Integration of building science and data science to de-risk an affordable strategy for building decarbonisation

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ABSTRACT

The tools and technology today enable building owners to achieve very low energy consumption and healthy building performance without spending a premium in construction costs. Unacceptable levels of carbon emission, fuel poverty, inequitable indoor air quality, pandemics, and poor outdoor air quality demand that we change the way we look at buildings. Irrespective of motivation, high-performance buildings are rapidly becoming table stakes in the discussion of sustainability or sustainable development. Experienced building owners have determined that aligning the financial, social and environmental goals of sustainable buildings is best achieved by integrating building science and data science, using key components of the data infrastructure that are outlined in this paper. New buildings are easier than existing buildings to address, because envelope-first design strategies can be utilised to deliver high performance and legacy operational technology systems do not have to be mitigated. Existing buildings remain the challenge for most developers and building owners. The decarbonisation strategy outlined in this paper has been proven to cost-effectively address the contemporary demands on new and existing buildings.

Keywords: building science, data science, sustainability, building decarbonisation, zero carbon, smart building infrastructure, operational technology, independent data layer

BUILDING SCIENCE AND DATA SCIENCE OVERVIEW

Building science, for the purposes of this analysis, refers to the passive house methodology, which represents the highest-performing buildings based on building science before introducing renewables. The natural order of sustainability[1] is an envelope-first energy and indoor air quality methodology for new and existing buildings: passive first — active second — renewables last. The natural order of sustainability is an organic pathway to reach zero energy consumption and the

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healthiest of indoor environmental conditions. Building science is demonstrated using dynamic simulations from physics-based, whole-building sustainability modelling.

Data science enables smart buildings that use technology to assess and improve the performance of buildings. Data from operational technologies (OTs) provides building owners with greater control and a deeper understanding of space utilisation, energy consumption, security, environmental and maintenance needs. OTs are a category of computing and communication systems to manage, monitor and control building operations with a focus on the physical devices and processes they use.

Building science, in isolation, delivers high-performance buildings only at one point in time. Data science, in isolation, tracks building performance over time. The merging of building science and data science achieves and maintains high-performing buildings over the life of each building (see Figure 1). To merge building science and data science, we must standardise the real-time, time-series, independent data layer (IDL) and extract data from operational technologies in the most cost-effective, scalable and reliable manner possible. The physics-based sustainability model uses the time-series data from operational technologies for calibration. Once the model is operationalised, the IDL manages the dynamic time-series data from the model to inform decarbonisation master planning, monitoring-based commissioning, interrogation-based commissioning and testing of advanced data analytics prior to deployment.

Building owners today are standardising 'open integration' networks and controls in lieu of proprietary systems. This one move creates a single platform for all the OTs across the building(s), enabling easier and cheaper access to hourly building performance data. In this scenario, the minimum viable smart building infrastructure is an operational, whole-building performance model using primary source utility meters, indoor air quality sensors and a network controller for data aggregation.

BUILDING SCIENCE BEST PRACTICES

Building science models and simulates building designs to optimise the building

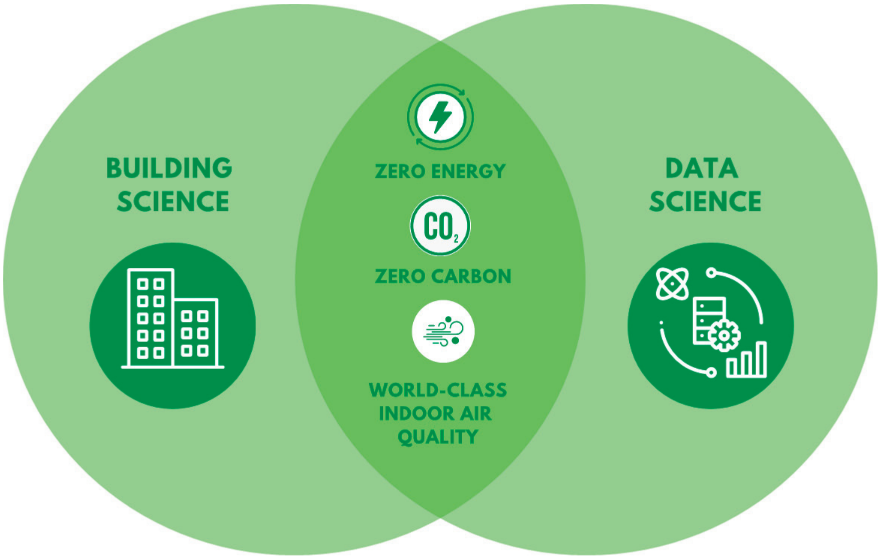


Figure 1 Building science and data science merge to achieve performance goals

envelope, reduce thermal energy waste and right-size equipment. These passive measures drastically reduce the need for active measures and make decarbonisation goals easier and cheaper to reach than many common construction methods of yesterday and today.

