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ARTIFICIAL INTELLIGENCE FOR ENERGY EFFICIENCY AND DEMAND SIDE MANAGEMENT IN MUNICIPAL-OWNED BUILDINGS IN SOUTH AFRICA

SAGEN SOUTH AFRICAN-GERMAN ENERGY PROGRAMME

german cooperation DEUTSCHE ZUSAMMENARBEIT

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TABLE OF CONTENTS

i. EXECUTIVE SUMMARY

South African municipalities face rising energy costs, aging infrastructure, and unreliable electricity supply, with public buildings consuming 34% of the nation's electricity. Artificial Intelligence (AI) presents a transformative solution, enabling predictive maintenance, smart Heating Ventilation and Air Conditioning (HVAC), and demand-side energy savings of 15–30%, even in low-data environments.

Key Insights:

1. AI applications, such as for real-time fault detection, load balancing, and the use of digital twins, have proven effective globally and locally.
2. Barriers include fragmented data, funding gaps, and skills shortages
3. Municipal readiness varies: While some cities have piloted smart meters, most lack infrastructure and integrated resources.

Recommendations:

- Start small: Pilot AI in high-impact buildings using existing data.
- Build partnerships: Collaborate with ESCOs (Energy Service Companies), universities, and donors for funding and knowledge transfer.
- Align policy: Integrate AI with national goals and municipal policies.

AI is not just a technological upgrade, it is a strategic tool that helps cut costs, reduce emissions, and deliver electricity optimally in-step with the future grid requirements. With phased adoption, through capacity development, piloting and strong partner support, South African municipalities can turn energy challenges into opportunities for resilient, inclusive growth.

ii. ACRONYMS

Acronym	Full Term
AI	Artificial Intelligence
AMR	Automated Meter Reading
BMS	Building Management Systems
BREEAM	Building Research Establishment Environmental Assessment
DEE	Department of Environmental and Energy
DFFE	Department of Forestry, Fisheries and the Environment
DKK	Danish Krone
DSM	Demand Side Management
ESCOs	Energy Service Companies
EV	Electric Vehicle
HVAC	Heating Ventilation and Air Conditioning
IEA	International Energy Agency
IoT	Internet of Things
ML	Machine Learning
NEES	National Energy Efficiency Strategy
NYCHA	New York City Housing Authority
PCC	Presidential Climate Commission
PV	Photovoltaic
ROI	Return on Investment
SANEDI	South African National Energy Institute
SANS	South African National Standards
SQL	Structured Query Language
tCO2e	tonne of carbon dioxide equivalent
Wi-Fi	Wireless Fidelity

1. BACKGROUND

South African municipalities are grappling with rising energy costs, grid instability, and increasing demand for reliable public services. These challenges are exacerbated by ageing infrastructure, limited funding, and a scarcity of data to support strategic energy planning. As cities grow and energy needs intensify, traditional approaches to energy efficiency and demand-side management (DSM) are proving insufficient. Although building automation and energy management systems have been available for some time, they focus mainly on monitoring and providing alarm capabilities. With the increasing convergence of smart buildings, there is great value in developing a central analytics platform to provide more insights from the combined data. Artificial Intelligence (AI), with its capacity for real-time analytics, predictive maintenance, and intelligent automation, presents an opportunity to transform how municipalities manage energy in public buildings.

This briefing note explores AI's potential to improve energy performance in the built environment by outlining practical case studies from both developed and developing contexts, and recommends actionable strategies for adoption within South African municipalities. South Africa's buildings consume 34% of the country's electricity [1] and contribute 36% to emissions [2]. With climate change mitigation requirements, energy security challenges and electricity costs escalating, improving energy efficiency and demand side management in buildings is critical. Municipal-owned buildings in South Africa such as administrative offices, community centres, and public facilities, are significant energy consumers, further stressing municipal budgets and contributing to emissions.

HVAC systems are responsible for approximately 60% of energy use in these buildings [3] and are often inefficient due to aging infrastructure, manual controls, and inconsistent maintenance. Balancing energy efficiency with occupant comfort is challenging, as retrofitting these buildings is costly and complex. In addition to financial, environmental benefits and comfort, AI-driven energy management can support a more equitable energy transition by improving service delivery in under-resourced public facilities such as clinics, rental housing and community centres—many of which serve women, youth, and vulnerable populations disproportionately affected by energy poverty.

