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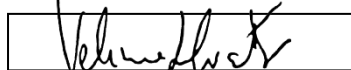
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The active role of buildings dynamic simulation in energy transition with hourly climate data in situ measurements

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Abstract. Dynamic simulation is increasingly vital in the energy transition, offering advantages over steady-state modeling. However, its widespread adoption faces hurdles, notably in acquiring real input data and interpreting results effectively, limiting its legal effectiveness in Italy and elsewhere. Energy audits, empowered by advanced modeling, should become standard practice, rather than reserved for exceptional buildings. Hourly dynamic simulation, crucial for capturing energy usage and occupant comfort variations, requires adaptable building automation systems utilizing sensor networks. This study compares two dynamic simulations conducted on an identical classroom at the University of Basilicata, Italy, using real input data collected via a sensor network, highlighting the importance of adaptable building automation systems accessible to all stakeholders. This inclusive approach enables tailored design solutions, aligning with EU ecological transition goals and positioning dynamic modeling as a key driver in sustainable building practices.

Keywords: dynamic simulation, energy transition, tailored energy design.

1 Introduction

The Energy Roadmap 2050 heralds a new era where all sectors - energy, construction, industry, transport, and agriculture - must adapt to a new energy paradigm. Over recent decades, a surge in energy-related legislation, directives, protocols, and communications underscore a concerted effort towards energy performance enhancements. Key to this transition is the integration of intelligent networks and automation in energy management, driving sustainability and efficiency. European Directive 2002/91/EC mandated energy audits to reduce energy consumption and CO₂ emissions. Subsequent directives, like 2010/31/EU, focused on improving building energy performance, introducing nearly Zero Energy Buildings (nZEB). Italy's UNI TS 11300, in line with 2002/91/EC, requires steady-state calculations. The latest advancement is seen in European energy standard EN ISO 52016, now the benchmark for building energy

performance calculations, requiring hourly dynamic modeling. For comprehensive insight into EU energy efficiency policies, refer to [1]. The Energy Roadmap 2050, a cornerstone of the European Green Deal [2], outlines the regulatory framework for a decarbonized economy, setting the stage for sector-wide competition within a redefined energy model.

Estimating a building's energy performance involves various methods, including energy balancing and steady-state, semi-steady-state, and dynamic simulations. Dynamic simulation offers a deeper understanding of system dynamics and energy depletion compared to other methods. However, its adoption faces challenges due to difficulties in obtaining real input data and interpreting results. As energy audits progress, a shift towards modern methodologies like hourly dynamic simulation becomes crucial for capturing nuanced variations in energy behavior and occupant comfort, enhancing performance prediction accuracy. The integration of occupant behavior models and empirical data within simulation software further enhances predictive accuracy, signaling a paradigm shift towards comprehensive energy management practices [3]. In particular, gathering input data for hourly dynamic modeling is essential. Relying solely on standardized data templates within software is no longer sufficient.

This study illustrates these concepts through a case study comparing two hourly dynamic simulations of a classroom at the University of Basilicata in Italy. One simulation used pre-loaded templates in DesignBuilder with EnergyPlus software, while the other utilized actual input data collected by a tailored sensor network. The comparison underscores the importance of adaptable sensor networks for building automation and energy diagnosis, facilitating the development of tailored technological solutions aligned with best practices and supporting the EU's environmental goals outlined in the Energy Roadmap 2050.

The paper outlines the study's structure, including introductory themes, case study analysis, research outcomes, and future research directions.

2 Dynamic vs standard simulation: concise overview

Energy simulation modelling is widely used to assess a building's energy performance for both new constructions and retrofit projects. While the data requirements for simulations are similar, the evaluation time span varies. Steady-state simulations simplify computations by averaging temperatures and consumption over heating seasons, while semi-stationary simulations analyze monthly data. In contrast, dynamic simulations offer a more accurate assessment by considering various factors like thermal inertia and changing environmental conditions, providing detailed daily views of a building's behavior. While standardized models serve practical purposes in daily operations, particularly for regulatory compliance, they may struggle to accommodate novel materials or innovative systems due to their rigid framework. Consequently, traditional calculations often fail to capture the complexity of a building's energy behavior accurately. Dynamic simulations, built on adaptable IT tools, allow for the exploration of innovative technologies, offering valuable insights into a building's behavior (see [4] for an excellent example). Dynamic simulation outputs provide comprehensive data, aiding in

understanding a building's performance for technicians and non-specialists alike. Despite the complexity of the process, analyzing simulation results enables insights into daily energy needs and comfort levels, facilitating informed design decisions and retrofit interventions. In summary, energy steady-state simulation and hourly dynamic simulation are two approaches used to model and analyze building energy performance, each with its own characteristics and advantages.