Energy benchmarks for the existing performance of buildings serve as points of contextual references with other similar buildings but do not define the pathway to building decarbonisation. Experience has shown that understanding how a building and its occupants use energy can lead to actions that save energy, whether it is a major building retrofit or merely turning off equipment and lights at the end of the day. Benchmarking with comparable buildings is useful for setting energy reduction targets. Energy consumption disclosure can be accomplished by using the following baseline analysis activities:

(1) Calculate operational carbon (CO_2e) metrics, completed through analysis of the historic utility utilisation, utility metering and/or energy audits;
(2) Calculate energy use intensity (EUI) benchmarks, including EUI-Site and EUI-Source calculations, completed through analysis of the historic utility utilisation, utility metering and/or energy audits;
(3) Enter buildings into Energy Star Portfolio Manager, the most common US energy benchmark system used today;
(4) Conduct building usage interviews to understand how the building is intended to function, also called current facility requirements (CFR). Select quality assurance testing to determine if the building is being used as intended and designed. Focusing on the desired end use is critically important to eliminating unnecessary energy wastes;
(5) Review the construction design documents including utility systems, as-built drawings and air balance reports;
(6) Review and survey renewable and alternative energy solutions;
(7) Conduct an audit of light levels and distribution, including light metering of existing spaces;
(8) Facilitate building envelope analysis, including whole-building air infiltration/exfiltration testing and infrared thermograph imaging audits;
(9) Begin to consider and discuss CO_2 equivalent (CO_2e) reduction goals. Goals should be performance-based, quantifiable, and include a timeframe.

Step 1: Identify your energy team

Assemble an integrated team of knowledgeable people with related project experience to cultivate a foundation of high-performance building knowledge and share energy conservation goals and concerns across disciplines. The energy team is the executive management team for the decarbonisation plan. The energy team engages project stakeholders and industry experts including owner, tenants, facilities management, maintenance personnel, service providers, designers, engineers and construction teams early in the planning process to facilitate the analysis and planning of building performance solutions. The energy team identifies and engages industry experts to align with and contribute to the sustainability project.

Achieving the goal of cost-effective, high-performance buildings relies on the contributions of the entire project team from pre-design through post-occupancy (see Figure 2). This holistic approach to energy conservation measures is essential, as existing buildings will require customised solutions to improve building performance.

Step 2: Identify opportunities

Create a comprehensive list of individual measures for potential energy optimisation consideration. It is important to prioritise purpose and application before specifying equipment, consider efficiency before

Figure 2 Building performance planning best practice

supply, select passive before active and prioritise simplicity over complexity.

Defining the optimal decarbonisation potential of buildings establishes the minimum level of energy required to implement all cutting-edge efficiency measures possible, given today's technology, not limited by financial, schedule, operational disruption, constructability constraints or other impediments. This defines the most optimistic boundary of performance that can be achieved by any new or existing building.

With that knowledge, the time is right to hold an innovation charrette. When scheduled early, this charrette brings together the energy team, project stakeholders and industry experts to brainstorm, discuss and converge on synergistic solutions. An innovation charrette assembles a diverse group of building experts to identify opportunities, barriers and solutions to pursuing the decarbonisation potential of any building.