2. SOUTH AFRICAN CONTEXT ON ENERGY EFFICIENCY

South Africa's energy landscape is characterised by a reliance on coal (accounting for over 74% [4] of electricity generation), frequent load shedding, and underfunded municipalities. Despite national energy efficiency targets, such as the 15% improvement goal in public buildings set out by the National Energy Efficiency Strategy, progress remains limited. Municipalities lack the resources to enable retrofitting. This includes energy infrastructure needed to measure and obtain performance data and staff capacity to enable energy efficiency implementation. Furthermore, municipalities struggle to secure funding for modernising energy systems or deploying smart technology.

While some municipalities have undertaken energy audits, these initiatives often cannot scale due to financial and technical constraints. Data is a recurring problem: smart meter penetration remains low, Building Management Systems (BMS) are rare, and energy audits are episodic rather than continuous. Without reliable data, municipalities cannot diagnose inefficiencies, measure performance, or implement automated solutions.

Aligning AI with National Energy and Climate Policy Goals

The integration of AI in energy efficiency and demand-side management directly supports South Africa's broader climate and energy policy goals. It aligns with the National Energy Efficiency Strategy (NEES) target of 15% energy savings in public buildings, contributes to the implementation of SANS 10400-XA energy performance standards, and enables municipalities to actively participate in the Just Energy Transition by modernising infrastructure and reducing reliance on fossil fuels. AI-enhanced building systems also support commitments under the municipal climate change/climate action plans, and can help operationalise data-driven initiatives outlined by Presidential Climate Commission (PCC), South African National Energy Development Institute (SANEDI), Department of Forestry, Fisheries and the Environment (DFFE) and Department of Electricity and Energy (DEE). In this way, AI is not just a technical innovation—it is a strategic enabler of national development priorities.

3. THE GLOBAL SHIFT TOWARDS SMART, AI-ENABLED ENERGY MANAGEMENT

Globally, Cities are embracing AI to manage energy in buildings with unprecedented precision. AI-driven solutions—including building automation systems, digital twins, and cloud-based management platforms—are being used to optimise energy performance and minimise costs. AI makes it possible to manage buildings as responsive, intelligent systems that learn and adapt to internal and external conditions. The integration of AI with Internet of Things (IoT) devices and sensor networks enables real-time monitoring of HVAC, lighting, water heating, and ventilation systems.

Digital twins, for example, offer real-time virtual models of physical buildings, allowing facility managers to simulate and test different operational scenarios. Predictive analytics based on historical and live data empowers proactive maintenance and fine-tuned energy management. Cities like Amsterdam and Singapore are not only reducing energy consumption through AI, but also participating in demand response programs and virtual power plant configurations. These technologies allow buildings to shift energy use to different times of day, turning what was once a non-flexible load—a fixed, predictable pattern of electricity demand—into a flexible load, which can be increased or decreased in response to signals from the grid. Flexible loads are a valuable commodity in today's energy markets because they help energy market operators to better manage peaks and troughs in electricity demand, and incorporate more intermittent renewable energy sources into the grid.

4. APPLICATIONS OF AI ON ENERGY EFFICIENCY

AI applications in buildings can be grouped into several key categories [5]:

- **Predictive Analytics & Forecasting**
  AI models use historical data, occupancy schedules, and weather forecasts to predict energy demand with high accuracy.
- **Real-Time Fault Detection & Predictive Maintenance**
  AI can detect anomalies in equipment performance, signalling early maintenance needs or anomalies.
- **Smart Control Systems & BMS Integration**
  AI-powered BMS platforms can dynamically adjust HVAC and lighting systems. These systems learn building behaviour and adapt controls to optimise comfort and energy use.
- **Low-Data Environments**
  Where smart meter data is unavailable, AI can use proxies such as Wi-Fi access logs or occupancy patterns to infer energy baselines. Tools have also been developed to create energy baselines using monthly billing information weather, data and low -level occupancy data to estimate disaggregated daily energy consumption. Studies have shown the accuracy of these estimations to be 70-80% [6].

