response by using natural ventilation when conditions are favourable and mechanical support only when necessary, but this substantially increases design complexity. Hybrid systems require coordinated decisions across system type, component placement and sizing, and controller logic. Controller behaviour is particularly influential, as the thresholds and rules governing transitions between natural, hybrid, and mechanical modes strongly affect IAQ, energy use, and cost. Because these design layers interact nonlinearly, optimising any subset in isolation can prematurely restrict the solution space and lead to local rather than global optima. This paper presents the initial methodological development of an optimisation framework for early-stage hybrid residential ventilation design. The framework integrates system-type selection, component specification, and controller parametrisation into a unified decision structure. Performance is evaluated through coupled airflow and energy simulations and assessed against IAQ and cost indicators. The large decision space and high computational burden underscore the need for efficient optimisation. The work clarifies the methodological requirements for capturing the full hybrid ventilation design space and avoiding early commitment to suboptimal configurations. It establishes a systematic and computationally efficient foundation for future optimisation studies and for practitioners addressing complex residential ventilation design problems.

Environmental Emission Support for Design Activities in Urban Planning

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¹ *Aarhus Universitet*

² *CEBRA*

Abstract:

To meet future carbon reduction targets, life cycle assessment (LCA) must be integrated early in urban planning processes. However, current research on urban LCA tools seldom involves end-users from design practice, which risks limiting their applicability in real-world projects. This paper presents a co-creation process with an architectural design studio specializing in urban planning, aimed at developing a tool that bridges this gap. The process combined semi-structured interviews, iterative co-creation workshops, and a case study, culminating in a set of practice-oriented user needs for LCA support in early urban planning, along with the development of ‘LCA Volume’ – a novel urban LCA tool prototype embedded within the Rhino-Grasshopper environment. A case study demonstrates how LCA Volume enables designers to assess urban solution spaces, balancing building distribution, materials and preservation strategies against carbon impacts at both building and city scales. This positions LCA as an actionable design parameter, supporting informed decisions toward low-carbon urban futures.

Automated Life Cycle Assessment for Decision-Support in the Early Building Design Activity ‘Volume Massing’

Pil Purup¹, Morten Stistrup², Leo Gamborg Heinzl³, Steffen Petersen¹

¹ *Aarhus Universitet*

² *Rambøll*

³ *COWI*

Abstract:

This paper presents a novel concept for integrating automated life cycle assessment (LCA) as decision-support during the early architectural design activity known as Volume Massing, where architects explore conceptual mass models as simple volumes. The concept was co-created with an architectural design studio and a consulting engineering company to ensure practical relevance. Through a co-creation workshop, focus group interviews, and prototype development, a set of workflow-related user requirements and a proof-of-concept LCA prototype were developed. The prototype was deemed useful by practicing designers, demonstrating how LCA tools can be tailored to support early design activities – in this case volume massing.

FLEXED – A model-driven predictive control framework for flexible space heating and behind-the-meter assets in dwellings

Samuel de Vries¹, Olav Vijlbrief², Felix Claessen³, Behrouz Eslami Mossallam², Wester Coenraads², Wouter Borsboom², Andries van Wijhe², Richard Kemp²

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Abstract:

This paper presents the FLEXED framework for model-driven control of residential energy flexibility, with a focus on heat pumps as behind-the-meter assets. The framework enables optimal scheduling across multiple homes for applications such as cost reduction under dynamic tariffs and alleviation of grid congestion, while maintaining interoperability through standardised interfaces. A key contribution is the translation of detailed thermal model predictions into a simplified, standardised S2-FRBC state-machine representation. This enables the formulation of the control problem as a mixed-integer linear optimisation problem, allowing efficient and scalable scheduling of flexible assets. The approach is demonstrated in a case study of a dwelling with a ground-source heat pump and underfloor heating. Calibrated reduced-order models achieve high predictive accuracy (R^2 up to 0.92), supporting reliable flexibility estimation. Results show a 19% reduction in heating costs, while maintaining thermal comfort, demonstrating the potential of the approach for scalable residential demand flexibility.

A practice perspective on building simulation in design

Toivo Säwén¹

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Abstract:

Building simulation tools have gained interest among architectural practitioners who want to use assessment results to inform the design process, not only confirm the performance once the design is completed. While tool development efforts have emphasised how digital tools originating in the technical domain can become usable, these improvements have not led to a corresponding increase in tool uptake. The present work investigates the processes by which tools become useful in practice. It approaches usefulness of tools through qualitative methods (interviews, observations, and usability testing) and practice theories, showing how tools are embedded relationally in the design process. It is argued that the usefulness of building simulation tools can be improved through a better understanding of the relational context of tool application in practice. This context includes digital ecosystems, assemblages of technical experts, municipal decision-makers, national regulations, environmental certification systems, as well as residents and the wider ecosystem of the built environment. The work offers the theoretical and methodological foundation to achieve this relational, contextual understanding through a practice perspective.

Keywords: building performance analysis; life cycle assessment; architectural design practice; ethnography; usability testing; literature review

Classifying operational behavior in CHP-integrated collective heating systems: a multi-site analysis

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¹ *University of Antwerp*

² *Noven*

Abstract:

Combined heat and power (CHP) units in collective residential heating systems are widely deployed, yet their operational behavior across real multi-site portfolios remains poorly documented compared to demand side components. This gap limits the development of fault detection and diagnosis (FDD) methods, which depend on labelled real-world data, and may leave operators without a structured way to describe what their units are doing across a portfolio. This paper addresses both. We introduce a five-class taxonomy of CHP operational behavior, distinguishing stable operation, unstable cycling, two fluctuation regimes, and extended outages. The taxonomy is grounded in a per site expert labelled dataset built from 5-minute monitoring data across 35 building-integrated CHP sites in Belgium over the 2025 to 2026 heating season. A portfolio level KPI framework links each category to its time share, prevalence, and economic impact under the Brussels green certificate scheme. Sites spent on average 74.7% of the season in stable operation, but the distribution was heterogeneous and extended outages dominated economic losses at €11,638 across 21 sites. These findings show which deviation types dominate portfolio losses, and which require features beyond mean output for detection.

Calibrated intra-era archetypes for the Swedish multi-family housing stock

Sanjay Somanath¹, Djamila Memdova¹, Johan Blomsterber¹, Toivo Säwén¹, Alexander Hollberg¹

¹ *Chalmers University of Technology*

Abstract:

Urban building energy models (UBEM) often represent a whole construction era with a single archetype. This misses within-era variation and leaves sensitive parameters such as infiltration to absorb residual errors between model predictions and measured energy performance (EP) during calibration. This study tests whether intra-era archetypes improve agreement with measured EP for Gothenburg's 1955–1975 MFH stock and how to select representative buildings for archetype calibration within the subgroup. The method is demonstrated on 2,020 buildings. The results show that splitting one era into multiple archetypes reduces prediction error more reliably than calibrating a single era-wide model: simply partitioning the stock at template defaults lifts the share of buildings within $\pm 20\%$ of measured EP from 25.7 % to 60.9 %, while residual-median anchor calibration of the partitioned model reduces city-wide bias from -32.45 % to -6.42 %. Choosing the representative building carefully matters: a poor choice shifts the entire group in the wrong direction. The method is applicable across Sweden wherever building footprints and energy certificate data are available. Within each group, however, one calibrated archetype is still too simple when buildings vary widely.

Early-stage modelling of an office building peak capacity under heating conditions

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¹ Tallinn University of Technology

Abstract:

The Energy Performance of Buildings Directive requires buildings to support demand-side flexibility and react to external energy system signals; therefore, quantification of building peak loads already at the design stage is important. This paper proposes a method for assessing building peak capacity during heating conditions in Estonia. The method is based on typical early design-stage energy simulations conducted for fulfilling the Estonian energy performance requirements. The heating system peak load obtained with typical reference year was similar to the one reached at constant design outdoor temperature and it was mainly influenced by building envelope parameters (range ca 15 W/m²) without any impact from ventilation heat recovery temperature efficiency due to minimum exhaust temperature set to avoid frost in the heat recovery heat exchanger. Air-to-water heat pump dimensioned to 50% of design heat losses increased the electric peak load by 30-40 W/m² compared to non-electric heating. The direct electric heating increased the peak load further by approximately 10 W/m². The analysis revealed that accounting for the simultaneous loads of facility electricity and fans is required to correctly assess the peak loads at standard usage, because the internal heat gains significantly decreased the space heating need in a zero-emission office building. These findings support the use of existing hourly simulation outputs not only for annual energy performance assessment, but also for early-stage estimation of heating and electrical peak capacity.

