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From Cooling Load to Carbon Ledger: A Cloud-Native Building Operating System Evaluated Across 68 Buildings in a Hot-Arid Climate

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ARTICLE DETAILS	ABSTRACT
Article History Received: June 2026 Accepted: August 2026 Published Online: September 2026	Commercial building portfolios in hot-arid economies face an unusual combination of pressures. Cooling can account for as much as seventy to eighty percent of a building's electricity demand, energy and carbon disclosure obligations are tightening, and the building automation estate that should provide the evidence base remains fragmented across proprietary, single-vendor controllers that do not interoperate. Conventional building management systems were engineered for supervisory control of heating, ventilation, and air conditioning, not for portfolio-scale measurement, analytics, and environmental, social, and governance (ESG) reporting. This paper addresses that gap through a design-science study. The contribution is BuildOT One, a cloud-native Building Operating System (BOS) reference architecture that organises device, edge, connectivity, time-series persistence, digital-twin, intelligence, and application concerns into independently deployable layers governed by a multi-tenant security model. The architecture is instantiated as a production platform and evaluated against six months of operational telemetry from a live deployment across a large managed real-estate portfolio in Dubai, comprising sixty-eight monitored buildings on twenty-five sites and four hundred and twenty-nine connected meters and sensors spanning electrical, thermal (cooling), water, on-site solar, and indoor-air-quality streams. Approximately seven million raw readings were ingested and reduced to verified monthly consumption using a reset-filtered register-difference method. The evaluation quantifies the platform's ingestion reliability, recovers a clear cooling-driven seasonal load signature (portfolio electrical demand rising from 3.41 GWh in February to 5.25 GWh in May), characterises on-site solar generation, and reports reading-weighted indoor-environmental-quality compliance, including 99.2 percent of carbon-dioxide readings below 1000 ppm. We further show that robust ingestion against real-world data pathologies, meter resets, register overflow, and export truncation, is a first-class operational capability rather than a preprocessing afterthought. The results demonstrate that a layered, cloud-native BOS can serve as a single measurement and intelligence substrate for energy, cooling, and ESG functions across a heterogeneous portfolio, and they surface the floor-area and baseline data that future savings-attribution studies require.
Keywords Building operating system Cloud-native architecture Internet of Things Building energy management Digital twin Indoor environmental quality ESG reporting Design science Hot-arid climate	
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1. INTRODUCTION

Buildings are where most people spend most of their time, and they are also where a large share of national energy is consumed and emitted. In the United Arab Emirates the imbalance is acute. Buildings account for roughly seventy percent of net energy use, and within a typical building the air-conditioning load can reach seventy to eighty percent of total electricity demand (Shanks & Nezamifar, 2013; Mohammed et al., 2024). The drivers are structural rather than incidental. Outdoor summer temperatures routinely exceed forty-five degrees Celsius, humidity along the coast is high, and electricity has historically been inexpensive, so mechanical cooling has become the default response to comfort rather than a measure of last resort (AMW, 2025). Climate projections make the trajectory worse. Cooling demand for a representative UAE office building is expected to rise by about twenty-two percent by 2050 and by about forty percent by 2080 under a business-as-usual scenario (Shanks & Nezamifar, 2013). Against that backdrop, Dubai has committed to supplying forty percent of its cooling needs from district cooling and to retrofitting tens of thousands of buildings by 2030 (MarkNtel, 2025).

Two further pressures compound the energy challenge. The first is disclosure. Asset owners increasingly report operational carbon under the Greenhouse Gas (GHG) Protocol and related frameworks, and the recent harmonisation of the GHG Protocol with the ISO 14060 family signals that activity-based, measured emissions data, not financial proxies, will define credible reporting (ESG Today, 2025). Activity-based accounting needs metered energy at the building level, sampled continuously, and reconciled against published grid emission factors. The second pressure is the state of the automation estate that should provide this data. Most large portfolios run a patchwork of building automation systems (BAS) from different manufacturers, each with its own controllers, protocols, and data model, installed building by building over many years (Gerhalter & Dahal, 2025). These systems were designed for supervisory control of plant, and they are competent at that. They were not designed to expose clean, harmonised, portfolio-wide measurement to analytics and reporting services, and in practice they do not (Himeur et al., 2022). The result is a structural gap. The industry has mature supervisory control and a growing catalogue of analytics techniques, but it lacks a widely validated software substrate that unifies measurement, modelling, intelligence, and reporting across a heterogeneous portfolio in the way an operating system unifies hardware and applications on a computer. The phrase Building Operating System (BOS) has appeared in vendor literature and in scattered academic work, yet there are few peer-reviewed reference architectures, and fewer still that are evaluated on real, portfolio-scale data from hot-arid climates, where the cooling-dominated load profile and the ESG reporting context differ materially from the European and East-Asian settings that dominate the literature (Khan et al., 2024; Gutierrez et al., 2025).