These technologies demonstrate that AI can deliver tangible benefits, even without detailed datasets and without the need for extensive retrofitting. A simple illustration of inputs and outputs and how it meets the goals is shown below.

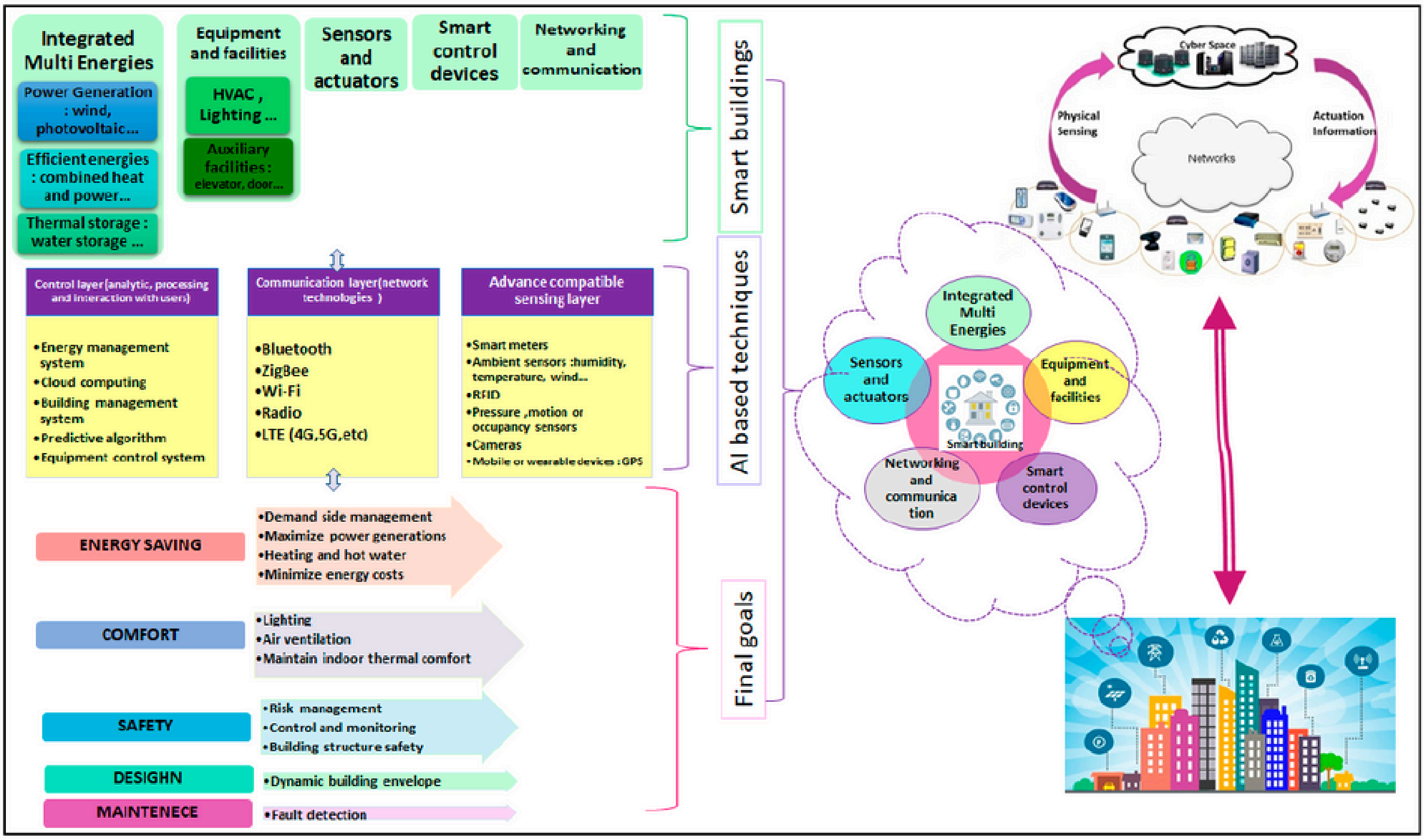

Figure 1: Hardware and software requirements needed to meet AI-enabled energy optimised buildings [7]

