Visualising operational energy and emissions using S-curve trajectories – a prototype tool

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Abstract

The paper covers the initial development of a prototype visualisation tool designed to enable live projects to track emerging operational energy and emissions. Verified changes to rated power, run times and load factors are visualised relative to a default (worst case) trajectory derived from published building performance studies. The default trajectory follows the S-curve concept of over-promise and under-delivery (1). The tool aims to help practitioners identify key risk factors that could compromise building performance and mitigate these risks at different stages of procurement. The visualisation will link directly to the Operational Energy and Carbon (OpEC) workbook, the subject of a complementary Symposium paper by Field and Bunn (2). A prototype OpEC Visualisation will be presented at the Symposium.

Keywords Operational energy, S-curve, visualisation, Soft Landings

1.0 Introduction

To manage energy consumption you must be able to measure it. This is true of buildings in all stages of their lifecycles, not just in their operational phases. For new and retrofitted buildings an energy profile begins to emerge from the earliest days of modelling and design energy assessments. That profile – whether actively tracked by a project team or not – develops during procurement and construction as loads appear and as systems move from concept design to detailed design, and thence to installed products. The commissioning phase is where a building's subsequent operational energy profile becomes cemented, both in terms of the efficacy of installed systems, and any tendencies for wasteful or sub-optimal operation (4). Operational characteristics influenced by parasitic relationships (e.g. heating bringing on cooling, or vice versa) can also become locked-in unless such characteristics are quickly noticed and resolved.

Although opportunities to reduce wasteful operation arise in the Defects Liability Period (DLP), excessive energy consumption can go unnoticed and unresolved as a DLP team focuses on more fundamental failings (3). Left unchecked, energy wastefulness and high emissions can become chronic shortcomings. Risks are higher if professional designers are not retained in the early operational phase to help in post-defects fine-tuning, and in the absence of systematic post-occupancy evaluation.

Projects that adopt Soft Landings via the RIBA *Plan for Use* (5) or Government Soft Landings – GSL (6) are, theoretically, in a better position to reduce excessive operational energy and carbon dioxide emissions. However, Soft Landings interventions in the aftercare phases are unlikely to overcome ingrained failings that have occurred during design and construction. Arguably, project teams need greater visibility and appreciation of energy penalties at the points they are incurred (for example, through value engineering decisions that save capital cost at the expense of system efficiency) rather than only discover them when the building is switched on. At that point it may be too late to mitigate the operational energy consequences.

There are many powerful ways for project teams to understand the energy and carbon consequences of their decisions during project delivery. Dynamic simulation modelling (DSM) tools possess the capability to model the energy consequences of most technical choices. CIBSE *TM54 Evaluating Operational Energy Performance of Buildings at the Design Stage* (7) also equips design professionals with the necessary procedures to calculate likely operational energy outcomes. However, neither of these two approaches are a panacea.

For a start, compliance-based energy modelling based on simplified boundary conditions is somewhat different to scenario-based modelling. For the latter, simulation modellers rarely possess expertise in building performance analysis necessary for realistic and detailed modelling. If they are also detached and remote from the build team, then they will be poorly positioned to calculate diversities and orders of magnitude that typically drive operational energy consumption and emissions beyond the notional values generated for regulatory compliance or idealised performance models.

CIBSE *TM54* has its own shortcomings. While its procedures can be followed by most spreadsheet-conversant design professionals, its use tends to be the preserve of building services design engineers, not architects or project managers. Energy analysis is, by its nature, a specialist activity. As a consequence, *TM54* outputs are not necessarily in a form that can be easily assimilated by generalists in positions of authority, such as project managers, budget holders, and a multiplicity of client-side advisors. A *TM54* analysis may not be specifically budgeted for, but even if it is a contracted deliverable, a *TM54* analysis may not be on a project's critical path. Overall, therefore, energy modelling during project delivery does not get the continual high attention it deserves.