This paper addresses that gap. It treats the design of a BOS as a research problem and follows the design-science paradigm, in which a purposeful artifact is constructed and then evaluated against the problem it is meant to solve (Hevner et al., 2004; Peffers et al., 2007). The artifact is BuildOT One, a cloud-native BOS reference architecture and its production instantiation. The evaluation draws on six months of live operational telemetry from a managed real-estate portfolio in Dubai. The study is guided by three research questions. First, what layered architecture allows a single platform to ingest, model, and serve heterogeneous building telemetry across a multi-tenant portfolio while remaining independently scalable and governable (RQ1)? Second, can such a platform reliably convert raw, imperfect meter streams into verified energy, cooling, and environmental intelligence at portfolio scale, and what does that intelligence reveal about a hot-arid portfolio (RQ2)? Third, what data foundations are required before a platform of this kind can support defensible energy-savings attribution and ESG disclosure (RQ3)?

The contributions are threefold. We present a seven-layer BOS reference architecture with explicit design principles, an interoperability and semantic strategy, and a multi-tenant security and governance model, positioned against existing IoT-platform and next-generation BAS proposals. We report a six-month operational evaluation across sixty-eight buildings and four hundred and twenty-nine devices, including a register-difference measurement method that is robust to the meter resets, register overflow, and export truncation that occur in real deployments, and we use it to recover a cooling-driven seasonal signature and reading-weighted indoor-environmental-quality compliance for the portfolio. Finally, we make explicit the floor-area and pre-deployment baseline requirements that separate an operational-intelligence evaluation from a savings-attribution study, and we show how the platform's own anomaly surfacing supports data governance. This work extends the present author's earlier studies on the adoption of digitised facilities and on IoT-driven transformation of smart buildings, moving from questions of adoption toward the engineering and evaluation of the platform itself (Ahmad and Alshurideh, 2023; Ahmad and Alshurideh, 2025).

The remainder of the paper is organised as follows. Section 2 reviews related work across IoT platforms and next-generation BAS, cloud-native architecture for the built environment, digital twins and analytics, and energy and ESG intelligence in hot climates. Section 3 sets out the design-science method, the evaluation design, and the deployment context. Section 4 presents the BuildOT One reference architecture. Section 5 describes the production implementation. Section 6 reports the empirical evaluation. Section 7 discusses findings, generalisability, and limitations, and Section 8 concludes.

2. LITERATURE REVIEW AND RELATED WORK

2.1. IoT platforms and next-generation building management systems

The limitations of conventional BAS are well documented. Himeur et al. (2022) survey artificial-intelligence and big-data analytics for building automation and management and observe that, in practice, deployed systems ensure little beyond HVAC control, leaving performance evaluation, abnormal-consumption detection, and efficiency improvement to human operators. Minoli et al. (2017) set out early requirements and architectures for IoT-enabled smart buildings and argue that power-over-Ethernet and IP-based sensing can restructure in-building connectivity toward next-generation management systems. These works frame the opportunity but stop short of a portfolio-scale, multi-tenant software substrate. Subsequent platform studies have tended to be either campus-scale demonstrations or single-building testbeds. Ahmed et al. (2022) present an IoT platform for remote monitoring and control of smart buildings on an intelligent campus, and Marinakis and Doukas (2018) describe a web-based system for intelligent energy management that ingests heterogeneous and dynamic sources and issues rule-based action plans. Both validate components of the idea at limited scale.

A recurrent theme is interoperability. Open, standardised data models and API-first designs are repeatedly identified as the route out of vendor lock-in, allowing HVAC, lighting, metering, and access control from different manufacturers to be unified through protocols such as BACnet, Modbus, MQTT, and LoRaWAN (Gerhalter & Dahal, 2025). Semantic metadata schemes, notably the Brick schema, address the complementary problem of describing what each point means so that applications written once can be ported across buildings (Balaji

et al., 2018). The architecture proposed in this paper adopts an API-first, semantically described stance precisely because the evaluation portfolio is heterogeneous by construction.

2.2. Cloud-native and microservices architectures for the built environment

Outside the building domain, cloud-native engineering has converged on a small set of principles. Systems are decomposed into independently deployable services, packaged in containers, orchestrated for elastic scaling and failover, and integrated through API gateways and event streams, which together yield fault isolation, independent lifecycle management, and horizontal scalability as device fleets and data volumes grow (flove, 2025). These principles map naturally onto building telemetry, where ingestion, time-series storage, modelling, analytics, and presentation have very different scaling and availability profiles and should not be bound into a monolith. Modular middleware research for smart campuses has begun to apply the same ideas, using microservice decomposition to integrate heterogeneous IoT devices while balancing scalability, interoperability, and energy efficiency (Gutierrez et al., 2025). The contribution here is to specialise these general principles into a building-specific layering, with a digital-twin tier and an ESG-reporting tier that have no analogue in generic IoT-platform templates, and then to test the resulting architecture on real portfolio data.