5. CASE STUDIES

5.1 Global case studies offer valuable insights for South Africa

- **The Edge, Amsterdam:** This Deloitte headoffice building uses nearly 30 000 IoT sensors and AI to optimise lighting, HVAC, and occupancy, consuming 70% less electricity than typical offices. Its aquifer thermal storage and solar panels make it energy-positive, earning a BREEAM Outstanding rating [8].
- **Shangai Tower, China:** AI optimises HVAC and lighting in this 632-meter skyscraper, reducing energy use by up to 54%. Its high-performance envelope and wind turbines enhance efficiency, making it one of the most sustainable tall buildings globally [9].
- **Microsoft Redmond Campus, USA:** Microsoft's campus uses an AI-driven BMS to monitor and adjust energy use across 13 buildings. Machine learning optimises HVAC and lighting, achieving 20% energy savings, with digital twins enhancing predictive maintenance [10].
- **Holstebro Municipality, Denmark:** Since August 2021, the Danish municipality of Holstebro has used Ento AI to optimise energy use in public buildings. The system analyses data from utility meters alongside weather, time, and building attributes. Using predictive analytics and machine learning, it identifies and prioritises energy-saving measures based on impact and ROI. In the first year, the municipality saved over DKK 1 million (R2.8 million) [11] [12].
- **The New York City Housing Authority** used an AI-driven predictive maintenance system in 50 buildings, retrofitting boilers, water pumps, and electrical panels with IoT sensors to monitor temperature, vibration, pressure, and energy use. Machine learning algorithms analysed this data alongside historical records, predicting equipment failures weeks in advance. Residents, initially sceptical of "smart" systems due to privacy concerns, reported fewer disruptions. Within a year, saw 22% fewer emergency repairs, 15% lower energy costs. The payback period was under 18 months, prompting plans to expand to 500+ buildings by 2025 [13].
- **Cammeby's International Office Building, New York:** BrainBox AI's ARIA system optimises HVAC operations by analysing data from energy bills, HVAC and lighting systems, weather forecasts, and utility tariffs. The building saw a 15.8% reduction in HVAC electricity use, saving $42,951 and avoiding 37.14 tCO_2e. The AI also optimised condenser water flow for server rooms, ensuring thermal demand was met while improving efficiency [14].
- **The Building Energy Efficiency system:** This solution is being rolled out across Europe. Every day, the system derives a forecast for the next day's energy grid mix, weather conditions and the buildings' utilisation and capability to use energy flexibly. Based on that, the system calculates an optimised control schedule for heating, ventilation, cooling, water heating, EV charging and other flexible appliances. The schedule shifts energy usage towards renewables and minimises the energy usage through a proactive control, while maintaining a comfortable environment for the buildings users [15].

5.2. African Case Studies

- **Data poor locations (Ghana, Senegal, and Uganda):** The International Energy Agency and Massachusetts Institute of Technology, developed a model which can estimate the current or anticipated electricity needs for every building, using an open-source model which gathers satellite data and electricity meter data. The model then uses algorithms to learn from high-resolution images of buildings, identifying the patterns that best correlate their image and location to a certain level of energy demand. This provides a broad consumption range. The municipality can then use this information to identify buildings that should be targeted for the installation of smart meters and energy efficiency interventions [16].
- **Maseru Mall, Lesotho:** This commercial complex employs a AI-based BMS to control lighting and HVAC, resulting in energy consumption reduction. Smart sensors adjust systems based on occupancy, addressing grid constraints in a resource-limited setting [17].
- **Nairobi Commercial Tower, Kenya:** This high-rise uses AI for energy forecasting and demand response, optimizing HVAC and reducing energy consumption by 27% [18].
- **Plentify Geyser Control:** In homes and municipal hostels, HotBot reduced heating costs by up to 30% through AI-trained scheduling.

6. IMPLEMENTATION REQUIREMENTS

A successful transition to AI-enhanced energy management requires these resources in place:

- **Data:** Energy consumption; weather; occupancy data, including buildings registry and asset inventory
- **Infrastructure:** low-cost IoT sensors and smart meters linked to a control module, or existing BMS that is already collecting data from multiple sources, even if it is used for energy related functions like access control, vertical transport, fire safety, etc.
- **Analytics and reporting:** a system that runs collected data through advanced analytics and prepares reports for operators, engineers, and managers
- **Skills:** technical skills in data analytics, IoT systems, and energy modelling, along with operational capacity in facilities management and change management is needed. This can be acquired through partnerships and skills transfers.