Energy conservation measures are typically classified under the following categories:

- *Envelope*: Upgraded insulation and air infiltration prevention, moisture management, green and/or cool roof, optimum window-to-wall ratio, addition of high-efficiency windows and doors, including the use of tinting, sunshades and rain screens, passive thermal energy storage, active thermal storage and thermal mass;
- *Site*: Strategic placement of deciduous trees to permit winter sun and block summer sun. Natural and artificial shading for building walls to reduce heat load. Review of vertical hard surfaces, including proximity and materials, to mitigate heat-island effect near the building envelope. Analysis of wind patterns to maximise natural ventilation and renewable sources of energy, while negating buffering;
- *Heating, ventilation and air conditioning (HVAC)*: Replacement, alteration or elimination of mechanical equipment. Includes active and passive heating and cooling methods. Examples include natural ventilation, evaporative cooling, night venting and air purge, underfloor air distribution, increased ventilation rate, operable windows, energy recovery ventilation, high-efficiency HVAC, radiant floor heating, radiant cooling panels, ground source heat pumps, passive chilled beams, ice storage, heat recovery and economisers;
- *Lighting*: Replacement and/or alteration to the lighting system, including the incorporation of task lighting, lighting controls and daylighting. Examples include top lighting (skylights), side lighting (clerestory), high-performance glass, high-efficiency lighting, exterior window shading, interior window blinds, occupancy sensors and lighting controls:
  - *Daylighting*: A sub-set of lighting defined as an energy feature rather than

a view or aesthetic feature. Acceptable daylighting measures incorporate exterior and interior shading, light sensors and/or light tubes;

- *Controls*: Includes the addition of an energy monitoring system, building automation system, building management system (BMS), demand control ventilation, CO_2 sensors and/or lighting and occupancy controls;
- *Renewable energy generation*: Examples include solar photovoltaics (PV), active solar, passive solar, solar hot water heaters, district hot water, combined heat and power (CHP) cogeneration system, wind power, hydro power and energy storage;
- *Policy modifications*: Energy management policy, expand the allowable ranges for indoor temperature and humidity, and Energy Star certified office equipment and auxiliary appliances.

Step 3: Create scenarios

Using the knowledge gained thus far, the energy team will create bundles of measures that form various investment options for the decision makers. Preferential weight will be given to passive measures over active measures because of the operational carbon reduction. Once a comprehensive list of individual measures is identified, each measure will be analysed in relation to the project goals. Then the individual measures will be logically grouped and analysed for a compounded impact on the project goals. Experience has proven that combining individual energy optimisation measures is the most efficient method to optimise building performance.

First, bundled measures are evaluated by constructability groupings and building triggers for timing purposes. Timing is aligned with equipment replacement cycles, occupant disturbance, sequence of construction for thermal load reduction measures and equipment modifications and budgeting. A major end-of-life system and equipment replacement offers the opportunity to add energy improvements to make building(s) more efficient at minimal added cost. It is important to develop an implementation timeline that may be immediate or over several years.

Second, bundled measures are entered into energy performance models to analyse their impact on CO_2e. We develop a dynamic, hourly, whole-building energy model of the building to simulate annual energy performance, and to generate energy savings estimates for the energy efficiency measures generated during the analysis. The CO_2e simulation is generated using physics-based, dynamic energy modelling software with state-of-the-art energy simulation engine which allows detailed simulation of building envelope performance, complex building HVAC and process systems, daylight harvesting energy savings and passive heating, cooling and ventilation approaches. IES VE is recognised as the leading energy analysis package because of its broad range of capabilities and proven accuracy. eQuest and EnergyPlus have similar capabilities.

Subcomponent modelling and validation is performed as necessary to confirm systems and assemblies, including thermal bridge analysis, hygrothermal durability analysis and engineering building components like lighting and daylighting, and their relative impact on the building HVAC and lighting systems. The energy model findings aid in making informed choices to improve energy efficiency, reduce utility costs, upgrade infrastructure and reduce the environmental impact of the building serving to predict future building performance.

Third, bundled measures are evaluated by their financial impact. Using customised financial payback return on investment (ROI) models, the energy team will analyse the intersection of the financial tolerances of the owner with the planned CO_2e target of the design strategies. In short, the team needs to integrate CO_2e targets into a financial payback model. The total financial benefits of high-performance buildings should not, however, be judged based on initial and operational costs alone. A comprehensive triple bottom line and integrated bottom line analysis should include a review that captures social, health and financial benefits. The analysis will identify financially profitable niches which were missed when money alone was the driving factor. Today, high-performance construction is commonly viewed as an integrated bottom line investment.