2.3. Digital twins and analytics for building operations

Digital twins have moved from manufacturing into the built environment as a means of integrating traditional building technologies with building information modelling, IoT, mixed reality, and artificial intelligence to improve operation and maintenance (Ma et al., 2025). Twin-enabled analytics has proved especially valuable for anomaly detection. Lu et al. (2020) demonstrate digital-twin-enabled anomaly detection for built-asset monitoring in operation and maintenance, and a substantial body of work applies machine learning to fault detection and diagnosis in HVAC and chiller systems, with data-driven methods reviewed comprehensively by Mirnaghi and Haghighat (2020) and more recent fast-machine-learning and self-supervised approaches surveyed by subsequent authors (Mshragi & Petri, 2025; Das, 2025). Occupancy estimation and prediction form a parallel analytics strand that feeds demand-responsive control (Khan et al., 2024). The platform described here treats the twin as an architectural layer that hosts these analytics rather than as a standalone application, which lets a single live model serve energy, comfort, and ESG consumers at once.

2.4. Energy and ESG intelligence in hot-arid climates

The energy-efficiency literature for hot-arid buildings is rich on the demand side and thinner on the platform side. Reviews of energy-saving techniques for UAE buildings find that HVAC optimisation through variable-refrigerant-flow systems, adaptive setpoints, and artificial-intelligence-based controls can deliver twenty to forty percent reductions, envelope measures fifteen to forty-eight percent, rooftop photovoltaics up to forty percent reductions in grid dependence, and smart-building technologies, IoT sensing, twin-based prediction, and predictive maintenance, ten to thirty percent in operation (Almheiri et al., 2025). District cooling is positioned as the regional decarbonisation lever, with the UAE market valued at four million tons of cooling in 2024 and Dubai targeting forty percent district-cooling penetration by 2030 (MarkNtel, 2025). On the disclosure side, IoT-enabled measurement is increasingly recognised as the basis for trustworthy measurement, reporting, and verification, since continuous sensing raises the share of high-tier activity data and enables near-real-time anomaly detection in Scope 1 and Scope 2 inventories (Adewumi et al., 2026). What is largely missing is an integrated, validated software platform that connects the measurement substrate to both the energy-optimisation and the ESG-reporting use cases at portfolio scale, evaluated on real data from the region. The present study is positioned in that gap.

3. METHODOLOGY

3.1. Design-science research approach

The study follows design-science research (DSR), which seeks knowledge through the construction and evaluation of a purposeful artifact that addresses a recognised problem, and which is judged by the artifact's utility against that problem (Hevner et al., 2004). We adopt the six activities of the design-science research methodology of Peffers et al. (2007), mapped onto the development of BuildOT One. Problem identification and motivation correspond to the fragmentation, cooling-intensity, and disclosure pressures set out in Section 1. Definition of objectives corresponds to the three research questions and the design principles in Section 4.1. Design and development correspond to the seven-layer architecture and its production instantiation in Sections 4 and 5. Demonstration corresponds to the live multi-building deployment. Evaluation corresponds to the six-month operational analysis in Section 6. Communication corresponds to this paper. Treating the platform as a design artifact, rather than as a fixed product to be described, makes the architectural decisions and their evaluation criteria explicit and, in principle, transferable to other implementations.

3.2. Evaluation design and metrics

The evaluation is observational and conducted in the field, using telemetry generated by the platform during normal operation rather than in a controlled experiment. Four families of metric were defined in advance. Ingestion and coverage metrics characterise the platform as a measurement system, including the number of connected devices by stream, the number of monitored buildings and sites, the total volume of readings ingested, and the proportion of readings affected by data pathologies. Energy and resource metrics quantify monthly electrical, thermal (cooling), and on-site solar generation at building and portfolio level. Environmental metrics quantify indoor temperature, relative humidity, carbon dioxide, and particulate matter, together with compliance against reference comfort and air-quality bands. Data-quality metrics record the incidence and type of register anomalies, which double as evidence of the platform's anomaly-surfacing capability. Energy verification follows the spirit of the International Performance Measurement and Verification Protocol by

working from metered consumption rather than modelled estimates (EVO, 2016), although, as Section 6 makes clear, the present dataset supports operational characterisation rather than formal savings determination because it contains no pre-deployment baseline.