3 Case study: a classroom comparative energy modelling

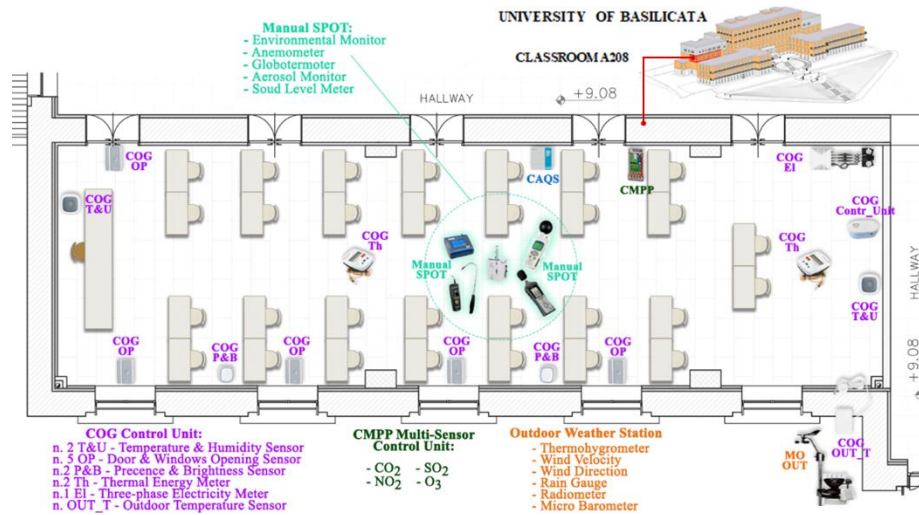
The University of Basilicata in Matera, Italy, is located at 420 meters above sea level, the campus comprises interconnected buildings housing administrative offices, classrooms, and laboratories. Classroom A208, object of the analysis, is situated on the second floor of the main building and it covers an area of 118 sqm and a volume of 642 mc. It features five aluminum frames on the southeast side and is equipped with VRV air conditioning units for temperature control. The classroom serves architectural drawing and survey laboratory activities for up to thirty students and one or two teachers.

School/academic buildings are non-residential and have discontinuous use. The variation of indoor parameter is significant. As a result, they necessitate a very precise computation based on actual usage. The IAQ is an unavoidable component that must be considered in healthy building design since pollutant concentrations vary greatly and this data cannot be computed using a standard simulation. Currently, there is a shortage of study into the energy modelling of buildings for school/academic uses, which tends to concentrate on the implications of infrastructures on student performance [5]. Yet, most researches conducted in this sector have the same goal: to assess the reliability of the calculating methods available nowadays [6]. The accuracy of hourly dynamic simulations in building energy performance evaluation is a critical aspect. It emphasizes challenges related to the precision of input data, particularly regarding the building envelope and external environmental conditions. Current methods, including standard templates and literature references, are inadequate for school buildings, necessitating the creation of specific templates based on in situ measurements of key parameters.

Based on the case study's goals and the research project's objectives, hourly dynamic simulation emerges as the most suitable choice. The first simulation is carried out with pre-set templates in the DesignBuilder and EnergyPlus software, while the second simulation utilized authentic data collected from the demonstrator between July 2023 and March 2024, offering detailed insights into its conditions over time. Spot measurements provided data for both occupied and unoccupied scenarios. Data from various sources, including meteorological databases [7] for actual boundary conditions, customized templates, and IAQ monitoring, were incorporated into the second model. Surveys helped capture user interactions with building systems and comfort levels. However, challenges arise due to the variability in user behavior, prompting the need for improved IAQ control solutions tied to outdoor air quality. A comparative summary is presented in the **Errore. L'origine riferimento non è stata trovata.**, while the equipment implemented in the classroom A208 is schematized in **Errore. L'origine riferimento non è stata trovata.**

Table 1. Comparison of input data for the two models.

Input data				Model n.1	Model n.2
Climate	Outdoor	Site	Weather & Contaminants	Template	Actual
		Building	Height & Orientation	Actual	Actual
	Outdoor	Gains	Shadings External walls	Partially	Full
Geometry	Indoor	Envelope	Internal partitions	Templates	Actual
			Intermediate ceilings Doors, windows, blinds		
		Zone	Areas and volumes Internal thermal mass	Actual	Actual
Plant	Indoor	Building	HVAC and DHW	Templates	Actual
			Electrical equipment		
	Outdoor	Building	Artificial lighting	Templates	Actual
Usage	Indoor	Zone IAQ	Environmental setpoints	Classroom template	Actual and measured
			Air CO ₂ & Contaminants		
			Temperatures & Humidity		
	Users	Schedules	Occupancy rate	Academic calendar template	Actual as scheduled
			Workdays/Holidays		
		Comfort	Electrical equipment	Not applicable	Surveys
			Clothing and Metabolism		
			Perceptions by behavior		