Each bundled measure should be subjected to proper financial analysis, constructability analysis and cost estimates. Applying life cycle cost analysis (LCCA), which evaluates packages of related measures as opposed to individual measures, will illustrate the greatest possible energy and cost savings. LCCA examines bundles of efficiency measures in relation to 'business-as-usual', estimating capital cost savings from equipment downsizing.

Step 4: Create pathway to very low or zero carbon

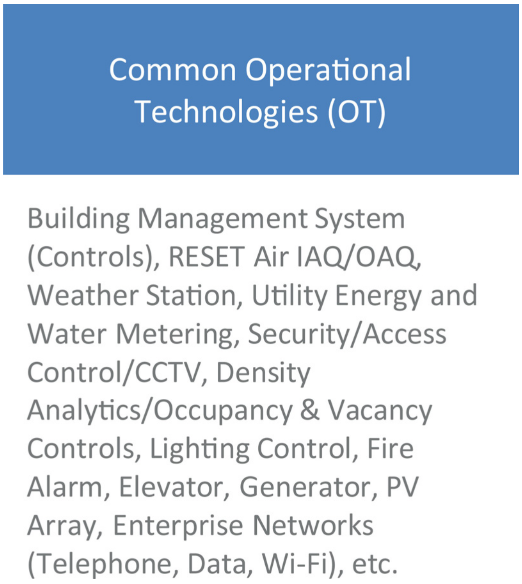
Zero operational carbon is achieved when a building generates as much energy as it consumes over the course of a year.

A significant reduction in energy consumption enables renewable energy the ability to power a greater percentage of a building's demand, resulting in smaller and more affordable renewable energy systems providing higher cost-benefit value. Similarly, the use of carbon offsets to reach zero carbon is also reduced using an efficiency-first approach to building decarbonisation. This plan places building owners within reach of achieving true zero carbon performance. A pathway to very low or even zero carbon is not necessarily a scenario that needs to be pursued on every project, but it is helpful to owners and developers to have a high-level plan that illustrates a future path to zero carbon.

DATA SCIENCE BEST PRACTICES

For building owners and developers to choose to invest in open-integration technologies, they must believe that they will get an appropriate return on investment or greater value in the capabilities from integrated operational technologies. In that regard, we find it helpful to break down smart building infrastructure into five critical components: operational technologies (see Figure 3), converged Internet of Things (IoT)/OT/IT networks, data aggregation, independent data layer and building intelligence layers.

Early innovators in each of these areas were pioneers in their fields. In many cases bringing a component solution to the market requires a multifaceted, platformed-based solution. To reach open integration, however, every component must be 'open' to enable the best providers to compete and integrate. Let us examine each component of smart building infrastructure (see Figure 4).



Common Operational Technologies (OT)

Building Management System (Controls), RESET Air IAQ/OAQ, Weather Station, Utility Energy and Water Metering, Security/Access Control/CCTV, Density Analytics/Occupancy & Vacancy Controls, Lighting Control, Fire Alarm, Elevator, Generator, PV Array, Enterprise Networks (Telephone, Data, Wi-Fi), etc.