7. MUNICIPAL STATUS QUO

This section draws on structured interviews with three municipalities, eThekwini, City of Cape Town, and Cape Agulhas Local Municipality, to assess the current state of readiness to implement AI-enabled energy efficiency solutions, highlighting data availability and smart metering infrastructure in municipal buildings. Refer to the appendices for individual responses.

The availability of energy consumption data and smart metering infrastructure varies significantly across municipalities, reflecting broader disparities in institutional capacity and funding. While a few municipalities have made investments in obtaining data by utilising smart metering, the majority remain at the foundational stages, with data either not gathered at all or still largely gathered manually, and only for billing purposes. The use of BMS is limited and uneven across municipalities, often tied to donor funding, certification requirements, or flagship building projects. Even where BMS systems exist, they are not consistently used for energy efficiency purposes. Cross-cutting issues in the municipality include service provider dependency, lack of integration protocols, and underutilisation of existing data. Nonetheless, municipalities are keen to expand BMS capabilities, especially if paired with AI tools.

Although municipalities are experimenting with AI for other applications, the direct use of AI for energy optimisation in municipal buildings is still emerging. Municipalities expressed strong interest in its potential for real-time consumption analysis, predictive demand forecasting, automation of controls (e.g., HVAC, lighting), and predictive maintenance planning. Municipalities emphasised starting small and scaling with clear value demonstrations, supported by capacity-building and strategic integration.

8. RISKS AND MITIGATION STRATEGIES FOR AI DEPLOYMENT IN ENERGY EFFICIENCY

The following implementation challenges have been identified. Based on this, mitigation strategies suitable for municipalities are proposed.

Table 1: Risk and mitigation strategies

Risk	Description	Mitigation Strategy
Institutional Resistance	Municipal staff may resist adopting AI due to unfamiliarity or perceived disruption.	Invest in change management, staff training, and communicate the long-term benefits.
Procurement Challenges	Municipalities risk dependence on a single vendor for proprietary AI/BMS systems, limiting flexibility and inflating long-term costs.	Demand open standards that require vendors to comply with interoperable protocols that can be easily picked up by other vendors. Knowledge transfer clauses which mandate vendor training for municipal staff.
Costs	High initial investment costs for AI systems and infrastructure.	Seek funding from donors, public-private partnerships, and staggered investment models.
Institutional Fragmentation	Lack of coordination and integration across municipal departments (Energy, ICT, Facilities) and stakeholders hinder implementation.	Foster cross-departmental collaboration that align with departmental and national mandates. Create centralised governance structures.
Skills Shortages	Limited expertise in AI, data science, and energy management within municipalities.	Invest in training programs, partnerships with academic institutions, and hiring skilled professionals. Enforce vendor knowledge transfer.
Data Privacy and Cybersecurity	Risk of sensitive building e.g. occupancy data in rental housing, or operational data being exposed or misused.	Implement clear data governance frameworks, encryption standards, and access controls.

9. A READINESS FRAMEWORK FOR MUNICIPALITIES

Based on international best practice and the status of readiness in South African municipalities, the following five core dimensions need addressing for successful implementation of AI-based energy management in municipal buildings:

- **Data Readiness**

Start small – collect any available data such as monthly utility bills, occupancy logs, or weather records. Where real-time data is missing, employ models that use historical billing data and publicly available weather data to estimate consumption, occupancy proxies using WiFi logs etc. and develop a proxy baseline, and then deploy temporary basic sensors to gather sub-hourly energy readings to verify the consumption profile.

- **Infrastructure Readiness**

Retrofit key buildings with sensors, measurement and communication devices or integrate existing BMS with AI platforms. Even small datasets, collected over a few weeks, can inform actionable models. Encourage interoperability between sensors, platforms, and software providers.

- **Institutional Readiness**

Partner widely: Involve local universities, private vendors, and civil society in co-developing solutions. Knowledge transfer is essential. Leadership buy-in is critical to prioritise AI in operational planning.