Machine Learning for Dynamic Predictions of Household Energy Demand

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² *University of Southampton*

Abstract:

The UK Government is due to introduce the new Home Energy Model (HEM) to replace the existing Standard Assessment Procedure (SAP) for estimating the energy efficiency of homes for domestic Energy Performance Certificates (EPCs). The opensource methodology for the HEM proposes a core physical building model capable of accepting code “wrappers” that can predict home energy usage based on occupant specific information with the potential to develop an interactive EPC interface for end-users. Such an initiative would require the development of models that can more accurately predict home energy usage based on inputs relating to both physical building and occupant characteristics. Using data from the Smart Energy Research Laboratory (SERL), this research combines exploratory analysis of half-hourly energy use across socioeconomic groups during the coldest week of a UK study period spanning July 2021 to June 2024 with the CatBoost machine learning algorithm for predicting daily household energy demand. The model achieved RMSE values of 14.62 kWh/day within sample and 22.53 kWh/day out-of-sample, exceeding existing benchmarks.

A flexible hybrid physics-machine learning workflow for seasonal hourly energy modelling in a hospital building

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¹ *Università di Pisa*

² *DESTEC, University of Pisa*

³ *Idiap Research Institute*

Abstract:

Hourly energy modelling for complex buildings like hospitals poses significant challenges, particularly regarding the distinct dynamics of heating and cooling seasonal regimes. This paper presents a two-phase hybrid physics-data-driven workflow for hourly thermal energy supply forecasting in an Italian hospital, delivering accurate forecasts and calibrated uncertainty bands while maintaining physical interpretability. In Phase 1, a four-node grey-box RC model is calibrated via Bayesian Optimization by minimizing a composite objective combining RMSE, bias, and regularization terms structurally aligned with ASHRAE Guideline 14. The decision vector includes an internal gain coefficient per unit area, an effective air change rate, and scaling factors for thermal capacities of internal mass, envelope, and floor slab. A key methodological feature is the use of monitored building data as boundary condition for the internal node, enabling robust seasonal thermal mass identification through observed thermal over-conditioning dynamics. In Phase 2, a Gradient Boosting Regressor corrects the physical residual using meteorological, RC-simulated node temperatures, and autoregressive features, while Conformalized Quantile Regression constructs calibrated 90% prediction intervals. The workflow is validated on S. Croce hospital in Tuscany using multi-year measurements spanning both heating and cooling seasons. For winter, three independent two-month validation periods yield CV(RMSE) between 8.64% and 17.58% with $|NMBE| < 3\%$, fully complying with ASHRAE Guideline 14. Summer cooling presents intermittent loads dominated by chiller on/off behaviour: CV(RMSE) reaches 26.23% with NMBE of 5.00%, highlighting the limitations of RC formulations without explicit switching logic and motivating future model extensions.

An Experimental Platform for Reinforcement Learning in Building Control Systems

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Abstract:

Reinforcement learning (RL) is becoming increasingly important in building control systems (BCS) because it offers the opportunity to ensure key performance indicators (KPI) such as energy efficiency and comfort, even under changing operational conditions. Time-consuming manual parameterization and adjustments are no longer necessary, as the system independently learns optimal operating strategies from data and feedback. Since training in live operation could negatively impact KPIs, simulations are required for the development and evaluation of RL-based BCS. Existing simulation workflows for RL training of control systems are mostly fragmented, difficult to reproduce, and complex. This study addresses these obstacles and presents a comprehensive, modular experimentation platform with front-end, back-end, and test environment subsystems, as well as a structured configuration model for environments, controllers, reward functions, and training settings via a graphical user interface. Clearly defined interfaces allow for the easy integration of new environments, controllers, and rewards. The container architecture enables portable deployment across different physical nodes. The evaluation demonstrates performance parity with established frameworks. Additionally, key RL design parameters can be varied directly within the user interface. The study results confirm the reproducibility, extensibility, and portability of the developed platform.

Calibrating Jordanian residential building archetypes using sparse indoor thermal monitoring data

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¹ *University of Porto*

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Abstract:

Urban Building Energy Models (UBEMs) are increasingly used to analyse building performance across multiple spatial scales, yet their reliability depends on accurate calibration. Conventional approaches typically rely on energy-use data, often unavailable for residential buildings and influenced by occupational and operational parameters. Indoor temperature offers a promising alternative, yet it remains unclear how much control over boundary conditions, occupancy, and operational factors is needed when collecting such data for UBEM calibration. This study investigates whether indoor temperature data collected under uncontrolled occupied conditions or controlled settings can support UBEM archetype-based calibration. Two one-week datasets from apartments representative of the same archetype were analysed at both compartment level and aggregated building level. Multi-objective calibration was used to minimize CVRMSE and maximize a temperature-based accuracy metric. Controlled monitoring presented the closest agreement between measured and simulated temperatures, whereas uncontrolled data introduced greater variability but still satisfied ASHRAE error thresholds. Building-level aggregation further reduced error by 50%. The findings suggest that sparse indoor temperature can support archetype calibration without fully controlled monitoring. For future campaigns, sparse monitoring periods should be strategically selected under different climatic conditions; window operation and HVAC use should be documented, while controlled periods can help isolate physical building behaviour.

Iterative workflow between OB data collection and simulations of OB impact on energy use in building setups; a demonstrative case study

Tobias Wikman¹, Chanachok Chokwitthaya¹, Weizhuo Lu¹, Thomas Olofsson¹

¹ *Umeå University*

Abstract:

Occupant behavior (OB) influences building energy use. While single-building and district scales have been widely studied, the multi-building level remains less explored. Accurately simulating these impacts requires understanding how OB data and simulation methods interact and inform one another. This work presents an iterative workflow in which OB data collection and simulations of OB impacts on multi-building energy use continuously inform each other. The workflow integrates OB data collection with its application in building energy simulations, where simulation outcomes guide further data collection. A case study was conducted using the IHBI lab at Umeå University and a simulation framework by Wikman et al. to demonstrate parts of the workflow and assess feasibility. Results show that OB data from the IHBI lab can be applied in building energy simulations with limited pre-processing. Future work could expand stepwise activation of actions in OB data collection to capture greater behavioral nuance. Investigating supplementary behaviors such as clothing adjustments versus cooling systems would improve representation of OB effects when OB data collection is used to verify real-world plausibility of the applied OB:s. Larger case studies with alternative simulation and OB data collection methods would demonstrate robustness and generalizability of the workflow.

DETRANS potential model for energy- and power demand savings in the Norwegian building stock

Tor Helge Dokka¹

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Abstract:

The building stock in Norway accounts for approximately 50% of the country's total electricity consumption, which annually amounts to around 130 TWh. The maximum power demand from buildings represents about 75% of the total demand in a normal year. Previous studies have identified a substantial potential for reducing energy use, electricity consumption, and peak power demand in Norwegian buildings. Such reductions could free capacity in the national grid, enabling the growth of new green technology companies and supporting the electrification of the transport and offshore sectors, thereby contributing significantly to the reduction of Norway's greenhouse gas emissions. Within the research project DETRANS, a potential model for energy use, electricity consumption, and power demand has been developed. The model is based on 17 building categories, ranging from single-family houses to complex hospital facilities. Each category is further divided into eight energy performance standards, spanning from non-renovated buildings constructed under the building codes of the 1960s to plus-energy buildings. This results in 136 simulation models, which are analyzed using the dynamic building simulation software SIMIEN across six climate zones representing the most relevant variations in the Norwegian climate. The energy, electricity, and power intensities derived from these simulations are multiplied by the most up-to-date statistics on the Norwegian building stock. The models and their results are calibrated both against micro-level statistics (e.g., measured energy intensity for individual buildings) and macro-level statistics (e.g., national energy use in TWh). The model is applied to explore different energy transformation scenarios for the building stock over 5, 10, 20, and 30 years. These scenarios provide insights into how the building sector can contribute to the broader energy transition required to achieve a low- or zero-emission economy by 2050–2055.

Making Net-Zero Actionable: Structuring Nature-Inspired Strategies by Lifecycle Stage and Circular Design Goals

Omar Borham¹, Ben Croxford¹, Duncan Wilson¹

¹ *University College London*

Abstract:

Despite growing interest in biomimicry as a framework for sustainable urban design, its integration into planning practice remains limited, especially in tools that translate ecological strategies into structured guidance aligned with measurable performance goals. This paper presents a goal-oriented framework that enables early-stage decision-making toward circularity, zero emissions, and net-zero energy outcomes, grounded in life cycle thinking. The tool is built on a multi-dimensional relational database of 184 biomimetic strategies derived from successful built environment precedents. The framework structures strategies by their contribution to high-level sustainability targets, integrating classifications by Life Cycle Assessment (LCA) module, spatial scale, and urban system. This allows users to explore interventions based on where they can achieve higher impacts across the project life cycle, from embodied emissions to operational performance. The developed tool is comprised of two user-facing formats: a deck of visual pattern cards and a Power BI digital interface that enables dynamic filtering by design goal, context, or constraint. Together, they support participatory exploration and promote cross-sectoral, multi-scalar systems thinking. The framework was refined through 8 expert interviews with architects, planners, and policymakers, and further tested in two expert scenario workshops focusing on sustainable circular goals in built environments. These engagements informed refinements in taxonomy, visual clarity, and alignment with decision-making workflows. By structuring strategies around lifecycle stages and emissions-related design outcomes, this work demonstrates how nature-inspired principles can be made more actionable for practitioners seeking to embed circularity, life cycle awareness, and decarbonisation into early-stage planning.