Figure 3 Common OT technologies

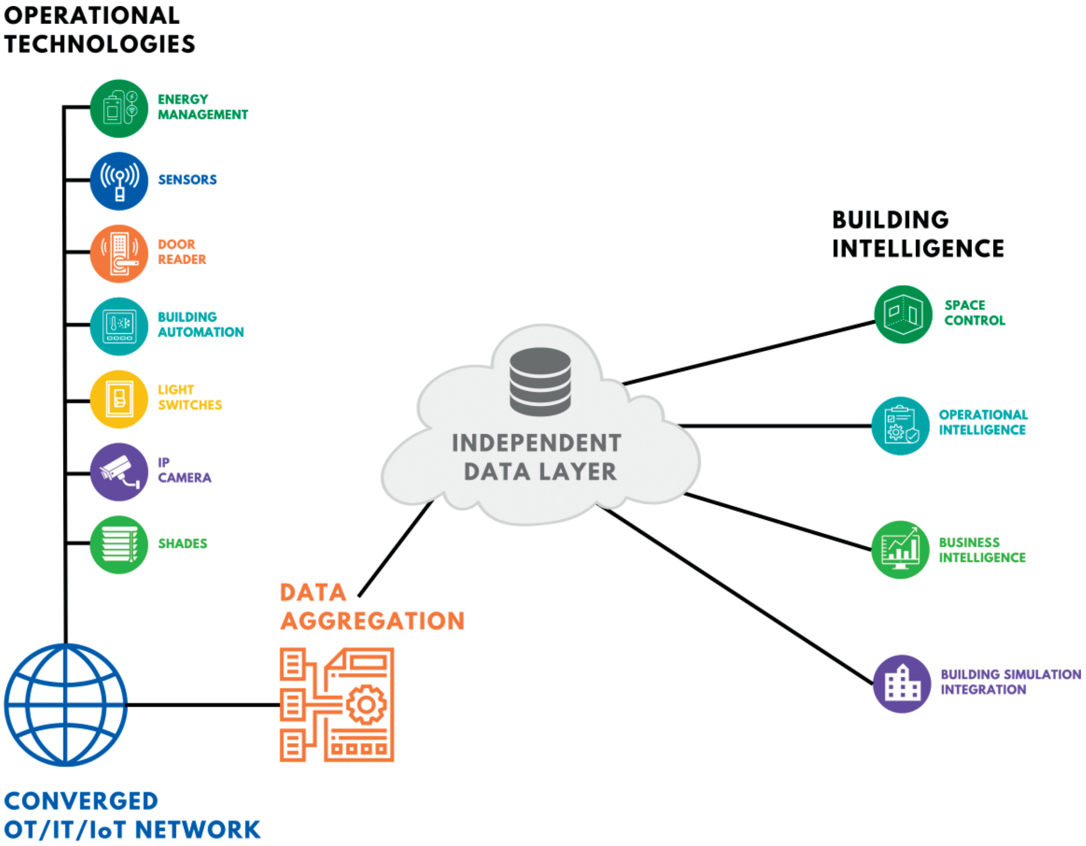


Figure 4 Democratising building data

ASSESS YOUR OPERATIONAL TECHNOLOGIES (OT) INVENTORY

The number of IoT meter and sensor devices grew 18 per cent in 2022 to 14.4bn globally, and it is estimated that there will be 27bn IoT devices by 2025. IoT meters and sensors are cost-effective tools to track building performance. The risk to building owners is that without careful planning and thoughtful consideration of network architecture, the addition of IoT devices may quickly become confusing, disconnected, expensive and inefficient.

Smart building infrastructure, including a properly designed OT network, permits the easy deployment of new IoT and the quick retirement of obsolete IoT. Remaining platform and network-neutral gives building owners control, transparency and ongoing access to all data to ensure they are never beholden to proprietary IoT solutions.

In addition to newer IoT technologies, traditional OT systems such as those listed in Figure 3 play a key part of the data story that is critical for operational insight. These systems typically rely on outdated communication architectures and protocols. They are often the bottleneck for data transparency due to disparate intersystem connectivity and proprietary data sourcing models. Modern smart building engineers purposefully design these systems to meet the demands of data transparency by leveraging Internet protocols (IP) to the edge, which allow software application programming interface (API) level integrations to the edge devices. This is a key architectural consideration to gain the most leverage from an independent data layer. By alleviating gateways, client-server architecture and old-style field bus technologies, IP-based hardware aggregates, communicates and integrates data at faster speeds, making it easier to exchange and leverage that data for decision making using operational analytics.

For high-performance buildings, the minimum required deployment of IoT/OT/IT includes a whole-building operational model, primary source digital utility meters, indoor air quality monitors and building automation systems–building management systems (BAS–BMS) integration. With this data integrated and overlayed for real-time comparisons, we can begin to key-in on operational inefficiencies and better understand assumptions that go into future energy models for design.

CONVERGE AND SECURE IOT/OT/IT NETWORKS

To deploy the IoT devices and integrated OT systems and gain access to the data from all the building technology systems, a converged OT network is necessary. What was accomplished in the past with separate vertical networks can now be accomplished with network virtualisation and software-defined networking. Each system can meet its own unique communications and security requirements and sub-systems are able to communicate with predetermined logical access routes. This topology can extend to the network security layer, allowing remote access to each individual system without exposing the remaining systems. This creates a layered security approach that also provides visibility to all systems and components for network management. This level of convergence, however, now makes the OT network a critical component of the building infrastructure, mandating a high degree of network security. Proper design, installation and ongoing operational management of this network has become the most critical requirement for OT teams.

