



“Towards Sustainability through Innovation in Opera Houses: A Case Study of Teatro Real”



“The development of our society is conditioned by the use and harnessing of energy, which serves as the main lever for guaranteeing well-being.”

As defined by the World Bank:

“Energy is at the heart of development. Without it, communities live in darkness, essential services such as medical and educational facilities are severely affected, and businesses operate under severe limitations. Energy makes possible investment, innovation, and new industries that drive job creation and growth for entire economies. Universal access to affordable, reliable, and sustainable energy — Sustainable Development Goal (SDG) 7 — is essential to achieving other SDGs and lies at the core of efforts to address climate change.”

To guarantee climate neutrality by 2050, the European Union has established the European Green Deal as part of its strategy against climate change and for emissions reduction. Among the most relevant legislative updates, the Energy Performance of Buildings Directive (EPBD, Directive 2024/1275) sets the following obligations:

- Energy audits and energy certification (HULC Calener). RD 56/2016, EU 2022/27, CTE.
- Nearly Zero-Energy Buildings (nZEB/ECCN), zero emissions for new buildings from 2028/2030. EPBD, CTE.
- Mandatory renovations for the least efficient buildings. EPBD.
- Promotion of renewable energies and self-consumption (e.g., heat pumps). EPBD.
- Energy management control systems with smart readiness indicators (SRI). RITE, EPBD.
- Non-financial reporting obligations, ESG (Law 11/2018, EU 2022/2464).
- Exemplary role of public administrations. EPBD.
- RD 36/2023, CAEs (Energy Saving Certificates), SNOEE.
- Circular economy and waste management.

The **improvement of energy efficiency** in buildings is based on three pillars:

1. **Constructive characteristics:** the envelope.
2. **Energy supply and technical installations** available.
3. **Active energy management** via a Building Management System (BMS).

The Teatro Real, one of the most important opera houses in the world and a protected cultural landmark in Madrid, has undertaken a comprehensive program to become a nearly zero-energy building (nZEB). Guided by EU directives such as the European Green Deal and the Energy Performance of Buildings Directive (EPBD), the institution has implemented measures that combine architectural, technical, and digital innovation with cultural heritage preservation. In recent years, the theatre has integrated sustainability into its operations, demonstrating that the performing arts can contribute to environmental and social responsibility without compromising artistic excellence.

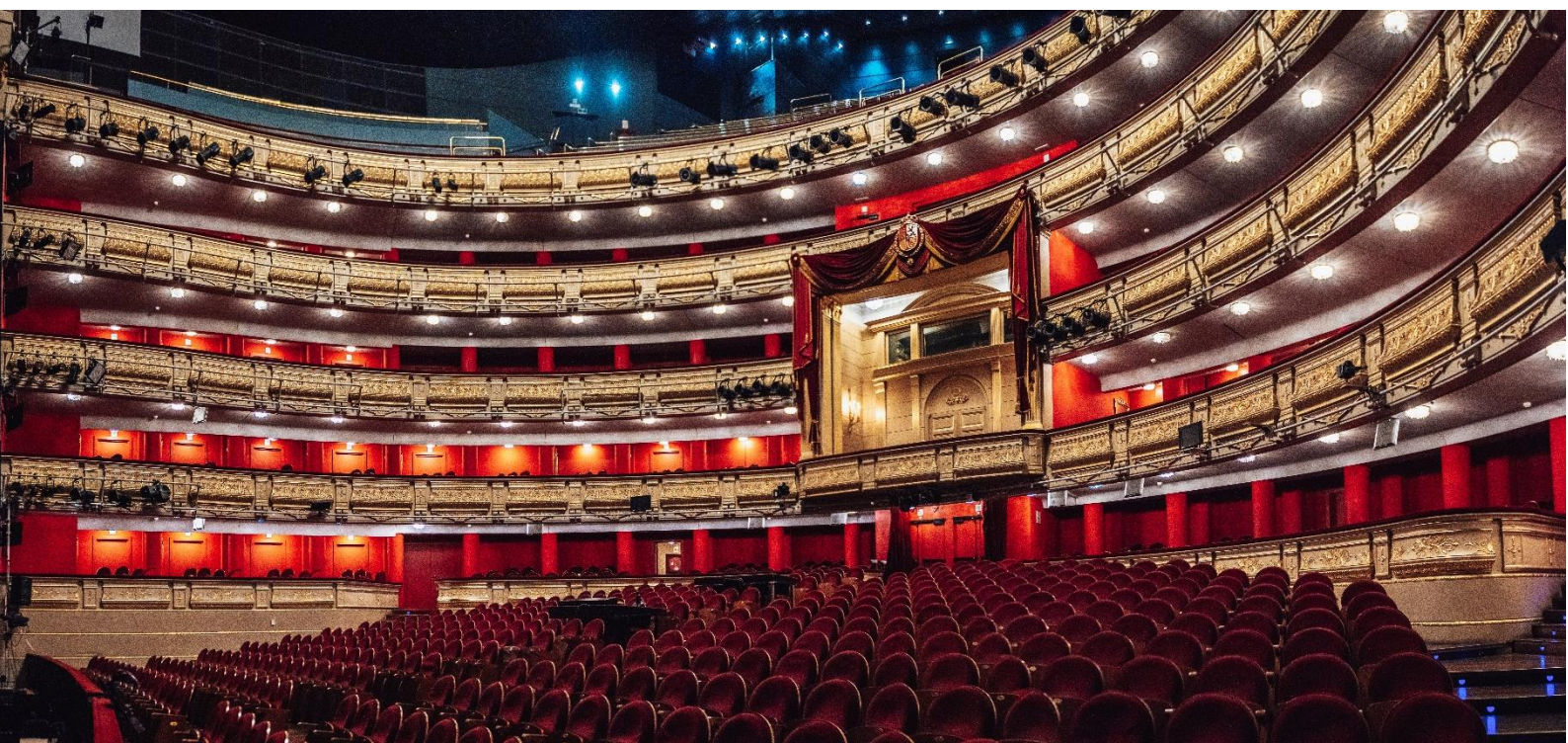
One of the main areas of focus has been energy efficiency. The Teatro Real has invested in modern lighting systems, including LED technology, to reduce electricity consumption while enhancing stage productions. The building also optimizes its heating and cooling systems, lowering its carbon footprint in line with the city's environmental objectives.