Climatedataforbuildings.eu – An Open Platform for Present-Day and Future Climate Data Tailored to Building Performance Simulation Across Europe

Arnkell Petersen¹, Thomas Thiis¹

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Abstract:

Reliable climate data are fundamental to the accuracy and credibility of building performance simulations, particularly as the sector adapts to accelerating climatic change. Climatedataforbuildings.eu is an open, web-based platform providing harmonized, quality-controlled, and transparently documented climate data for building performance simulation across Europe. The platform delivers more than 7,200 Typical Meteorological Year (TMY) files for over 5,000 European locations, based on the Copernicus European Regional ReAnalysis (CERRA) dataset, together with more than 70,000 Future Meteorological Year (FMY) files generated through ensemble-based climate morphing under Representative Concentration Pathway (RCP) and Shared Socioeconomic Pathway (SSP) scenarios for the time horizons 2050 and 2080. Particular emphasis is placed on metadata standards, provenance tracking, and documentation practices that support traceability, reproducibility, and interoperability. By combining robust methodology with accessible interactive tools, the platform lowers the threshold for future-climate analysis, enables consistent comparisons across locations, and supports more informed design and policy decisions for a changing climate. This contribution presents the platform's design philosophy, methodological underpinnings, interactive tools, and its role in lowering the threshold for practitioners to incorporate climate change considerations into building design and policy analysis.

Modelling of district heating return water usage in apartment buildings

Jiayi Liu¹

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Abstract:

Low-temperature district heating (LTDH) can improve district heating efficiency and facilitate the use of low-grade heat sources, but a full transition from existing high-temperature district heating networks requires substantial infrastructure renovation. Utilizing district heating return water (DHRW) as a low-temperature heat source at the building level offers a potential transitional solution, yet its simulation within established building energy simulation tools remains limited. To address this gap, this study developed a customized DHRW heating system model in IDA ICE 5.1 using the ESBO module. The model represents DHRW as the primary heat source and includes separate heat exchangers for space heating and domestic hot water production. Independent backup heaters and a two-setpoint control strategy were implemented to quantify auxiliary heating demand and simulate system operation under limited return water temperature conditions. The model was applied to a 1969 apartment building in Helsinki region using measured local return water temperature data. Three cases were compared: conventional high-temperature district heating, DHRW without backup heating, and DHRW with electric backup heating. The results show that DHRW covered 77% of the annual heating demand and 62% of the peak heating power demand, while backup heating remained necessary for domestic hot water and cold-period peak loads.

Towards a national fault database: Initial mapping of prevalence, consequences, and current handling practices in ventilation systems

Kamilla Johra¹, Aileen Yang¹, Alessia Bellini², Kari Thunshelle¹, Hicham Heimar Johra¹

¹ SINTEF Community

² Construction City

Abstract:

This paper addresses the lack of a systematic, data-driven understanding of ventilation faults in Norwegian commercial buildings, which leads to increased energy use, reduced indoor environmental quality, and higher maintenance costs. The study aims to establish an evidence-based foundation for a national fault database by identifying prevalent faults, their causes, consequences, and current handling practices. The methodology combines an online survey of industry stakeholders (N=20) assessing current fault data practices, and a multi-stakeholder workshop (33 participants, 22 companies and organizations) generating structured fault-symptom data across building lifecycle phases. The results reveal significant fragmentation in fault data management: only 55% of respondents report having a fault database, and existing datasets often lack critical elements such as time-series data, corrective actions, and verified fault causality. Workshop findings show that faults are most frequently associated with the design (29%) and operational (28%) phases. System installation, integration and configuration faults dominate (37%), and detection remains largely reactive, driven by user complaints (31%) rather than data-driven methods (9%). The study highlights substantial gaps between theoretical and practical fault handling and underscores the need for standardized taxonomies and integrated data structures. It provides a foundation for developing AI-enabled fault detection and diagnosis, and more effective maintenance strategies in the Norwegian building sector.

The Bimorph Human Factor: How Behavior in Buildings and Behavior Around BIM Alters Project Performance Results – Framed Against ISO 19650

Aikaterini Konstantina Chrysochou¹

¹ *RESC*

Abstract:

In building performance simulation, significant effort is made to refine models of occupant behavior, to improve predictions of thermal comfort and energy use. At the same time, BIM models are commonly treated as objective and reliable inputs to these simulations. However, this assumption merits critical reflection. BIM is not neutral; it is shaped by human behavior within design teams. These behaviors are revealed through resistance to new tools, selective workflow adoption, and late or informal model changes - a situation that directly affects model fidelity and boundary conditions, yet it is rarely discussed in simulation practice. This provocation asks whether human-centered simulation can be considered robust when the human behavior embedded in BIM production remains outside the modelling scope.

Ranking energy flexibility key performance indicators for office buildings

Benedikt Mirwald¹, Matthias Mitterhofer²

¹ *TH Rosenheim*

² *TH-Rosenheim*

Abstract:

Energy-flexible buildings play a key role in establishing renewable energy systems and stabilizing the future European power grid. To design, evaluate, and compare flexible buildings, appropriate key performance indicators (KPIs) are required. However, the large number of existing KPIs, their differing definitions and overlapping concepts currently limit comparability and hinder practical application. This paper aims to systematically identify, structure, and prioritize KPIs suitable for quantifying the energy flexibility of office buildings. A literature review covering more than 30 publications resulted in the identification and consolidation of 58 flexibility-related KPIs. These indicators were categorized and evaluated using a multi-criteria decision-making framework. Four evaluation criteria were defined based on literature and expert input. The Analytic Hierarchy Process (AHP) was applied to derive criterion weightings, followed by the TOPSIS method to rank the KPIs regarding their meaningfulness. The results reveal a ranked set of KPIs that capture complementary technical and economic aspects of building energy flexibility. The highest-ranked indicators include the total energy change ratio, the flexibility potential in terms of energy cost savings, the flexibility index, the flexibility factor, and the procurement cost avoided flexibility. Together, these KPIs enable both baseline-required and baseline-free assessments, supporting flexibility evaluation across different data availability scenarios. The proposed ranking framework is transparent, reproducible, and suitable for simulation-based studies as well as comparative assessments. The identified KPI set provides a methodological foundation for future validation using simulated and measured building data and contributes to the harmonization of flexibility assessment approaches in the context of smart and sustainable office buildings.

Climate change and simulation-based building design: Insights from practitioner workshops

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¹ Aarhus University

² Danish Technological Institute

Abstract:

Rising ambient temperatures due to climate change increase the risk of overheating in Danish dwellings, challenging indoor comfort and energy efficiency. Current Danish design practice relies on simulations using average historical weather data, without accounting for extremes or future climate scenarios. As part of a broader research effort to develop new design practices, workshops were conducted with practitioners from the Danish building industry. These focused on: (1) approaches to integrating future climate data, including historical versus projected scenarios; (2) identification of building typologies most susceptible to overheating; and (3) mitigation measures and barriers to their implementation. Each workshop combined expert presentations, individual reflections, and plenary discussions supported by interactive tools. This study contributes empirical evidence from practitioner workshops on the integration of future climate data in simulation-based design, highlighting systematic misalignments between current regulatory practice and the requirements of climate-resilient building design. These findings provide a basis for informing future design methodologies and regulatory development.

Towards Automated Digitisation of HVAC P&IDs: Rule-Based Knowledge Graph Refinement Using LMM-Assisted Human-in-the-Loop

Lasse Hamborg¹, Kevin Michael Smith¹, Christian Anker Hviid¹

¹ DTU

Abstract:

Whole-building simulations using Building Energy Models (BEMs) rely on accurate representations of HVAC systems. However, insufficient HVAC semantics in IFC-based Building Information Models (BIMs) constrain BIM2BEM workflows, particularly when mapping HVAC systems to building zones. Piping and Instrumentation Diagrams (P&IDs) often contain the missing system topology and can therefore support HVAC enrichment of BEMs. Yet, translating P&IDs into ontology-based knowledge graphs (KGs) remains challenging, as automated extraction methods produce imperfect outputs that require validation and refinement. This study investigates how much human guidance is required to refine a P&ID-extracted KG for BEM enrichment. An incomplete KG (requiring 40 triple modifications) extracted from a P&ID by a large multimodal model (LMM) is validated against five BEM-oriented compliance rules. In an LMM-assisted human-in-the-loop (HITL) refinement workflow, three HITL prompting strategies are tested: single-issue refinement, ruleset-targeted refinement, and autonomous generic refinement. The guided strategies achieved full compliance within three LMM turns, increasing F1-score from 81.4 % to 100 %, while the autonomous strategy failed to reach full compliance, converging at 95.9 %. The results indicate that LMMs can support KG correction when guided by validation rules but cannot yet be trusted to autonomously detect and resolve all inconsistencies.