DATA AGGREGATION

The data from IoT meters and sensors needs to be collected and processed and owners today expect to control their building data. The Niagara framework is one of the established tools that practitioners deploy to aggregate data in buildings with multiple integrated systems and IoT devices in the built environment. Its open API, open-distribution business model and open-protocol support provides the freedom to scale up and down with meters and sensors, as desired, in a building. The aggregation platform connects and controls devices while normalising, visualising and analysing data from nearly any building system or subsystem and can connect to other data sources via APIs, IP-based protocols or newer-to-market MQTT devices. The aggregation platform should be flexible and scalable to a single building or many buildings.

While other toolsets are available, one reason practitioners often favour Niagara is broad market availability, since it is supported by controls companies such as Distech, Johnson Controls (Facility Explorer), Honeywell (WEBs), Vykon and others. Ultimately any aggregation framework or tool will connect to a wide variety of systems, translate protocols into a common language and be interoperable with systems up and downstream.

INDEPENDENT DATA LAYER

Data is the key to controlling building operations. Real-time, time-series data in the built environment is managed by an integrated interface, commonly known as an independent data layer (IDL). It is important to note that the technology exists today, as described below, but you must know how to implement and specify the technology and interoperability.

Unfortunately, real-time time-series data management systems (DMS) are the most frequently overlooked part of smart building infrastructure. Most proprietary BAS–BMS systems: 1) store their data in 'on-premises' computers with no backup; 2) have limited security and access; and 3) overwrite historical data. Building owners incorrectly assume that one of the system vendors has control of their building data.

Owners often learn of their missing data when they target specific energy conservation measures. It is at that time when they discover that there are major shortcomings in their legacy, proprietary BAS–BMS systems, including gaps in historical data. Common BAS–BMS shortcomings include limited data archiving capabilities (time, granularity, flexibility), limited user-friendliness in accessing, visualising and sharing the data, limited enhancements to proprietary legacy systems and limited capabilities for integrating with other systems (ie power meters, HVAC equipment, lighting, security, fire alarm and so on).

With all OT data converged and normalised at the platform level, data is easily digestible and contextualised in the independent data layer. New visualisation tools, sourced from the independent data layer, can be deployed to meet different stakeholders' demands. For instance, the development of an IoT-based integrated sustainability dashboard requires a platform for interconnected devices.

A true independent data layer must deliver an open enterprise infrastructure to connect sensor-based data, systems and people. An IDL should collect, analyse, visualise and share large amounts of high-fidelity time-series real-time data from multiple sources and otherwise incompatible systems, formats and standards across all user groups. Most importantly, an IDL should ensure building owners and developers own, control and always have full access to their data. If an IDL is proprietary, in any way, the vendor should be required to provide building owners and developers an exit plan that details how owners will, at no additional cost, retain their data history, data model and structure, should an owner choose to move IDL services to another vendor.

Some organisations with large portfolios of buildings, such as universities, already use an IDL to manage data in plant operations. In those cases, leveraging the existing IDL system to accommodate building data is the most holistic and cost-effective step for those organisations. It should be noted, however, that innovation in the space of the IDL component of smart building infrastructure is moving rapidly, so it is important to keep an open mind. Watch the development of the world of digital twins and the evolution of the contemporary master systems integrator world with great interest. Today, we believe the best approach for organisations looking for data independence to construct a thoughtful request for proposal (RFP) is to find an approach to an IDL that reflects the data needs and expected use cases of their organisation. That will ensure each organisation finds the right balance between data management scope and costs.

ADVANCED DATA ANALYTIC LAYER CAPABILITIES

Data, to be usable, needs to be understood by everyone at first glance. Finding better context for data and displaying it for easy comprehension is our greatest challenge. We expect an effective dashboard to quickly demonstrate a building's performance, ideally, with the context to show if it is performing as it was invested in to perform. With the right context, visualisation becomes the cornerstone of measuring and verifying the performance of new or existing buildings (see Figure 5).