For these reasons, neither compliance nor simplified and isolated performance modelling *c*an prevent large rises in operational energy consumption caused by events that occur during the design and build phases. Some changes may be defensible (e.g. longer hours of use), while others may not (e.g. cost-cutting product substitution). Decades of evidence from building performance evaluations reveal that energy performance gaps between design expectation and building operation remain remarkably resilient to being closed (8).

Arguably a different approach is needed project stakeholders to engage with the operational energy and carbon consequences of their project decisions. The approach would require the ability to compute energy penalties as they emerge, quickly and fairly. A live project's energy trajectory should be visualisable in a form that non-specialists can understand and act upon, preferably at each key project gateway.

This paper describes a prototype approach in development that builds upon the S-curve trajectory theory first reported at the 2015 CIBSE Symposium and subsequently adopted by the CIBSE (1) and the RIBA (5) in professional guidance. A proof-of-concept tool, the Operational Energy and Carbon (OpEC) Visualisation, will be integrated with the *Operational Energy and Carbon Framework* (3) and the OpEC spreadsheet-based energy-tracking workbook (9).

2.0 The energy S-curve and its causes

The S-curve is a notional trajectory of operational energy consumption from design to operation. Its origins lie in 25 years of UK building performance evaluation (BPE) and post-occupancy evaluation (POE) studies. Published studies regularly show failures to achieve energy performance targets by between factors of 2 and 5 over design expectation, and in some extreme cases by factors greater than 10 (1-3). The frequency of higher consumption led to the coining of the term the 'performance gap' (10). The performance gap is generally taken to be the difference between design expectation of a building's performance and its operational outcomes. The gap is commonly quantified in energy use intensity and resultant carbon dioxide emissions, although it can also be expressed using other quantitative and qualitative metrics.

The simplistic definition of the performance gap has some problems. The first is that it lays the root cause of under-performance with design professionals, as they are the origin of the operational energy expectations. The subsequent influence of the build phase on outturn energy performance is rarely (if ever) considered, let alone measured. The same is true of client and contractor-inspired variations during procurement, and the energy effects of operational policies as they emerge. The second problem is a lack of agreement on the point of performance measurement. Some guidance recommends measurement after defects have been resolved, while others recommend measurement after one full year of operation, preferably with some provision for professional fine-tuning (11). RIBA guidance (5) recommends initial performance evaluation within the 12-month Defects Liability Period, before a building has been through its first heating and cooling seasons and while snags are still being resolved – a dubious proposition at best.

Irrespective of these differences in definition, there is a common tendency to over-promise and under-deliver on a range of performance metrics at points throughout the project delivery cycle. Figure 1 shows the notional trajectory of a project where declarations to do better than the requirements of *Part L* of the *Building Regulations* at the outset swing to excessive consumption when the building is occupied.