AI-supported integration of recycled materials under data uncertainty: Towards green circular construction possibilities

Abylay Mukanov¹, Chujun Zong¹, Hongrui Chen¹, Werner Lang¹

¹ *Technical University of Munich*

Abstract:

The construction industry is a major contributor to resource consumption and waste generation, which makes the integration of recycled materials a key factor in shifting towards circular and low-carbon building practices. Despite their availability, recycled materials are challenging to use in construction applications due to their variability in compositions, incomplete or inconsistent data, unknown origins, and the absence of standardized methods to handle uncertainty. Previous studies showed the potential of machine learning models for prediction of material properties and optimizing their stable compositions. However, most of approaches rely on deterministic point predictions and do not quantify the uncertainty and reliability of the data. In the context of recycled materials where batch-to-batch variability and data gaps are inherent, this limitation becomes critical, restricting systematic and trustworthy integration of recycled materials into construction applications. This paper proposes a Machine Learning (ML) - supported uncertainty aware methodology for waste material evaluation and classification. The objective is to convert a material uncertainty into quantifiable and decision ready information, ensuring the reliable and justified use of recycled resources. The methodology is based on a two-stage approach. The first stage uses ML algorithms to handle uncertainty of material, while second stage identifies the possible use, producing material suitability profile, identifying most feasible recycling pathways, key risk flags. The results demonstrated on the basis of a real-world case study – mineral waste, obtained from industrial recycling processes, shows that this framework can evaluate recycled material batches, understand their reliability and circularity potential, enabling risk informed recycled material applications such as cement, concrete, asphalt, filler, increasing transparency and trust in recycled materials.

Impact of future climate on overheating of buildings in Sweden

Mark Murphy¹, Weizhuo Lu¹, Thomas Olofsson¹, Gireesh Nair¹

¹ Umeå University

Abstract:

Overheating in residential buildings is expected to exacerbate as the global outdoor temperature continues to rise. This study explores the extent to which different building standards in the cold climate of northern Sweden can be affected by indoor overheating under current and future climate conditions. Further, we investigate the effectiveness of different overheating control strategies, including increased airing, solar shading, mechanical cooling with stand-alone room air conditioners, a summertime bypass of the heat recovery unit, and mechanical cooling via the ventilation. The study is based on simulation of a residential building in two climate zones in Sweden. The study results show that within the RCP 4.5 scenario in 2100, all the simulated buildings except for the passive house in south Sweden were able to avoid excessive overheating by using a combination of various cooling strategies such as bypass, airing and external solar shading. The warmer climate scenario RCP 8.5 pushes the overheating well above the limit in all 3 building standards in both locations.

FlexibleCommunity: An Incentive-Based Dynamic Flexibility Management Simulator

Shahab Tohidi¹, Hugo Miguel Nunes¹, Shahrzad Pour¹, Razgar Ebrahimi¹, Henrik Madsen¹

¹ *Technical University of Denmark*

Abstract:

This paper introduces FlexibleCommunity, an incentive-based energy management simulator for investigating demand-response strategies of communities and generating high-resolution datasets capturing both explicit and implicit participation. The simulator can be configured to represent an arbitrary number of buildings, enabling scalable modeling of communities with heterogeneous dwellings equipped with price-responsive heating systems of varying types and capacities. It also integrates photovoltaic (PV) systems, electric vehicles (EVs), and battery storage to represent multiple flexibility mechanisms. FlexibleCommunity includes stochastic occupant behavior to improve realism and capture uncertainty in energy use patterns. The generated datasets contain time-series data on energy consumption, price signals, weather conditions, and solar irradiance, supporting applications such as load forecasting and flexibility assessment. To improve accessibility, it includes a graphical user interface (GUI) for configuration, visualization, and dataset generation.

Modeling of energy performance in swimming pools – a case study from Bosön sports development center

Arvid Johannisson¹

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Abstract:

Swimming pools belong to some of the most energy-intensive building archetypes. Previous studies have also shown that swimming pools have significant potential to improve energy efficiency. Bosön is the Sports Development Center of Sweden, owned and operated by the Swedish Sport Confederation. The campus is located outside of Stockholm and currently there is a lack of knowledge about the swimming pool's energy demands. The aim of this paper is therefore to develop a model for analyzing energy performance and efficiency measures at Bosön and other swimming pools. The method is based on on-site measurements combined with building simulations of the swimming pool using IDA ICE. The results indicate that the developed model can simulate the swimming pool energy demands and indoor climate with good agreement to the conducted measurements. Furthermore, the simulations also show that heat gains and loads included in the pool model have a significant impact on the energy balance.

Simulation-based assessment of PV integration on complex roof geometries and insights for neighbourhood-scale energy analysis in Nordic climates

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Abstract:

The integration of photovoltaic (PV) systems in existing buildings is a key strategy to increase local renewable energy production in neighbourhoods, including Nordic regions. However, complex building geometries as well as architectural and technological constraints introduce challenges to accurately assess solar potential and aggregate results beyond the single-building scale. The study explores PV integration on two large sports facilities in Ørland municipality, Norway, addressing challenges posed by complex geometries and architectural constraints in high-latitude regions and it discusses methodological implications of using building-scale results as inputs for neighbourhood-level energy analyses. Using Rhinoceros for 3D modeling and Grasshopper with Ladybug/Honeybee for solar analysis, multiple scenarios were simulated to assess overshadowing, solar reflections, and terrain effects. Configurations combined different PV technologies (e.g., monocrystalline and standard crystalline silicon, coloured BIPV tiles, and flexible thin-film CIGS) with varied mounting strategies and integration levels, such as building-integrated PV (BIPV) and building applied (BAPV) systems. Each scenario was evaluated for energy yield, installation complexity, and architectural quality. Results show strong variability in solar potential across surfaces, annual PV electricity production, techno-economic analysis and influencing neighbourhood-scale aggregation. Monocrystalline silicon achieved the best performance (370 MWh/yr, lowest cost, 3.7-yr payback), standard crystalline was mid-range (19 yrs), coloured BIPV prioritized aesthetics but reduced output, and thin-film offered good energy at very high cost (27 yrs payback). Scenarios favouring visual integration generally sacrificed energy performance. The findings highlight the importance of detailed building-scale simulations and careful modeling assumptions for reliable solar potential assessments in cold, high-latitude climates.

Energy losses through window airing in Swedish dwellings

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Abstract:

Window airing by the means of opening windows and doors by purpose by the occupant of a dwelling means, besides the extra ventilation it gives, that there will be an added energy use for heating the air that is exchanged from the outdoor to the indoor temperature. In energy simulations this is usually approximated rather roughly, for example to 4 kWh/(m²heated floor·year) in Sweden independent of where in Sweden it is. The research group has measured window airing with own developed equipment and data management in 15 dwellings, in Umeå and South Sweden, over a year, with a time resolution of 1 minute and an angular resolution in the magnitude of 1 °. This includes 53 windows or doors that were opened to at least some extent, some pivot hung windows and some side hung windows. The analysis of the measured data is presented in another paper, however this paper presents a summary of the opening results and continue with an analysis of the energy use that is added as a result of the actually measured openings. This is done by combining the measurement results with theory of resulting airflow if the angle of a certain window is known. For very small angles, measurements were made of the resulting airflow by help of tracer gas technique. For larger airflows, literature was used to give the flow that was incorporated with a power balance to represent the dwellings. Minute simulations were done with parametric variations and compared with the same situation without window airing to answer the added energy use by the airing. The result shows that the figure of 4 kWh/(m²heated floor·year) is plausible in some cases but the variation is large, between almost 0 and several times 4 kWh/(m²heated floor·year). It also shows that the difference between just simulating the energy loss of a window with fixed indoor temperature over estimates the added energy use in a practical building due to the internal heat gains.