For example, monitoring-based commissioning services import, manage and interrogate real building performance data

KODE Labs HQ

KODE Labs Building

Building Simulation vs. Actual Performance

Meter

Site EUI	Source EUI	Total Costs	GHG Emissions
59.92	124.04	145,503	1,042.14

Simulation

Site EUI	Source EUI	Total Costs	GHG Emissions
82.49	180.02	231.8K	1,522.2

Invoice

Site EUI	Source EUI	Total Costs	GHG Emissions
64.51	125.46	183,160.7	1,045.65

Figure 5 Integrating building science and data science

against the whole-building energy model simulation data. Actual consumption data is compared to the simulation model to enhance building performance. Simulation profiles can be used to improve operational models or help close the performance gap by bringing design models closer to reality. Integrating building performance metrics with simulation metrics has additional benefits, as follows:

(1) Investigate the impact of retrofit options using real building data;
(2) Undertake post-occupancy evaluations;
(3) Improve operational models for performance contracting;
(4) Aid in delivering a seamless handoff from construction into building operation;
(5) Help close the performance gap by simulating designs closer to reality;
(6) Testing data analytics, such as fault detection and diagnostics, prior to deployment.

The visualisation interface is technically the easiest of all the elements to solve and has the most options, so owners and project teams are lured into making visualisation decisions first. Many building owners, however, assume incorrectly that when they choose their visualisation, they are also getting a database management system. The visualisation should be chosen last after the rest of the smart building infrastructure is established to ensure the visualisation delivers the necessary functionality.

The smart building data infrastructure solution we describe is not expensive. In fact, when comparing best-in-class components to proprietary solutions, the best-in-class components are typically less expensive and provide far greater value.

PORTFOLIO INFRASTRUCTURE

Enlighted building owners who deploy building science and data science strategies in their decarbonisation strategies can use this same process for groups of buildings. Connecting the independent data layer or integrated interface to multiple buildings is easily accomplished with many digital twins and geographic information systems (GIS) platforms. The results are automated and customised reports for each benchmarked property, which provide a building's energy performance ratings, CO_2e metrics, site and source EUI and annual energy costs. This industry standard for documenting building performance at a high level will allow the energy team members to rank the buildings and better understand how they compare.

Energy master planning for groups of buildings is accomplished in the same way we describe individual buildings. Community modelling is initiated through the generation of 3D models for the district building stock, which becomes the foundation to support future smart community activities including, but not limited to, individual building energy master planning, data storage and extraction and benchmarking through various project phases. Community modelling allows owners to investigate various project analytics (energy, daylight, solar radiation, PV potential, airflow, Leadership in Energy Environmental Design [LEED], climate, etc.) at a macro level and refine the detail to a micro perspective depending on the desired metrics.

Energy master planning for communities includes the creation of 3D massing model geometry for districts or groups of buildings. Once the model is built, building owners conduct advanced simulation studies for various analytics as prioritised and defined by the owner. This may include site blocking, building massing, preliminary solar array studies, PV potential, alternative energy system analysis, pedestrian/vehicle/mass transit transport studies, wind and ventilation calculations, district energy evaluations, water balance, CO_2e per district/zone, whole site energy consumption, etc. The independent data layer connects this data to advanced data analytic layers for the purposes of generating reports and visualising simulated and trended building performance data.

The unique value of the plan brings together a highly complementary system that provides the owner with a vast amount of real data and the ability to control their building(s) using that data.

Managing groups of buildings in this manner proves invaluable in creating and optimising energy management policy for portfolio-wide targets and timelines. An energy team can also implement a comprehensive strategic plan for organisation-wide renewable energy solutions.

Finally, an energy team with a comprehensive energy management policy backed up with documented CO_2e performance feeds the sustainable footprint management most building stakeholders are expecting today.

SUMMARY

If you find yourself choosing the visualisation before setting performance goals and/or discretely implementing individual components of smart building data infrastructure — stop. The risk you run is installing a dashboard that will never validate performance against goals or financial expectations. Design the smart building infrastructure platform and converged network first. Then develop an implementation plan that respects and integrates legacy systems. This is a holistic and cost-effective approach to evidence-based performance and building decarbonisation. It will ensure transparent access to data that will support and defend a lifetime of investment decisions for your building.

The convergence of global challenges requires building owners and project teams to look at buildings differently. Building performance is no longer an option. Performance is expected by owners, investors, occupants and governments. Merging building science and data science is the most cost-effective way to deliver expected building performance over the life of a building.

REFERENCE

(1) Auros Group, 'Natural Order of Sustainability', available at https://www.aurosgroup.com/post/natural-order-of-sustainability (accessed 11th November, 2022).