3.3. Deployment context and dataset

The deployment is a managed real-estate portfolio in Dubai operated under a single asset-management mandate, comprising mixed-use communities, retail and leisure destinations, hospitality assets, and staff-accommodation campuses. For the evaluation window of 1 January to 22 June 2026, the platform exported telemetry from five metering and sensing streams: electrical energy meters, thermal (British thermal unit, or BTU) cooling-energy meters, water meters, on-site solar generation meters, and multi-parameter indoor-air-quality sensors. The exported corpus comprised approximately seven million timestamped readings. Electrical, thermal, water, and solar meters report cumulative registers sampled at roughly fifteen-to-twenty-minute intervals, while air-quality sensors report instantaneous environmental values. Coverage by stream is summarised in Table 1. All site and building identifiers were retained internally for aggregation and are reported here at portfolio and anonymised-site granularity.

Table 1. Connected device fleet and coverage across the evaluation portfolio (1 Jan – 22 Jun 2026).

Telemetry stream	Devices	Sites	Quantity measured
Electrical energy	279	23	Cumulative active energy (kWh)
Water	88	23	Cumulative volume (L)
Indoor air quality	35	22	T, RH, CO ₂ , PM, TVOC, noise, light
Thermal / cooling (BTU)	15	7	Cumulative cooling energy (kWh)
On-site solar	12	2	Cumulative generation/export (kWh)
Total	429	25	68 buildings monitored

4. THE BUILDOT ONE REFERENCE ARCHITECTURE

4.1 Overview and design principles

BuildOT One is organised as seven layers, each owning a distinct concern and communicating with its neighbours through versioned interfaces. From the physical estate upward, these are the device and edge layer, the connectivity and ingestion layer, the time-series persistence and semantic layer, the digital-twin layer, the intelligence and analytics layer, the application and module layer, and a cross-cutting multi-tenancy, security, and governance layer that envelops the rest. The layering is not merely descriptive. It encodes five design principles that follow from the research questions. Separation of concerns allows each layer to scale and fail independently, so that a surge in ingestion does not degrade reporting and a model retraining job does not interrupt control. API-first and semantic interoperability ensure that heterogeneous equipment is normalised at the edge and described in a common vocabulary, so that an application written once runs across the portfolio. Multi-tenancy by construction isolates each asset owner's data and access while sharing the underlying platform. Measurement before control reflects a deliberate sequencing in which the platform first becomes a trustworthy system of record and only then closes control loops. Evidence-and-reversibility governs any autonomous action, which must be justified by data and be reversible, a principle that becomes central as agentic capabilities are added. Figure 1 summarises the layering.

Layer one is the physical and edge tier. The portfolio's metering and sensing estate, electrical, thermal, water, solar, and air-quality devices, connects through edge gateways that perform protocol translation, local buffering, and first-line normalisation. The platform is mid-transition from microcontroller-class nodes toward higher-capability edge gateways capable of on-device inference, which allows latency-sensitive logic and data-reduction to move closer to the source without changing the upstream contract. Layer two is connectivity and ingestion. Devices publish over MQTT and related protocols into a horizontally scalable ingestion service that validates, timestamps, and routes messages onto an internal event stream. Decoupling ingestion from storage in this way absorbs bursty device behaviour and isolates downstream services from device-side faults.

Layer three is persistence and semantics. High-resolution series are written to a purpose-built time-series store, while a semantic registry records what each point represents, the equipment it belongs to, and the building and site it serves, drawing on established building-metadata vocabularies (Balaji et al., 2018). This separation of raw signal from meaning is what allows portfolio-wide queries to be expressed once and answered consistently across vendors. Layer four is the digital twin, a live structural and behavioural model of each asset that binds incoming telemetry to equipment and space, and exposes a queryable representation to higher layers. The twin is the single point at which energy, comfort, and ESG consumers read a consistent state. Layer five is intelligence and analytics, a family of services for consumption profiling, fault and anomaly detection, forecasting, and comfort analysis that subscribe to the twin and to the event stream. Layer six is the application and module layer, where domain modules, energy management, air and indoor-environmental quality, sustainability and ESG intelligence, intelligent operations, and a reporting hub, are delivered to users through a backend-for-frontend pattern that tailors data to each interface without duplicating business logic. Layer seven, governance, runs through all of the above and is described in Section 4.3.