- **Financial Readiness**

Obtain management support and develop a roadmap or frameworks to solicit donor support and build partnerships with private ESCOs who can provide the capital needed for AI pilots.

- **Policy & Governance Readiness**

Develop policies that align the mandates encompassing electricity supply, energy efficiency and demand side management, data management and data security for the municipality. Policies must enable the flexible adoption and integration of new technologies and systems. Align with industry standards and follow global best practice.

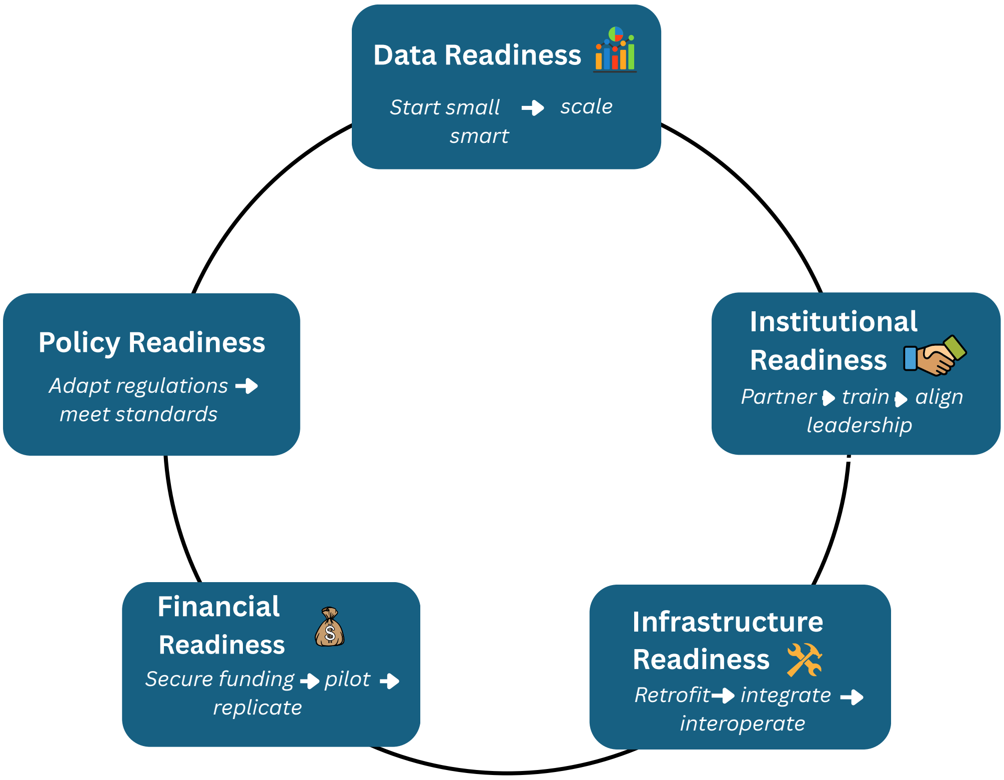

Figure 2: AI readiness requirements

Municipal readiness requires significant financial and institutional investment before AI can be fully utilized to optimise energy consumption. Supporting organisations can assist municipalities with building their capacities and developing strategies and policies, as well as run pilot projects that can evaluate and fine tune how implementation can happen at scale. Table 2 provides a summary of the support that can be provided.

Table 2: Donor Support Levers for AI-Enabled Energy Efficiency in Municipal Buildings

Support Lever	Short Term (0–1 yr)	Medium Term (1–3 yrs)	Long Term (3+ yrs)
🧪 **Pilot Co-Funding**	✅ **Fund AI & smart meter pilots**		
🗂️ **Open Data Platforms**		✅ **Develop shared repositories**	
🛠️ **Technical Assistance**	✅ **Procurement & integration support**	✅ **AI model development**	
🎓 **Capacity Building for Staff**	✅ **Training workshops**	✅ **Advanced skills transfer**	
📜 **Regulatory Framework Development**		✅ **Draft standards & policies**	✅ **Institutionalise frameworks**
🤝 **Public-Private Partnerships**		✅ **Initiate collaborations**	✅ **Scale partnerships**
🌐 **Knowledge-Sharing Platforms**	✅ **Host webinars & workshops**	✅ **Regional exchanges**	✅ **Global forums**

10. CONCLUSION

AI offers significant potential to enhance energy efficiency and demand side management in municipal-owned buildings in South Africa, addressing critical challenges like high energy consumption, budget constraints, and emissions while contributing to grid flexibility. Global and local case studies demonstrate that AI-driven solutions can achieve substantial savings (20–70%) even in resource-constrained settings. Local examples like Plentify's geyser control and Holstebro's predictive systems further prove that scalable impact is possible with limited initial data.