Another important initiative concerns waste management and recycling. Stage sets and costumes are often reused or repurposed for new productions, minimizing unnecessary waste. The theater also encourages suppliers and collaborators to follow sustainable practices, extending its environmental impact beyond its walls.

Beyond the technical aspects, the Teatro Real plays a key role in raising awareness. Through educational programs and collaborations, it highlights the importance of sustainability to younger generations and audiences who may not otherwise connect culture with environmental issues.

The Teatro Real's approach demonstrates that cultural institutions can act as agents of change. By integrating sustainability into its artistic mission, the theatre shows that tradition and innovation can coexist in harmony with respect for the planet.

In a time when climate challenges are urgent, the Teatro Real proves that opera houses and theatres can inspire not only through music and performance but also through responsible practices that contribute to a more sustainable society.



Environmental Sustainability Actions at Teatro Real, Madrid

Key Measures and Achievements

- **Energy Audits and Baseline (2018):** Established according to ISO 50001, considering climate, audience levels, and activity schedules.
- **Energy with renewable Guarantee of Origin (GoO) (2019)**
- **Carbon footprint** record in MITECO from 2019
- **Lighting (2019-2020):** Complete replacement of over 11,000 lamps with LED technology (2019–2020), saving over 40% in lighting consumption.
- **HVAC Modernization (2023):** Installation of high-performance chillers, heat pumps, water pumps, air treatment units, and air quality sensors, achieving a 33% reduction in HVAC energy use and improving the energy rating to **B**.
- **Energy Savings Certificates (CAEs) and MITECO Registration (2023)**

A major milestone in the Teatro Real's sustainability program was the valorization of energy savings through the national Energy Savings Certificates (CAEs) system, coordinated by the Ministry for the Ecological Transition and Demographic Challenge (MITECO). This process officially recognized the reductions obtained after the 2023 HVAC modernization, which included the replacement of chillers, heat pumps, pumps, air handling units, and hot water production systems.

The intervention achieved a 33% reduction in annual HVAC energy consumption, equivalent to approximately 1.2 GWh per year, and improved the building's energy **certification to Grade B**. These savings were formally registered as CAEs, making the Teatro Real the first cultural heritage building in Spain to be included in the MITECO register.

- **Exterior Lighting (2025):** Renovation with more than 40% energy savings.
- **Solar Photovoltaic Roof (2024) Innovative solution that integrates the most advanced technology with the protection of protected historical heritage.** Installation of walkable solar glass panels (169 kWp, 190 MWh/year), reducing primary energy demand by 453,604 kWh annually and CO₂ emissions by 67,389 kg/year. **This upgraded the building to an A energy rating.**
- **Artificial Intelligence and Smart Energy Management**

The Teatro Real has pioneered AI-based multi-objective optimization of its **Building Management System (BMS)**. Using data mining, machine learning, and advanced algorithms (genetic and swarm), the AI autonomously manages HVAC operations, achieving up to 60% energy savings while maintaining comfort. This approach has introduced **dynamic functional zoning** and predictive maintenance, reinforcing the building's Smart Readiness Indicator (SRI) and supporting cultural heritage preservation.



Global Results

- **Teatro Real, nearly zero-energy building (nZEB)**
- **Energy use reduced** from 7 GWh/year to 4 GWh/year.
- **Main efficiency index** improved from 100 to 50 kWh/m²/year, with the goal of <50 by 2026.
- **Carbon neutrality (Net Zero)** achieved in scopes 1 and 2 since 2019.
- **Recognition:** Winner of the 2024 “Best Energy Efficiency and Sustainability Action” award.
- **KPIs:** reference indicators for other theatres and other heritage-protected buildings.

Conclusion

Through a combination of renewable energy integration, advanced HVAC modernization, AI-driven optimization, and strict compliance with EU directives, the Teatro Real has become a model of sustainable cultural heritage management. These actions not only reduce energy and emissions but also set a precedent for balancing **historic preservation with climate neutrality and digital innovation**

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