**Fig. 1.** Depiction of the variety of sensors installed in and out the classroom under analysis.

3.1 Hourly dynamic simulation comparison: results and discussion

Errore. L'origine riferimento non è stata trovata. illustrates two graphs depicting hourly fluctuations of key parameters. The first graph covers October 2nd, 2023, from 00 AM to 11 PM, aligning with the beginning of the lessons. The second graph portrays January 15th, 2024, covering the same timeframe, but exhibiting a different, more pronounced seasonality marked by lower operating temperatures. In the graphs, dotted lines represent fluctuations derived from simulations using templates, whereas continuous lines depict fluctuations based on simulations using real data. A notable disparity in is observable between the two simulations across most parameters. Upon examining the entire parameter set and timespan, it's evident that model n.1 tends to inaccurately predict real performance 37% of the time, while accurately predicting or improving performance 63% of the time. Therefore, model n.1 compromises the prediction of real behavior and the actual energy needs of the classroom A208.

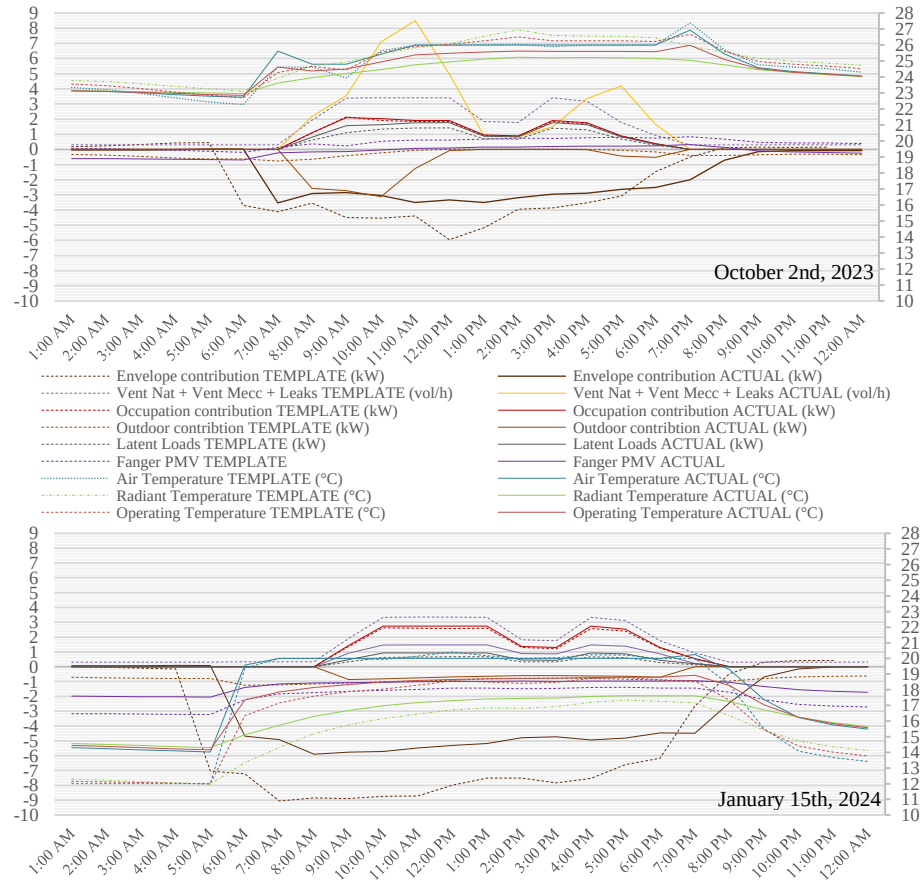


Fig. 2. Comparisons of key parameter fluctuations on two different seasonal days for the two simulation models.

4 Conclusions

Dynamic energy simulations offer detailed insights into system behaviors, enabling the design of more efficient and reliable systems, in line with recent EU directives.

The case study presented offers valuable comparative features on its energy performance. It underscores the importance of educating stakeholders on energy management to mitigate the rebound effect and promote sustainable practices. This analysis helps in refining predictive models and optimizing energy management strategies to ensure comfort and efficiency across varying environmental conditions. Furthermore, the case study highlights the need for building automation systems to optimize energy management across diverse building types. This holistic approach, combined with best practices, can significantly contribute to meet EU energy targets. This work is part of a larger project aimed at overcoming simulation tool limitations and making evidence-based decisions to meet energy and IAQ goals. Future plans involve plant management strategies through an IBIS ECO cloud platform, integrating analytical tools, life cycle cost analysis, and machine learning for dynamic modeling. Validated models will fill guidelines for holistic management of building-system-environment-user interactions.

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