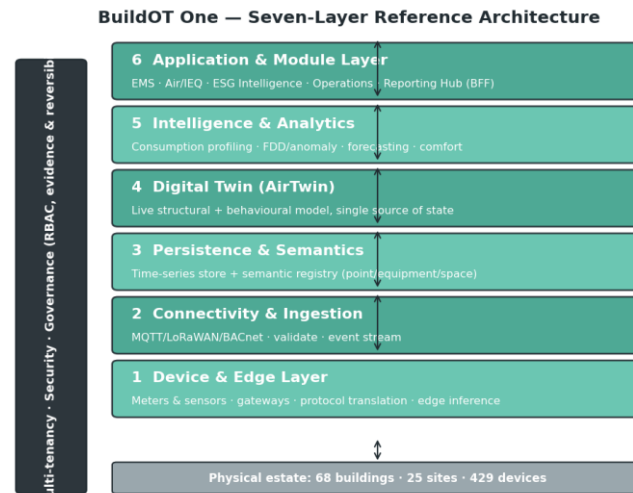


Figure 1. The seven-layer BuildOT One reference architecture. Each layer is independently deployable and communicates through versioned interfaces; governance is cross-cutting.

4.2. Data path and the semantic model

A reading's journey illustrates how the layers cooperate. An electrical meter publishes a cumulative active-energy value to its edge gateway, which normalises units and forwards the message over MQTT. The ingestion service validates and timestamps the message and places it on the event stream. The time-series store persists the raw series, while the semantic registry resolves the device to its parent equipment, building, and site. The twin updates its state, and any subscribed analytics, for example a consumption profiler or a register-anomaly detector, react. Because consumption is carried as a cumulative register rather than as an interval value, the platform computes usage as the difference between successive readings, a detail that turns out to be decisive for data quality and is treated formally in Section 6.1. The semantic registry is what makes the difference computable consistently across hundreds of heterogeneous meters, since it is the registry, not the device, that asserts the meaning and grouping of each point.

4.3. Multi-tenancy, security, and governance

Because the platform serves multiple asset owners from shared infrastructure, isolation is an architectural property rather than a configuration option. Every record is scoped to a tenant, and access is mediated by role-based controls evaluated on every request. An operational lesson learned during development, and reflected in the platform's test discipline, is that privileged developer or super-administrator credentials must never be treated as authoritative for tenant-scoped data, because they can mask isolation defects that only a genuine tenant session would expose. Verification therefore relies on real tenant-session fixtures rather than privileged bypasses. The governance layer also enforces the evidence-and-reversibility principle. Analytics may recommend, and increasingly may act, but actions are gated by data sufficiency and are designed to be reversible, with explicit stop conditions, so that autonomy never runs ahead of evidence. This stance positions the platform to add agentic operation safely, which we return to in Section 8.

5. PRODUCTION IMPLEMENTATION

BuildOT One is deployed as a cloud-native system. Services are containerised and orchestrated for elastic scaling and rolling deployment, ingestion and storage are separated as described above, and releases pass typecheck-gated continuous integration before promotion. The metering and sensing estate communicates over MQTT and related field protocols into the ingestion tier, and high-resolution telemetry is retained in a time-series store from which the analytics and reporting layers draw. The ESG and sustainability module aligns its calculations with recognised frameworks, including the GHG Protocol and the ISO 14060 family for inventory boundaries and accounting, and applies the local distribution utility's published emission factors to convert metered electricity into Scope 2 emissions, with measurement-and-verification logic informed by the International Performance Measurement and Verification Protocol (EVO, 2016; ESG Today, 2025). The application modules share the digital twin and semantic registry, so that an energy figure, a comfort statistic, and a carbon number are all derived from the same underlying state rather than from parallel, divergent pipelines. The evaluation in Section 6 was produced from the platform's own exported telemetry, which means the analysis exercises the same data path that the production modules consume.

6. EVALUATION

6.1. Measurement method and data-pipeline reliability

Electrical, thermal, water, and solar meters expose cumulative registers, so consumption over any interval is the increase in the register across that interval, not the sum of the reported values. Two real-world phenomena complicate this. Meters occasionally reset or roll over, which produces a spurious negative step, and some devices intermittently emit out-of-range values. A naive sum, or even a per-day maximum-minus-minimum, mishandles both. We therefore compute consumption per device per month as the sum of strictly positive

consecutive register differences, after discarding negative steps (resets) and steps that exceed a per-stream plausibility ceiling (gaps), and after rejecting individual readings whose absolute value is physically impossible. This order-independent method recovers true incremental consumption while neutralising resets and overflow. On the electrical stream, only 0.7 percent of consecutive steps were affected by resets or outliers, and on the thermal stream 0.8 percent, which places both among the high-confidence series. The method materially changes results. On a representative monthly file, a per-day maximum-minus-minimum estimate understated consumption by 8.8 percent relative to the positive-difference method, because whole reset-days were discarded rather than the single offending step. The data pipeline also encountered three pathologies that are worth reporting as findings in their own right, because surfacing them is part of what a measurement platform must do. First, three of the twelve solar inverters emitted register overflow values on the order of 1.1 billion from April onward; the absolute-value gate removed these before differencing, after which the affected inverters' registers read as continuous. Second, two monthly water exports were truncated at the spreadsheet engine's hard row limit of 1,048,575 rows, and the water registers proved non-monotonic on a large fraction of devices, so water is reported here for coverage only and is excluded from quantitative consumption claims pending register cleaning. Third, meter resets were present but rare on the energy streams. None of these are unusual in a live portfolio, and the platform's value lies partly in detecting them automatically rather than passing them silently into a carbon report.