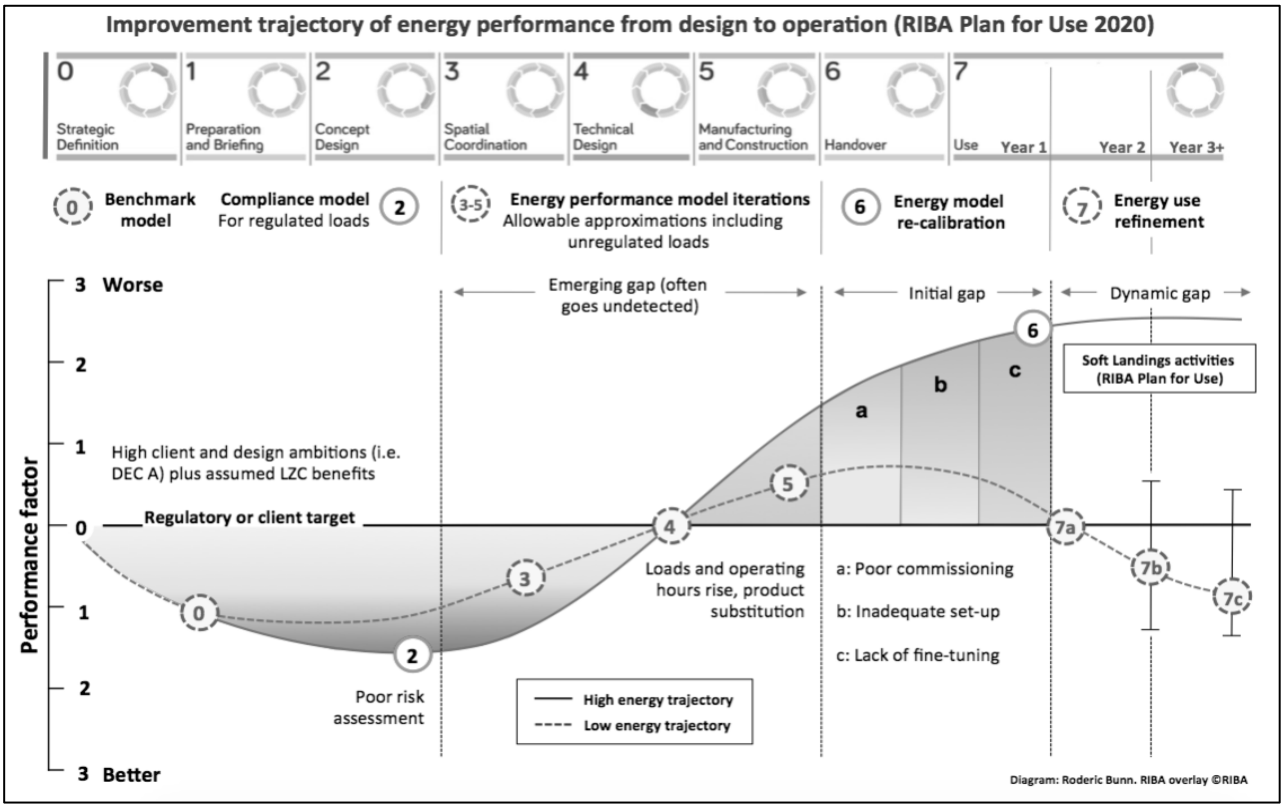

Figure 1 - The notional S-curve trajectory illustrating over-promise and under-delivery in energy terms across a project delivery programme illustrated by the 2020 RIBA *Plan of Work* and *Plan for Use* stages. The chart also shows a flatter (hashed) trajectory demonstrating how mitigation measures motivated by periodic reality-checking of outturn energy modelling in RIBA Stages 3-5 may reduce performance gap penalties, followed by Soft Landings improvement interventions to deal with unanticipated or unresolved energy wastage.

Other than mandatory BRUKL reporting and Energy Performance Certification, there is no statutory requirement nor a commercial imperative for project teams to track energy penalties during project delivery. There is no mechanism by which the deleterious effect of known contributors to under-performance, such as rushed, compressed or otherwise sub-standard commissioning, can be calculated. In the absence of continual energy modelling and sensitivity analysis mentioned earlier, a client and a project team could easily remain largely ignorant of impending energy penalties and their consequential emissions.

Figure 2 shows how the theoretical S-curve occurs in practice, based on conventional points of measurement. The data distribution illustrated, for a large school constructed in the last ten years, is typical of buildings suffering from an energy performance gap (1). Such analysis is often mired by Energy Performance Certification of questionable quality, and whether the contribution of non-regulated equipment loads has been included. As with Figure 1, little evidence is available for the contribution to the performance gap from decisions (or lack of them) in RIBA Stages 5 and 6, uplifts in energy use due to lack of sensitivity analysis, and reality-checking as the technical design turns into actual installed systems. Moreover, project teams may be ignorant of any performance penalties incurred from product substitution and budget-related changes to system specifications, and increases in energy demand from shortcomings in build quality and commissioning. Most project teams are blind to the consequences of these factors up until the moment their buildings are brought into operation.