Energy use for ventilation in dwellings – Simulation comparison between plate and rotary heat exchanger in ventilation systems

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Abstract:

Ventilation is crucial for the indoor environment in buildings. At the same time, with the normally used technologies for ventilation today, it means that outdoor air must be exchanged with the buildings, creating a need for energy to heat the outdoor air. Same can be valid for cooling, not in focus in this paper. Typically, in mid Sweden, the energy loss of ventilation air is $0.35 \text{ l/(s}\cdot\text{m}^2\text{floor)} \cdot 1.2 \text{ kg/m}^3 \cdot 1 \text{ kJ/(kg}\cdot\text{°C)} \cdot 100\,000 \text{ °C}\cdot\text{h} = 42 \text{ kWh/m}^2\text{floor}$, when the airflow demanded by the Swedish building code is $0.35 \text{ l/(s}\cdot\text{m}^2\text{floor)}$. This is substantial but can be reduced by in the magnitude of 80 % by a heat recovery between exhaust and supply air, either in the type of a plate heat exchanger or with a rotary wheel between the two air streams. These two are in focus in this paper. The rotary wheel normally has the advantage of slightly higher temperature efficiency and in normal conditions no problem with frost accumulation, but will to a certain extent also recover moisture. If moisture determines the needed airflow, a slightly higher airflow is needed compared to a plate heat exchanger without moisture recovery. Another disadvantage with rotary wheels may be smell transfer, not analysed here, but in some cases they cannot be used. This paper will present a simulation comparison between these two types of heat exchangers regarding the total heating needed in a building including the heating of ventilation air. It will be based on numerical models of the heat exchangers, the power balance of the building and moisture supply in the buildings for different variations of parameters regarding moisture production and performance and use of the building. The outdoor climates that will be used will be focused on different parts of Sweden, and the typical moisture supply will be based on measurements in over approximately 200 Swedish dwellings. The outcome can help designers to choose among typical heat recovery systems in particular situations in dwellings.

A Literature Synthesis on Circularity in the Construction Sector

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Abstract:

The construction sector is a major source of environmental impacts, and these pressures are expected to increase as urbanisation drives growing demand for buildings, while current practices remain largely based on linear production and consumption models. Achieving a sustainable built environment requires a transition from linear practices to circular principles that prioritise reduction, reuse, repair, remanufacturing, and recycling of building materials and components. In recent years, research on circularity in the construction sector has expanded rapidly. There is a clear need to synthesise existing research to consolidate current understanding, identify emerging findings, and highlight remaining knowledge gaps; accordingly, this study conducts a systematic literature review. First, national Swedish research projects were identified through a structured search of the Swecris database. Second, an international literature review was carried out using the Scopus database. The synthesis focused on four thematic areas: digitalization, environmental and economic incentives, application domains across micro-, meso-, and macro-levels, and policies and regulations. In terms of digitalization, existing studies have focused mainly on building information modelling, product data templates (or material passport) to improve traceability and information management. But the potential of emerging technologies such as blockchain, artificial intelligence, and the integration and scaling of digital tools remains insufficiently explored. Analyses of environmental and economic incentives are often constrained by incomplete life-cycle coverage, resulting in incomparable or contradictory findings. Considering application domains, research continues to focus mainly on the micro level, while meso- and macro-levels are less examined. Finally, although some policy instruments and regulatory approaches have been proposed recently, their maturity and practical effectiveness remain unclear.

Quantifying the multiple benefits of rooftop extensions, attic conversions and renovations for climate and housing

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Abstract:

Building renovation is a key lever for reducing global emissions, as it reduces operational carbon emissions from energy use while limiting embodied carbon compared to new construction. Moreover, with rising housing demand and limited land availability, attic conversions and rooftop extensions offer a space-efficient solution by leveraging the existing building stock, supporting the EU's climate and housing goals. This study assessed the holistic performance of four attic transformation strategies in Germany: rooftop extension, attic conversion (from cold space to living space), renovation of a heated attic space, and simple re-roofing. Energy performance, indoor air quality, thermal comfort and daylight performance were evaluated for each case, and a life-cycle assessment (LCA) was also carried out. The performance of these transformation strategies was then benchmarked against business-as-usual (typical new-build or no renovation). The results showed that rooftop extensions and attic conversions could provide additional living space in cities with a lower environmental and spatial footprint than business-as-usual, without compromising on indoor environmental quality. Attic renovation strategies were also shown to improve environmental performance and IEQ. This study thereby suggests attic transformations as a strategic tool for sustainable urban development.

Keywords: Renovation; Attic; Energy; IEQ; LCA; Holistic

Digital Twin Modelling of Architected Hempcrete Building Envelopes for Hygrothermal and Acoustic Performance in Nordic Climates

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Abstract:

Buildings in Nordic climates face low temperatures, strong winds, large seasonal variations, and high expectations for acoustic comfort, placing significant demands on envelope materials. Hempcrete is a bio-based composite offering carbon sequestration, vapour permeability, broadband sound absorption, and effective hygrothermal buffering. Its heterogeneous pore structure enables short-term heat storage and delayed release, helping to moderate indoor temperature fluctuations. However, this material complexity leads to persistent discrepancies between experimental performance and predictions from conventional dynamic building simulation tools, which typically rely on simplified, homogeneous material models and lack coupled heat–moisture–acoustic capabilities. This study investigates hempcrete as an architected bio-based metamaterial with intentionally designed internal geometry. Inspired by acoustic and thermal metamaterials, the research explores periodic cavities, aligned aggregates, anisotropic channels, and Helmholtz type resonator concepts to enable frequency-selective sound attenuation, directional heat transfer, and enhanced hygrothermal response. A multi-scale methodology based on digital twins is adopted to link material-scale geometry with component and building-scale performance. Calibrated digital twins are translated into surrogate, direction and frequency-dependent properties compatible with existing simulation tools. Building-scale simulations are then used to assess impacts on energy demand, thermal stability, moisture risk, and acoustic comfort under representative Nordic climatic conditions. The study demonstrates a pathway towards predictive design of climate resilient building envelopes and highlights future needs for integrated hygrothermal–acoustic simulation methods.

Impact of Air Distribution Strategies on Thermal Comfort and Ventilation Efficiency in Indoor Swimming Pools

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Abstract:

Indoor swimming pools are one of the popular sport facilities worldwide and water evaporation is a key factor influencing such indoor environment. Achieving optimal indoor air quality in swimming pools via HVAC (heating, ventilation, and air conditioning) systems is challenging. This is primarily due to the complexities involved in maintaining a delicate balance between thermal comfort, humidity levels, and energy usage. This work focuses on different advanced air distribution systems based on textile ducts which include both diffuse and impulse air supply. The study includes configurations with (i) groups of small holes in the textile duct, and (ii) the rows of conical nozzles specifically for directional air distribution associated in recently built Åfjord Activity Center (during 2022). This facility offers a multitude of amenities, including a spacious swimming pool, a separate pool for children, and even a movie theater, among other features. Both systems are provided by the company KE-Fibertec. In this work, we aim to investigate the impact on the occupants, towards the improvement of the thermal comfort and air quality with enhanced ventilation efficiency. The complex dynamics of heat-momentum and mass transfer in a multicomponent gaseous system (air, chlorine, and water vapor) will be conducted by performing RANS (Reynolds-Averaged Navier-Stokes) simulations of the indoor swimming pool setup using STARCCM+, a commercial Computational Fluid Dynamics (CFD) tool. Various strategies for the placement of the ventilation system will be analyzed to assess the efficacy of the ventilation systems.

Thermal comfort in office-to-residential adaptive reuse: A Swedish case study

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Abstract:

Office-to-residential adaptive reuse is increasingly discussed as a sustainable response to office vacancies and housing demand, yet its implications for thermal comfort remain insufficiently understood. This study investigates thermal comfort in a Swedish office building under continued use as an office and under three office-to-residential adaptation scenarios representing low, moderate, and high levels of intervention into the existing structure. Based on thermal comfort simulation in IDA ICE (EQUA®), the study evaluates year-round indoor thermal conditions in representative zones through operative temperature metrics and the Predicted Percentage of Dissatisfied occupants comfort index. The scenario comparison did not show a simple pattern in which more extensive intervention led to improved or worsened thermal comfort. Instead, the base case showed the most severe overheating, the low intervention scenario remained strongly influenced by orientation and solar heat gain, the moderate intervention scenario resulted in the most balanced thermal conditions, and the high intervention scenario reduced peak temperatures while tending toward more persistent periods of overheating. The results therefore suggest that thermal comfort in office-to-residential adaptive reuse depends not only on the extent of intervention, but on how well adaptation measures fit the existing building typology and the new use.