6. 2. Electrical energy and the cooling-driven seasonal signature

Across the fifty-one buildings with electrical metering, the platform recorded 26.4 GWh of consumption over the evaluation window. The monthly portfolio profile, shown in Figure 2 and tabulated in Table 2, follows the signature expected of a cooling-dominated estate in a hot-arid climate. Demand falls to a winter minimum of 3.41 GWh in February, then rises steadily through spring to a peak of 5.25 GWh in May as ambient temperatures and cooling loads climb. June is shown for completeness but covers only twenty-two days. The thermal (cooling-energy) stream, drawn from the subset of sites instrumented with BTU meters, rises in parallel to a May peak of 8.31 GWh, reinforcing the interpretation that the electrical ramp is cooling-led rather than driven by a general increase in activity. This is consistent with regional evidence that cooling represents the dominant and most weather-sensitive component of building electricity demand in the UAE (Shanks & Nezamifar, 2013; Mohammed et al., 2024).

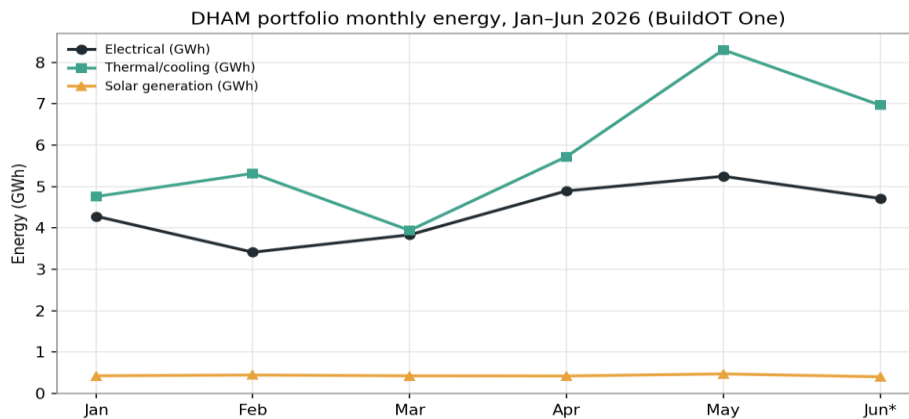


Figure 2. Portfolio monthly electrical, thermal (cooling), and on-site solar energy, January to June 2026. June covers 22 days. Electrical and thermal series rise together to a May peak, the cooling-driven signature of a hot-arid portfolio.

Table 2. Portfolio monthly energy by stream (GWh). June is a partial month (22 days).

Month	Electrical	Thermal/cooling	Solar generation
Jan	4.28	4.76	0.43
Feb	3.41	5.32	0.44
Mar	3.83	3.94	0.42
Apr	4.89	5.72	0.42
May	5.25	8.31	0.47
Jun*	4.71	6.97	0.40
6-mo total	26.4	35.0	2.59

Consumption is highly concentrated. The single largest asset, a retail-and-leisure destination, averaged 842 MWh per month and accounted for 5.05 GWh over the window, more than the next two sites combined. Figure 3 ranks the fifteen highest-consuming buildings. For portfolio operators this concentration is actionable, since efficiency and demand-management effort directed at a small number of high-intensity assets reaches a disproportionate share of total load. It also illustrates a

platform benefit that is easy to overlook, namely that ranking heterogeneous buildings on a common, verified basis is only possible because the semantic layer normalises every meter to a comparable quantity.