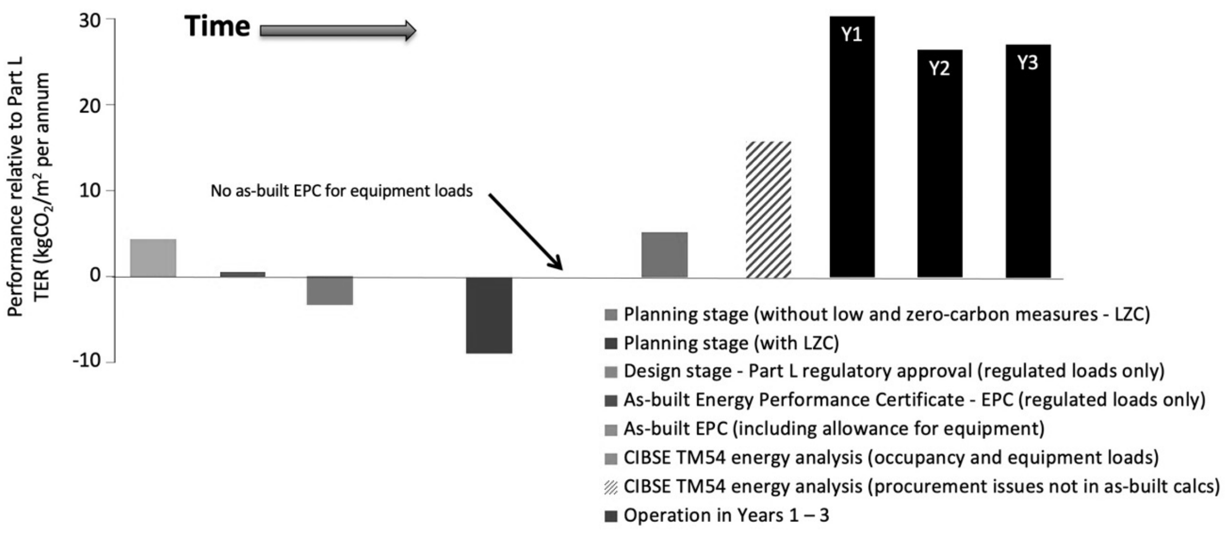

Figure 2 - The energy profiles of a large school from early design estimations to in-use performance, using the building's Target Emissions Rate (TER) calculation as a normalised parameter.

3.0 From S-curve theory to a practical tool

Initial research in 2013 laid the groundwork for a practical tool for tracking a project's operational energy trajectory, as reported at the 2015 CIBSE Symposium (1). Although the S-curve concept was subsequently refined and cited by CIBSE and RIBA guidance (5,12), research and development for a practical visualisation tool was placed in abeyance until such time as R&D funding could be obtained.

In 2021 funding was secured via the UK Construction Innovation Hub and the Centre for Digital Built Britain (CDBB) to develop a visualisation tool, primarily for use on Soft Landings and Government Soft Landings projects. Development was divided into two tranches of work:

3.1 Phase 1 (completed)

- Identification of energy and carbon data and information exchange points during project procurement and delivery consistent with public and private sector procurement plans, institutional plans of work, and supporting official and recommended guidance (3)

- Data and information exchanges for energy modelling at each RIBA *Plan of Work* and *Plan for Use* stage, for either modelling in spreadsheets or within a

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dynamic simulation model (DSM), or for both in parallel with data exchange between the two

- Publication of free-to-use guidance, the *Operational Energy and Carbon Reporting* (OpEC) *Framework* (3), geared to non-domestic projects adopting Soft Landings

- Creation of a free-to use spreadsheet OpEC Excel workbook to enable a user to track a project's emerging energy, carbon dioxide emissions and energy costs as loads emerge and change during project delivery and building operation (the subject of a complementary symposium paper (2) by Field and Bunn). The OpEC workbook saves iterations and auto-generates energy, carbon dioxide, and £kWh graphs at each iteration (9).