Life Cycle Assessment of 3D-Printed Housing with Recycled Construction and Demolition Waste: A Comparative Study with Conventional Methods

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Abstract:

Three-dimensional printed (3DP) buildings present a dual environmental narrative: they offer substantial potential for reducing construction and demolition waste (CDW), yet often require cement-rich mixes that elevate embodied carbon. Bahrain, an arid island state, generates approximately 524,000 tons of CDW annually, with only 52% recycled as of 2020, highlighting a critical opportunity for circular material integration. This study investigates the environmental performance of incorporating recycled CDW as a partial substitute for natural aggregates in 3DP housing, addressing both waste valorization and material scarcity. Using Building Information Modeling (BIM) and OneClick Life Cycle Assessment (LCA) software, a cradle-to-grave comparative analysis was conducted between a 3DP-CDW house and a conventional reinforced concrete house in Bahrain. Key impact categories assessed include global warming potential (GWP), water consumption, and acidification potential. The 3DP-CDW model outperformed the baseline across most indicators, achieving a net GWP reduction of 60,000 kg CO₂e, a nearly 200% improvement. Construction-stage emissions (A5) were fully offset (−182.37 kg CO₂e), and material waste was reduced by 70%. Bahrain's compact geography further enhances the feasibility of CDW logistics, while technical adaptations ensure performance in high-temperature environments. This study contributes to emerging Net-Zero discourse by offering a replicable model for integrating additive manufacturing with circular economy principles in the built environment.

Smart Build: A Machine Learning-Based Platform for Building Material Supply and Recommendations

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Abstract:

The Smart Build system addresses major problems in construction procurement such as manual decision-making, fragmented supply chains, delays, and cost overruns. It uses machine learning techniques to provide smart material and supplier recommendations based on project requirements, budget constraints, sustainability goals, and delivery schedules. By analyzing historical data, supplier performance, and market trends, the system predicts material prices and stock availability to support cost-effective purchasing decisions. Smart Build also promotes sustainable construction by recommending environmentally friendly materials and improving transparency in supplier selection. With features like live tracking, dashboards, and performance monitoring, the platform transforms traditional procurement into a streamlined, data-driven, and efficient process for contractors and builders.

Systematic ground-effect bias in heat transfer coefficient estimation

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² *Ghent university*

³ *Climate-Neutral and Resilient Buildings and Communities (REACT), Catalonia Institute for Energy Research (IREC), Spain*

Abstract:

Data-driven building energy models often represent the building envelope using a single effective heat transfer coefficient (HTC), implicitly assuming uniform boundary conditions. In practice, this assumption is violated because floors are thermally coupled to the ground, whose temperature differs systematically from outdoor air temperature. This work examines how omission of ground coupling introduces bias in HTC estimation. A window-level expression for the ground-effect relative bias is derived for a simplified RC representation and shown to depend on both the floor share of total envelope conductance and an accumulated ground-effect factor over the estimation window. The effect is then investigated using synthetic high-resolution data generated from detailed Modelica simulations of archetypal single-family houses, with 2R2C models identified on moving 21-day windows. Results show that the empirical relative bias scales systematically with floor heat-transfer share and that its seasonal variation is closely tracked by the derived ground-effect bias. At the same time, the mean bias across buildings remains close to zero, indicating cancellation between competing structural bias components. The findings show that omitted physics can produce systematic, yet interpretable parameter bias, even when predictive performance is strong, underscoring the need for bias-aware model formulations in building energy performance assessment.

Limited data, limited gains: machine learning versus linear statistical models for real energy prediction in EPB-labelled buildings

Matthias Van Hove¹

¹ *Ghent University*

Abstract:

Machine learning (ML) models have gained increasing attention for predicting building energy use, yet their applicability at building stock level using real data remains limited. This study evaluates two commonly used black-box ML algorithms, Extreme Gradient Boosting (XGB) and Support Vector Regression (SVR), for predicting yearly energy use in modern residential building stocks. Using large-scale datasets of Flemish single-family houses with real measured energy use and registry-available features, we compare ML models against classical ordinary least squares (OLS) regression and the regulatory calculation method. Results show that while data-driven models substantially outperform the regulatory method in terms of predictive accuracy, they do not outperform OLS regression. More importantly, all data-driven models systematically underestimate the variability of energy use, failing to reproduce the distribution and extreme values observed in the building stock. In contrast, the regulatory EPB method better preserves the variability but exhibits large systematic errors in the mean. These findings indicate that, under realistic data constraints, model performance is primarily limited by feature availability rather than algorithmic complexity. Consequently, simpler and more interpretable statistical models remain highly competitive, while limitations in capturing variability constrain the applicability of data-driven models for scenario analysis and policy evaluation.

From BIM and white-box models to grey-box models: model identification and long-horizon prediction of building thermal dynamics

Matthias Van Hove¹, Justinas Smertinas²

¹ *Ghent University*

² *Technical University of Denmark*

Abstract:

Grey-box models are widely used to represent building thermal dynamics because they balance physical interpretability and computational efficiency. Their identification, however, usually requires extensive measured data collected after building operation, which limits scalability and early-stage deployment. This paper proposes an automated framework for grey-box model identification using synthetic data generated by white-box simulations derived from building information models (BIM). A BIM model is translated via gbXML into a multizone Modelica simulation model, enabling physically consistent annual simulations under realistic weather and stochastic occupancy conditions. The generated data are then used to calibrate multiple candidate grey-box RC model structures. A dual evaluation strategy is introduced that combines classical statistical criteria (log-likelihood, AIC, BIC, likelihood-ratio tests) with long-horizon free-running simulation metrics relevant to annual energy prediction. Results for a representative multizone residential case show that models preferred by statistical fit do not necessarily provide the most reliable long-term predictions. A parsimonious two-state model achieved the best overall balance between complexity, interpretability, and heating-demand accuracy. The framework enables cost-effective pre-deployment identification of grey-box models and supports scalable applications in forecasting, control, and building-stock energy analysis.

Overheating assessment in a positive energy neighbourhood: Case of district digital energy twins for the European H2020 Project- oPEN Lab, Genk, Belgium

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Abstract:

Overheating risk in energy-efficient districts is increasing due to climate change yet remains underexplored at neighbourhood scale. This study evaluates overheating in a Positive Energy Neighbourhood (PENs) in Genk, Belgium, using a calibrated district-scale digital energy twin. The model represents 27 dwellings developed in OpenModelica. Calibration combines Morris-based sensitivity screening and NSGA-II optimization against monitored indoor temperatures and energy demand. The framework integrates monitored data, automated model generation, calibration, overheating assessment, and sensitivity analysis within a unified workflow. Overheating is quantified using Unmet Degree Hours (UDH) at thresholds of 24, 26, and 28°C during a six-day heatwave. A representative dwelling was subsequently analysed to identify key overheating drivers. Results from 300 simulations reveal substantial variability in overheating performance across thermal zones, with living rooms exhibiting persistent temperature exceedances. Glazing U-value emerged as the most influential parameter, showing the highest μ^* values and significant nonlinear interactions, while roof properties also demonstrated strong influence. Building orientation became increasingly important at higher temperature thresholds due to increased solar exposure. The proposed framework demonstrates how district digital twins can support overheating assessment, identify critical design parameters, and inform climate-resilient retrofit and planning strategies for Positive Energy Neighbourhoods.

Development of Thermal Compensation Models for convection-based cooling PECS

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Abstract:

Personalized Environmental Control Systems (PECS), which provide functions such as heating, cooling, ventilation, lighting, and acoustics, enable individualized regulation of the immediate workspace according to user preferences. The use of PECS can reduce the cooling and heating energy demand of the central air handling unit by enabling wider allowable indoor temperature ranges. This study examines the compensatory performance and energy efficiency of convection-based cooling PECS. Five scenarios with fans were experimentally tested and compared using a manikin equipped with equivalent temperature sensors in the Aachen Comfort Cube. At an operative temperature of 30 °C, the desk fan showed the best energy efficiency (0.7 W/K) and achieved a global Equivalent Temperature Difference (ETD) of $\Delta T_{eq} = 2.22$ K. The pedestal fan generated the largest ΔT_{eq} (7.41 K), though with a lower compensatory efficiency of 5.4 W/K. Thermal compensation models are derived from the measurement data, enabling integration of PECS into dynamic building simulation or building automation systems in order to evaluate the energy-saving potential in interaction with a central HVAC system.

Quantifying the influence of thermal zoning strategies on overheating predictions for Urban Building Energy Modelling (UBEM)

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Abstract:

The global climate has become increasingly characterized by extreme weather events and hot spells, raising concerns about the ability of the existing building stock to withstand growing thermal stress on indoor environments. Urban Building Energy Modelling (UBEM), beyond its primary application in energy assessments, can support overheating evaluations at scale, although limitations in data availability might compromise model fidelity. This study investigates thermal zoning as a critical methodological component within UBEM. Common approaches range from simplified single-zone models to more advanced configurations, such as core-perimeter, floor by floor and fully disaggregated multi-zone models, that offer increased physical realism at higher computational cost. A systematic comparison is conducted to assess their impact on overheating predictions. In addition, a novel zoning methodology is introduced, based on recurring patterns in functional room distribution within residential buildings, enabling a potentially automatable zoning algorithm. Results indicate that single-zone and core-perimeter models respectively under- and overestimate overheating, while floor-by-floor divisions and the new prototype method align well with the detailed reference with deviations up to 14%. However, for atypical layouts, deviations for the prototype method rise to 70% with differences equally attributed to thermal zoning and internal load allocation. Although further optimisation is necessary, this new zoning approach holds promising prospects for integration in automated UBEM workflows.