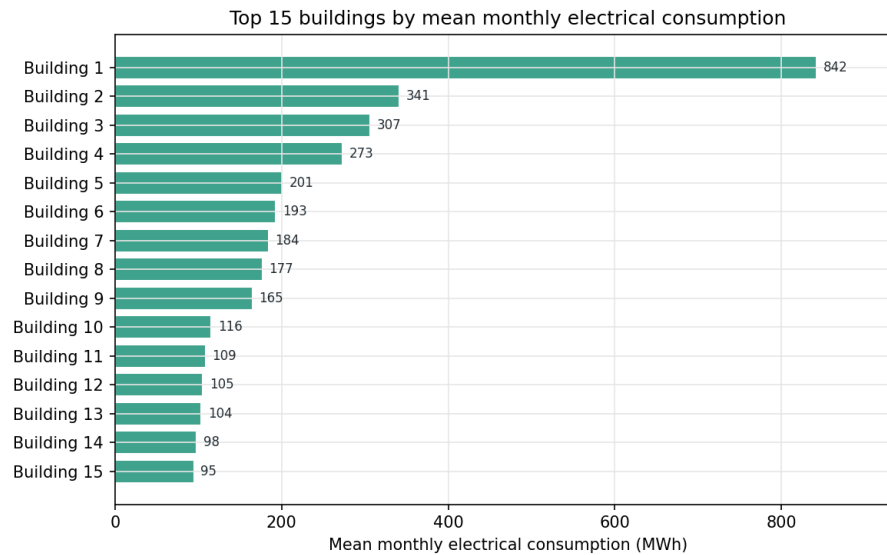


Figure 3. The fifteen highest-consuming buildings by mean monthly electrical demand. Consumption is concentrated in a small number of retail and mixed-use assets.

6. 3. On-site solar generation

Two sites are equipped with on-site solar generation, monitored by twelve meters. After the overflow correction described in Section 6.1, generation is stable at approximately 431 MWh per month, totalling 2.59 GWh over the window, with a mild upward tilt into the high-irradiance summer months. Relative to the portfolio's 26.4 GWh of metered electrical demand, on-site solar offsets a small but non-trivial fraction at the two equipped sites, and the platform's ability to meter generation and consumption on the same basis is what makes a self-consumption ratio computable. The episode also demonstrates why generation data cannot be taken at face value, since three inverters would have inflated reported generation by an order of magnitude had their overflow values entered the carbon accounts unchecked.

6. 4. Indoor environmental quality and compliance

Thirty-five multi-parameter sensors across twenty-two sites provide the indoor-environmental-quality (IEQ) record. Reading-weighted across the window, mean indoor temperature was 24.0 degrees Celsius, mean relative humidity 58.8 percent, mean carbon dioxide 519 parts per million, and mean fine particulate matter 11.8 micrograms per cubic metre. Compliance against reference bands is summarised in Figure 4. Carbon-dioxide compliance is excellent, with 99.2 percent of readings below 1000 parts per million, indicating that ventilation is generally adequate across the monitored spaces. Temperature compliance against a 20-to-26-degree band is high at 82.5 percent. Relative-humidity compliance against a 30-to-60-percent band is lower at 56.8 percent, with most exceedances on the high side, which is the expected and difficult signature of a humid coastal climate where latent load is hard to manage. Read together, these statistics show that the same platform that meters energy also provides a continuous, portfolio-wide governance record for occupant wellbeing, and that the principal IEQ challenge in this setting is humidity rather than ventilation or thermal control.

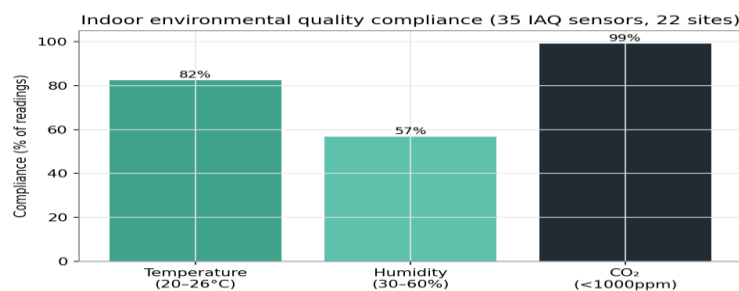


Figure 4. Reading-weighted indoor-environmental-quality compliance across 35 sensors on 22 sites. CO₂ compliance is near-universal; humidity is the binding constraint.

6.5. Implications for energy and ESG intelligence

The evaluation answers RQ2 in the affirmative. The platform converted approximately seven million imperfect readings into verified, portfolio-wide energy, cooling, solar, and environmental intelligence, recovered a physically coherent cooling-driven load signature, identified where consumption is concentrated, and produced a continuous IEQ compliance record, all from a single measurement substrate. For ESG reporting, the metered electrical series translates directly into Scope 2 emissions once multiplied by the distribution utility's published emission factors, and because the figures derive from activity data rather than financial proxies they meet the higher-tier expectation now embedded in harmonised GHG accounting (ESG Today, 2025; Adewumi et al., 2026). The same exercise exposes the boundary of what this dataset can support, which we treat as a finding rather than a caveat in Section 7.4.