3.2 Phase 2 (November 2021 to April 2022)

- Create a prototype energy trajectory modelling tool, termed the OpEC Visualisation, designed to enable a project team to visualise a design's emerging energy performance against a pre-programmed default (high energy) trajectory generated from BPE and POE studies of offices and schools

- Identify the OpEC Visualisation factors for both building fabric and engineering services that contribute to energy penalties during project delivery, and devise uplift factors at each project gateway (notionally RIBA stage gateways) for *BS ISO 12655:2013* categories of energy end-uses (13) as well as vital project delivery factors (e.g. evidence of poor commissioning)

- Program the indicative OpEC Visualisation factors longitudinally as a default (i.e. business as usual) trajectory and visualise in a dashboard interface

- Programme the visualisation interface with data-input functionality for a live project trajectory. This will enable project teams to visualise emerging energy performance as a trajectory that tracks against the default (high energy) trajectory

- Create an example trajectory and OpEC Visualisation prototype suitable for testing operational energy projections for each RIBA Stage gateway.

The decision to base the OpEC Visualisation on RIBA work stages is due to the new post-occupancy RIBA Stage 7, supported by the post-completion duties published in the 2020 RIBA *Plan for Use*. The work stages are consistent with both Soft Landings and Government Soft Landings (GSL). Other work stage formats such as those defined by BSRIA *BG6:2018 Design Framework for Building Services* (14) could be programmed into the OpEC Visualisation if there was demand for it.

The key to both the high energy reference trajectory (termed the Default Trajectory) and a live project's emerging trajectory are the uplift factors applied to a building's energy-consuming systems. These need to be based upon or otherwise derived from quality-assured empirical data.

4.0 Programming the (high energy) default trajectory

The primary evidence for the shape and amplitude of the default energy trajectory will be derived from recorded BPE and POE data. Primary sources are the PROBE research project (1995-2001), the Carbon Trust's Low Carbon Buildings Accelerator (LCBA) and Low Carbon Buildings Performance (LCBP) programmes (2006-2011), and the BEIS/Innovate UK Building Performance Evaluation (BPE) programme (2011-2015) (8). Detailed datasets held by the Institute for Environmental Design and Engineering (IEDE) at UCL are also being used for trajectory programming, such as from the TOP project (Total Operational Performance of Low Carbon Buildings in China and the UK) (12).

BPE and POE data tends to vary greatly in quality, accuracy, and completeness. The relatively large database accessible to the researchers provided latitude to use the most valid and robust energy data. A selection of high-quality data is often more useful than large datasets. While superficially impressive, large datasets may be riddled with errors and estimations, and often lack explanatory contextual details. The focus on high-quality BPE and POE analyses enabled energy penalties to be more reliably associated with given events occurring during project design and delivery.

Most BPE studies of the last 20 years have focused on offices and schools. As these building types have both under regular construction for decades, sizable subsets of these buildings are often subject to publicly accessible post-occupancy evaluations. Although the S-curve trajectory visualisation tool will fit best to these typologies (in common with the 2021 *LETI Climate Emergency Design Guide* (15)), the proposed tool will remain broadly applicable to other building typologies.

Quantifying the effects of construction decisions and commissioning practices on operational energy is problematic. The consequences of any given action are inherently unpredictable, not least due to interrelationships between systems that can either multiply or suppress a particular energy outcome. Some factors may be context-specific, while others may be particularly sensitive to system complexity, and exhibit fragilities as a result. Commissioning plays a major part. Generally, simple standalone systems are more robust and easier to commission well – with lower risks to outturn energy performance – than interdependent complex ones. That said many performance problems can lie on a spectrum of mild to severe.