Investigation of summertime indoor thermal microclimates in a Swedish case study apartment

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Abstract:

The increasing temperatures and heightened occurrence of heatwaves have raised concerns about overheating within the Swedish building stock. Indoor temperature analyses demonstrate that multi-residential buildings are particularly prone to elevated temperatures. Furthermore, substantial variation in summer thermal performance has been identified among apartments within the same building, indicating that evaluations conducted with aggregation at the building level may be insufficient. While modern monitoring capabilities allow for apartment-level assessment and model validation, sensors are typically placed in a single central location, such as in the apartment's hallway. Due to the sensor location, the actual temperature distributions within apartments may have fluctuations caused by influences like solar radiation through windows, apartment layout, occupancy patterns or internal gains. Therefore, reliance on a single sensor per unit may offer an incomplete depiction of these variations. This paper examines this hypothesis using stratified climate modelling at apartment level, with the aim of improving the robustness of summer thermal performance validation. The study involves thermal performance simulations of a case study apartment in Gothenburg, Sweden. Simulation results are compared with indoor temperature data collected at 15-minute intervals using a permanently installed hallway sensor. The results show that a single sensor is representative of a large portion of the apartment for most of the time. However, for detailed analyses, it may be insufficient as it does not capture spatial temperature variations.

Implementation of an EnergyPlus-Based Urban Building Energy Model for Mixed-Use Districts in Trondheim

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Abstract:

Urban Building Energy Modelling (UBEM) enables the analysis of building energy use at district and city scale and is increasingly used to support strategic urban energy planning. However, translating conceptual UBEM frameworks into operational simulation models remains challenging because of heterogeneous data availability, incomplete building-stock information and scale-dependent modelling decisions. This paper implements an EnergyPlus-based UBEM for Trondheim, Norway, focusing on data integration, archetype definition, geometric assumptions, weather inputs and post-processing. The workflow links cadastral and GIS data, building usage types and climate inputs into a transparent UMI/EnergyPlus pipeline, where UMI generates simplified urban shoebox representations and EnergyPlus performs dynamic building energy simulation. The approach is demonstrated for two Areas of Interest (AOI1: mixed-use port area; AOI2: predominantly residential), comparing stock composition, energy use intensities and end-use breakdowns. The results highlight trade-offs between preserving building-stock heterogeneity, managing uncertainty and maintaining scalability, providing a defensible first-pass baseline for future calibration, scenario analysis and port-city energy studies.

Assessing the impact of active building systems operation on overheating in PCM-integrated offices

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Abstract:

This study investigates the potential of combining phase change materials (PCMs) with operational strategies to mitigate overheating in office buildings in a temperate climate. While PCMs can dampen indoor temperature peaks through latent heat storage, their effectiveness depends on their ability to undergo cycles of melting and solidification. Building Automation and Control Systems (BACS) monitor and regulate indoor conditions through operational controls, facilitating PCM solidification during cooler periods and, thereby, influencing their performance. A simulation framework is developed to evaluate a PCM-integrated office building under multiple rule-based controls for night ventilation (NV) and solar shading. Overheating is quantified using overheating degree-hours (ODH). Results show that PCMs consistently reduce ODH when an appropriate melting temperature is selected, although performance strongly depends on operational controls. PCM-induced reductions improve from 20% without control to up to 90% when combined with NV and shading. NV flow rate and solar irradiance set-points are identified as key influencing parameters. The findings highlight the importance of their co-design, as PCMs are most effective when the phase change range aligns with indoor temperature profiles, enabling continuous latent heat storage. They complement operational strategies by reducing temperature peaks and improving summer thermal comfort.

Integration of Energy Analysis Tools within the Architectural Design Process: Lund University Normative Design Tool (LU-NDT)

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Abstract:

The persistent mismatch between the iterative design process and energy performance analysis remains a fundamental challenge in the Architecture, Engineering, and Construction (AEC) industry. Typically, dynamic Building Performance Simulation (BPS) is executed by external consultants late in the design project process, primarily to secure building permits. This delayed feedback loop breaks the iterative design workflow, making early geometry and material modifications prohibitively costly. Standard BIM-to-BEM interoperability attempts (e.g., IFC) often cause semantic data loss, while simplified cloud tools operate as opaque "black boxes," creating regulatory trust issues for engineers. To address this methodological gap, this paper explores integrating normative, quasi-steady-state calculations (ISO 52016-1) directly within the primary authoring environment. By embedding an integrated normative framework within Autodesk Revit, continuous, transparent performance feedback is achieved by feeding the analytical engine directly from the active BIM model. Evaluated within a Nordic climate context (Lund, Sweden) using Boverket and Sveby boundary conditions, the methodology is demonstrated across three levels of geometric complexity (IEA EBC Annex 91): a baseline shoebox, a Swedish typical residential house, and a Million Program building. The study demonstrates that integrated normative calculations provide a valid, transparent workflow to continuously support early-stage energy-efficient decisions without relying on fragile external data exports.

Assessing Phase Change Material Integration for Energy Demand Reduction in Scottish Residential Buildings

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Abstract:

Phase change materials (PCMs) offer a passive strategy for reducing building energy demand and improving indoor thermal stability. However, their performance in highly insulated dwellings remains uncertain because reduced temperature variation may limit phase-change activation. This study investigates PCM integration in Scottish residential buildings using dynamic simulation in DesignBuilder/EnergyPlus. A typical two-storey dwelling was modelled under the climates of Glasgow, Edinburgh, and Aberdeen. The influence of PCM melting temperature, layer thickness, placement within the wall, and application across envelope elements was examined. Results showed that a melting range near 21°C provided the best overall performance, with CrodaTherm 21 outperforming a generic PCM. Performance improved up to 20 mm thickness, beyond which gains were marginal. Inner-wall placement was more effective than middle or outer positions, while external wall application outperformed roof and floor integration. The optimised configuration reduced annual heating and cooling demand by up to 28%, increased winter indoor temperatures by 0.5–1.0°C, and reduced summer peaks by 1–2°C. These findings provide practical guidance for PCM integration in highly insulated dwellings and demonstrate its potential for low-energy residential design in cold maritime climates.

Economic comparison of borehole field regeneration options in a cold climate

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Abstract:

Shallow borehole heat exchangers can be used to collect energy for heating buildings using heat pumps. When more energy is needed, borehole fields of tens or even hundreds of boreholes can be used. However, as the size of the borehole field increases, its natural regeneration gets slower. In addition, to avoid excessive long-term drops in ground temperature, the boreholes need to be placed far apart from each other, which is a challenge in urban environments with limited plot sizes. To enable placement of boreholes closer together, additional energy needs to be fed into the ground to maintain ground temperature. This can be done using various heat sources, which have different temperature levels and availability. This study examines the relative usefulness of different heat sources (ambient air, ventilation exhaust air, sewage and solar heat) for direct use in heat pumps and for borehole field regeneration, considering a techno-economic viewpoint. The study was conducted through TRNSYS simulations of different heat sources in combination with heat pumps and a borehole field. Parametric analysis of various combinations of solar heat, ambient heat, ventilation exhaust heat and sewage waste were performed. The results provided a cost hierarchy of heat sources and showed the life cycle and ground temperature impacts of different system combinations.

Assessing the efficiency of CDW management systems in European countries

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Abstract:

The construction industry is a major contributor to greenhouse gas emissions, raw material consumption, and waste generation, making improved construction and demolition waste (CDW) management essential for advancing circular-economy objectives. In Europe, CDW represents one of the largest waste streams, yet cross-country evidence on the efficiency of national CDW management systems remains limited. Existing assessments are often country-specific and descriptive rather than comparative benchmarking studies, and frequently fail to distinguish between treatment pathways with different environmental and circularity implications. This study evaluates the relative efficiency of European countries in transforming CDW into desirable recovery outcomes using input-oriented Data Envelopment Analysis (DEA). Harmonized per-capita data were used to compare countries as decision-making units under both constant returns to scale (CRS) and variable returns to scale (VRS) assumptions, alongside sensitivity analysis using alternative input–output specifications. Results reveal substantial differences in efficiency across countries. Denmark, Finland, Hungary, and Luxembourg were fully efficient under both CRS and VRS assumptions, while many countries performed better under VRS, indicating scale-related inefficiencies. Sensitivity analysis showed that efficiency rankings depend strongly on the definition of CDW treatment pathways, with recycling emerging as a key driver of performance. The findings suggest that aggregate CDW treatment rates are insufficient for assessing circularity performance and highlight the need for differentiated policy targets addressing recycling, backfilling, and energy recovery.