7. FINDING AND DISCUSSION

7.1. Principal findings

Three findings stand out. First, a layered, cloud-native Building Operating System can serve as a single substrate for energy, cooling, solar, and environmental intelligence across a heterogeneous, multi-tenant portfolio, which addresses RQ1 not only as an architectural proposal but as a working instantiation evaluated on real data. Second, the dominant operational signal in a hot-arid commercial portfolio is cooling, and it is legible in both the electrical and the thermal streams, which confirms regional demand-side evidence at portfolio scale and from live operation rather than simulation. Third, data quality is not a preprocessing nuisance but a core platform function. Reset filtering, overflow rejection, and truncation detection were each necessary to produce defensible numbers, and a platform that surfaces these conditions is more valuable to an asset owner than one that hides them inside a clean-looking report.

7.2. Generalisability

The architecture is portfolio- and vendor-agnostic by design, since heterogeneity is normalised at the edge and meaning is asserted in the semantic layer rather than assumed from any one manufacturer. The seven-layer decomposition and the measurement method transfer directly to other portfolios and other climates. The empirical signatures are more context-specific. The cooling-led seasonality and the humidity-bound IEQ profile are characteristic of hot-arid coastal settings and would differ in heating-dominated or temperate climates, although the method for recovering whichever signature applies is unchanged. The concentration of consumption in a few high-intensity assets is likely to be common in mixed-use portfolios but should be verified case by case.

7.3. Practical implications

For operators, the results argue for sequencing investment by intensity, concentrating efficiency and demand-management effort on the small number of assets that dominate load, and for treating humidity control as the binding IEQ constraint in coastal hot-arid settings. For the disclosure function, the study shows that a single metering substrate can feed both operational optimisation and activity-based carbon accounting, which removes the common and costly duplication between an energy team's data and a sustainability team's data. For platform engineers, the data-quality findings are a reminder that ingestion robustness and anomaly surfacing deserve first-class design attention, not least because an unflagged overflow can corrupt a carbon report by an order of magnitude.

7.4. Limitations

Three limitations bound the claims and define the next steps. First, the dataset is six months of operational telemetry with no pre-deployment baseline for these specific buildings, so the study characterises what the platform measures and reveals rather than attributing a quantified saving to the platform itself. A defensible savings claim requires either historical pre-deployment consumption for the same assets or a controlled comparison, which is the natural subject of a follow-on study; separate single-site evidence of HVAC reductions on the order of twenty percent exists for the operator's portfolio and could anchor such work. Second, the export does not include gross floor areas, so energy-use-intensity normalisation in kilowatt-hours per square metre, the standard basis for cross-building comparison, could not be computed; absolute consumption is reported instead, and intensity benchmarking awaits floor-area data. Third, the water stream suffered export truncation and non-monotonic registers and is reported for coverage only. None of these limitations affects the architectural contribution or the electrical, thermal, solar, and IEQ results, and each defines a concrete data requirement for the next phase.

8. CONCLUSION AND FUTURE WORK

This paper presented BuildOT One, a cloud-native Building Operating System reference architecture, and evaluated it against six months of live telemetry from a sixty-eight-building portfolio in Dubai. The architectural contribution is a seven-layer, API-first, semantically described, multi-tenant decomposition that unifies measurement, modelling, intelligence, and reporting, and that was instantiated as a production platform rather than left as a proposal. The empirical contribution is a portfolio-scale demonstration that the platform converts roughly seven million imperfect readings into verified energy, cooling, solar, and environmental intelligence, recovering a cooling-driven seasonal load signature that peaks at 5.25 GWh of electrical demand in May, characterising on-site solar at approximately 431 MWh per month, and documenting near-universal carbon-dioxide compliance alongside a humidity-bound indoor-environmental-quality profile. A methodological contribution, the reset-and-overflow-robust register-difference method, proved necessary to obtain defensible figures and doubles as an anomaly-surfacing capability.

Future work follows directly from the limitations. Incorporating building floor areas will enable energy-use-intensity benchmarking and cross-portfolio comparison. Pairing the operational data with a pre-deployment baseline, or with a controlled comparison, will convert operational characterisation into formal savings attribution under the measurement-and-verification protocol. Remediating the water registers will extend the verified-consumption analysis to the water stream. Finally, the governance layer's evidence-and-reversibility principle positions the platform to add agentic operation, in which analytics not only recommend but act under explicit data-sufficiency gates and reversible, stop-gated control, which is the subject of ongoing development. Taken together, the results support the central claim that a layered, cloud-native Building Operating System can serve as a single, trustworthy intelligence substrate for energy, cooling, and ESG functions across a heterogeneous portfolio in a hot-arid climate.

Data availability

The operational telemetry analysed in this study was generated by a commercial deployment and is subject to the asset owner's confidentiality terms. Aggregated monthly figures sufficient to reproduce the reported analyses are available from the author on reasonable request.

Declaration of competing interest

One of the author is the founder of MachineSens IoT, which develops the BuildOT One platform described in this paper.

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