Applications such as smart BMS, predictive maintenance, and digital twins can optimise energy performance, but insights from eThekwini, City of Cape Town, and Cape Agulhas Local Municipality reveal uneven readiness. Many municipalities lack granular data, yet AI can bootstrap insights using proxies like billing records, Wi-Fi logs, and weather forecasts. This adaptability is key for South Africa's diverse contexts.

Barriers like costs, expertise gaps, and aging infrastructure require targeted strategies:

- Start small but think strategically - Use available data (billing, occupancy) to build baselines, then pilot in high-impact buildings like clinics and community centres—where savings directly improve equity and service delivery.
- Leverage partnerships - Collaborate with universities, ESCOs, and donors to co-fund pilots, share open-data platforms, and transfer technical skills. International models (e.g., IEA's satellite-based demand estimates) show how partnerships can bridge data gaps.
- Align with national policies - Embed AI projects in frameworks like the NEES, Energy Performance Certificates and SANS 10400-XA and the municipal climate change policies to unlock funding and ensure compliance.
- Mitigate risks upfront - Address institutional resistance through staff training, cybersecurity protocols, and flexible procurement to support innovation.

Critically, AI is not just a technical tool but a governance accelerator. The path forward requires phased experimentation, cross-departmental collaboration, and policy agility.

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	eThekwini	City of Cape Town	Cape Agulhas Local Municipality
Smart metering installations and implementation	Has a smart metering strategy. In 2018, the City piloted smart meters in key facilities and established an energy management system. A few more buildings have been added over the years to monitor consumption, however the data is not being utilised to optimise building operations on a day-to-day basis. Funding constraints prevent the City from installing the required infrastructure such as sub-meters. In addition, the siloed approach to municipal energy management could be improved to incorporate the City's broader energy management goals – the smart metering strategy is housed by the Electricity Department (customer-centric) while the smart metering project in City-owned buildings is implemented by the Climate Change Department.	The City has made notable strides, deploying over 1,200 billing meters and 250 sub-meters across its facilities. Sub-metering extends to wastewater treatment plants, solar PV installations, EV charging infrastructure, and selected large buildings. Nevertheless, metering is primarily used for monitoring of consumption, energy efficiency interventions and detection of anomalies, and more recently to obtain data needed for Energy Performance Certificates. The City also has BMS systems, but these are used primarily for access and security and not for dynamic control. Integration between smart meters and BMS remains a long-term goal due to procurement constraints, vendor lock-in challenges, and system incompatibilities.	Automated Meter Reading (AMR) technology for its bulk water and energy meters, especially in infrastructure like boreholes and server rooms. However, the focus remains on basic visualisation of consumption rather than analysis. Data is stored in SQL databases, but limited capacity has prevented deeper use for energy optimisation.
BUILDING MANAGEMENT SYSTEM (BMS) USAGE AND EXPERIENCES	BMS platforms are operational in landmark facilities such as the Moses Mabhida Stadium and the ICC. These systems manage HVAC, lighting, and security but were originally installed as part of compliance requirements. Their integration with energy data systems is limited, and municipal staff lack knowledge of full system capabilities.	BMS is installed in the Civic Centre and newer municipal buildings, primarily for non-energy functions like parking management, lifts, and access control. The systems are not integrated with the City's smart metering infrastructure. Procurement complexities and vendor lock-in have delayed efforts to unify and upgrade these systems.	Piloted small-scale automated systems in specific contexts, such as temperature and humidity control in server rooms. However, a full BMS architecture is not in place.
Use of AI for other City applications	Detecting illegal SSEG	Detecting illegal SSEG	None yet

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