A Synthetic Data-Driven Workflow for Predicting Borehole Thermal Performance Using Linear Regression

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Abstract:

Accurate prediction of borehole thermal performance is essential for the efficient design and operational control of Ground Source Heat Pump (GSHP) systems. While data-driven modeling is a mature field, limited real-world datasets often hinders model deployment. This study demonstrates a workflow that utilizes a numerical finite-difference simulator to generate synthetic yet realistic operational data by solving the transient heat conduction equation for a single U-tube borehole. A linear regression model is developed and trained on a rolling 7-day window to predict the exiting fluid temperature (T_{out}) at a 15-minute resolution. The model's performance was validated over a full year of simulated dynamic heating and cooling loads. Results indicate high predictive accuracy, with an aggregated Root Mean Square Error (RMSE) of 0.0357°C and an average training RMSE of 0.0008°C . The model successfully captures dynamic ground responses across varying seasonal loads. This adaptive approach demonstrates significant potential for integration into real-time optimization frameworks, such as those driven by next-day electricity spot market prices, by balancing computational efficiency with physical accuracy.

Public Buildings as CO₂ Capture Sites: Laboratory-Based Investigation of Direct Air CO₂ Capture (DAC₂) and Potential for CO₂ Enrichment in Greenhouses

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Abstract:

Direct Air CO₂ Capture (DAC₂) integrated into Heating, Ventilation and Air-Conditioning (HVAC) systems offers opportunities not only for reducing CO₂ concentrations but also for supporting localized food production through the supply of captured CO₂ to greenhouses. This study evaluates the potential of Swedish public buildings as distributed CO₂ capture sites for greenhouse tomato production. The approach combines laboratory measurements of a zeolite 13X-based DAC₂ unit, county-level estimates of public-building CO₂ capture potential, and building energy simulation of greenhouse heating demand in Gothenburg, Svea, and Luleå. The results show that the DAC₂ unit achieves a capture efficiency of 90% at CO₂ concentrations commonly observed in public buildings. At national level, the estimated CO₂ capture potential from Swedish public buildings is 8.21 Mt CO₂/year. Replacing Swedish tomato imports through domestic greenhouse production requires 0.99 million m² of additional greenhouse area and 0.03 Mt CO₂/year for enrichment. The corresponding heating demand ranges from 184.9 to 398.0 GWh/year, depending on location and greenhouse envelope U-value. The study demonstrates that CO₂ captured from Swedish public buildings has the potential to supply the enrichment demand associated with replacing tomato imports, while the required greenhouse heating demand varies substantially with location and envelope thermal performance.

Operating-envelope assessment of static-pressure reset control in VAV systems

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Abstract:

Variable Air Volume (VAV) ventilation systems are widely used in non-residential buildings because they allow airflow to be adjusted to zone-level demands. In practice, however, many systems are still operated with a Constant Static Pressure (CSP) setpoint, which leads to excessive duct pressure, increased VAV damper throttling, and unnecessary fan energy use under partial-load conditions. Static Pressure Reset (SPR) strategies can mitigate this inefficiency, but practical implementations are typically based on heuristic trim-and-respond logic and are influenced by VAV flow-control dynamics, actuator response, fan-map limitations, and minimum terminal pressure requirements. This paper presents a component-level simulation framework to assess VAV fan-control strategies under consistent physical conditions. Three strategies are compared: CSP, an ideal model-based SPR lower bound, and a practical dynamic SPR controller. The results show that the ideal SPR reduces fan energy by 56.3% relative to CSP, while the practical controller achieves a 43.9% reduction, representing 78.1% of the theoretical saving potential. The results further demonstrate that VAV system behavior cannot be represented by a single system curve, but instead corresponds to a controller-dependent operating envelope defined by the interaction between demand profiles, network layout, VAV constraints, fan characteristics, and control dynamics.

A Coupled Human–Machine–Environment Modeling Framework for Construction Systems

Jie Zhang¹

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Abstract:

Factory-like construction equipment such as the aerial building machine (ABM) enables the transformation of open construction sites into semi-indoor environments with controllable temperature, humidity, wind speed, and lighting. Meanwhile, the increasing integration of collaborative robots introduces new operational characteristics involving coupled environmental regulation and human–robot collaboration. This study proposes a construction system modeling framework that jointly considers environmental regulation, worker behavior, and human–robot collaboration in ABM scenarios. The framework characterizes environmental states, worker states, human–robot relationship states, and task states at the individual level. Based on different environmental regulation strategies and collaboration configurations, multiple construction scenarios are constructed to analyze system state interactions and validate the applicability of the framework in representing human–machine–environment coupling processes. The results indicate that the proposed framework provides a systematic approach for modeling and analyzing complex construction systems in intelligent construction environments.

Field measurement and CFD evaluation of adaptive attachment ventilation and tunnel ventilation in pig houses

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Abstract:

To address uneven airflow distribution, insufficient air velocity in the pig-occupied zone, and localized pollutant accumulation under conventional tunnel ventilation (TV), this study proposed an adaptive attachment ventilation (AAV) strategy and evaluates its performance through field measurements and CFD simulations. Field measurements showed that, under TV, the indoor air temperature ranged from 26 to 28°C, with a peak value of 28.4°C, while the relative humidity ranged from 60% to 100%. The measured air velocity was only 0.02-0.41 m/s, indicating weak and non-uniform airflow distribution in the pig-occupied zone. Numerical simulations further demonstrated that, under the same ventilation rate and supply-air temperature, AAV could guide fresh air toward the pig-occupied and breathing zones, thereby improving airflow coverage, local cooling, and pollutant removal. Compared with TV, AAV increased the air velocity in most pig-occupied areas to 0.6-0.8 m/s, reduced the temperature around most pig bodies to 23.6-24.4°C, and decreased the average NH₃ and CO₂ concentrations by 87% and 30%, respectively. These results indicate that adaptive attachment ventilation can effectively improve both the thermal environment and air quality in pig houses and provides a potential ventilation strategy for improving local environmental control in large-scale pig houses.

Analysis of the impacts of green roof and ground-level green area applications on urban heat island and stormwater runoff in urban design

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Abstract:

Rapid urbanization increases energy consumption, intensifies urban heat island (UHI) effects, and expands impervious surfaces, creating major environmental challenges. These conditions elevate outdoor air temperatures in metropolitan areas and complicate water conservation by increasing stormwater runoff. Since UHI intensity and runoff are strongly affected by impervious surface ratio, vegetation cover, and microclimatic conditions, evaluating both indicators together is essential for understanding the holistic impacts of different green area configurations in urban environments. In this context, this study comparatively investigates the effects of green roofs and ground-level green areas on UHI effect and stormwater runoff within an urban form composed of the slab building typology, identified in the literature as advantageous for energy performance. The widespread applicability of these interventions in existing urban areas formed the main rationale for their selection. Urban form was defined using two descriptors: three Floor Area Ratio (FAR) levels (low, medium, high) representing density and Ground-Level Green Area Ratio (GLGR) values (0%, 50%, 100%) representing green area configurations. Multiple urban alternatives, with and without green roofs, were evaluated for Istanbul's current climate using simulation-based analyses and formula-based calculations. Results indicate that lower density, green roofs, and ground-level green areas significantly reduce both UHI effect and stormwater runoff.

Rule Extraction for Occupant Window-Operation Behaviour: A Comparison of Classification Trees and Random Forests

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Abstract:

Occupant behaviour models used in building performance simulation range from compact, interpretable rule-based representations to complex ensemble machine learning approaches, simulated with stochastic approaches. While more complex stochastic approaches may capture a richer representation of occupant decision-making, it remains unclear whether this additional complexity leads to meaningfully different building energy simulation outcomes or whether deterministic rules extracted from them are adequate. In this study, window operation models are implemented within a co-simulation framework with a building performance simulation tool. Stochastic and rule-extracted deterministic implementations of Classification Tree (CT) and Random Forest (RF) modelling approaches were evaluated using models of four residential dwellings located in a warm Australian climate. Despite considerable differences in model complexity, CT and RF implementations produced comparable annual heating and cooling energy predictions across the investigated dwellings. Similar behavioural drivers and decision tree structures were observed across both modelling approaches, resulting in consistent representations of occupant window operation behaviour. The findings suggest that increased behavioural model complexity does not lead to significant differences in annual building energy predictions, with stochastic heating, stochastic cooling, deterministic heating and deterministic cooling predictions differing by only 0.8%, 1.7%, 3.1% and 5.9%, respectively. This highlights the potential of compact and interpretable behavioural models extracted from CTs for use in building simulation.

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