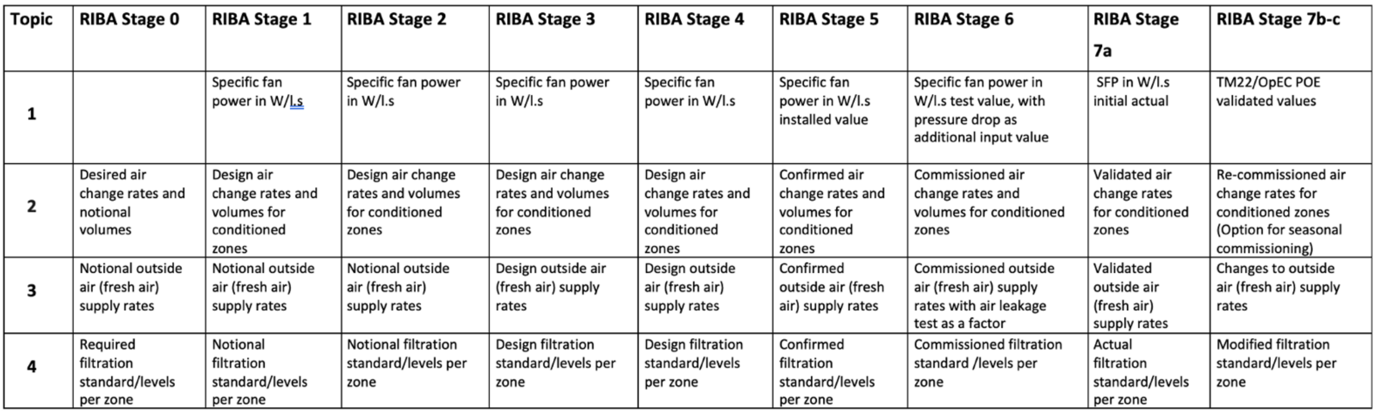
The authors were not the first to consider what energy penalty factors for inadequate commissioning and management might look like. In 2012 in preparation for the (subsequently aborted) Green Deal, draft modelling guidance was produced as a precursor to a Green Deal-tailored version of the SBEM calculation tool (iSBEM) (16, 17). The draft guidance for Green Deal assessments considered the application of management scores to energy consuming topics. The uplifts were based on quartile uplift factors (i.e. a best case factor of 1 and a worse case factor of 4), with a score applied depending on submitted evidence. Topics covered included HVAC system management skills, energy monitoring and targeting skills, and system maintenance policies and actions. The scores were intended to create an 'Actual' profile of a building compared with a 'Potentially Managed' profile – not dissimilar to the research concept of project trajectories and default trajectories.

A scaled approach to the calculation of energy performance penalties is therefore regarded as a defensible approach for the prototype OpEC visualisation, with uplifts applied to an emerging energy trajectory dependent upon the data and evidence supplied by the user (a project team). That said, performance gaps far greater than a factor of 4 over design declarations are not rare; many recent buildings have energy performance gaps in excess of that (Figure 2). However, the uplift factors applied to each energy-consuming item cannot be simply additive. The research team is therefore giving considerable thought to how scores for individual energy factors should be grouped, averaged, and weighted for their overall effect on operational energy (at any given project gateway). Furthermore, the team is carefully considering how individual factors (and groups of factors) should respond to mitigation actions.

As an example, Table 1 lists four key topics that influence specific fan power across the eight stages of the 2020 RIBA *Plan of Work.* The (notional) content in Table 1 defines topics that the users of the OpEC Visualisation will need to answer. Each answer must be accompanied by auditable sources of information and data for the user's input data answers to be validated and accepted by the visualisation system. The extent to which all requirements are satisfied determines the fraction of the uplift applied to the user's submitted values. If no verifiable evidence is provided, the visualisation records the input value but applies the full energy penalty uplift available at that stage, for that particular energy-consuming item or system. The uplift fraction can be up to, but cannot exceed, the relevant component value of the default energy trajectory.

The prototype OpEC Visualisation will initially be confined to four key questions per *BS ISO 12655:2013* energy end-uses, to represent ‘big wins’ and make the platform easy to use. These may expand with feedback and as the prototype develops into a practical tool.

Table 1 - Each energy consuming end-use in the OpEC Visualisation (defined by *ISO 12655* categories as used in CIBSE *TM54* and the *Operational Energy and Carbon Reporting Framework*) will have four questions requiring evidence as answers. The (notional) topics below cover specific fan power. Projects may not require detailed information at RIBA Stage 0.

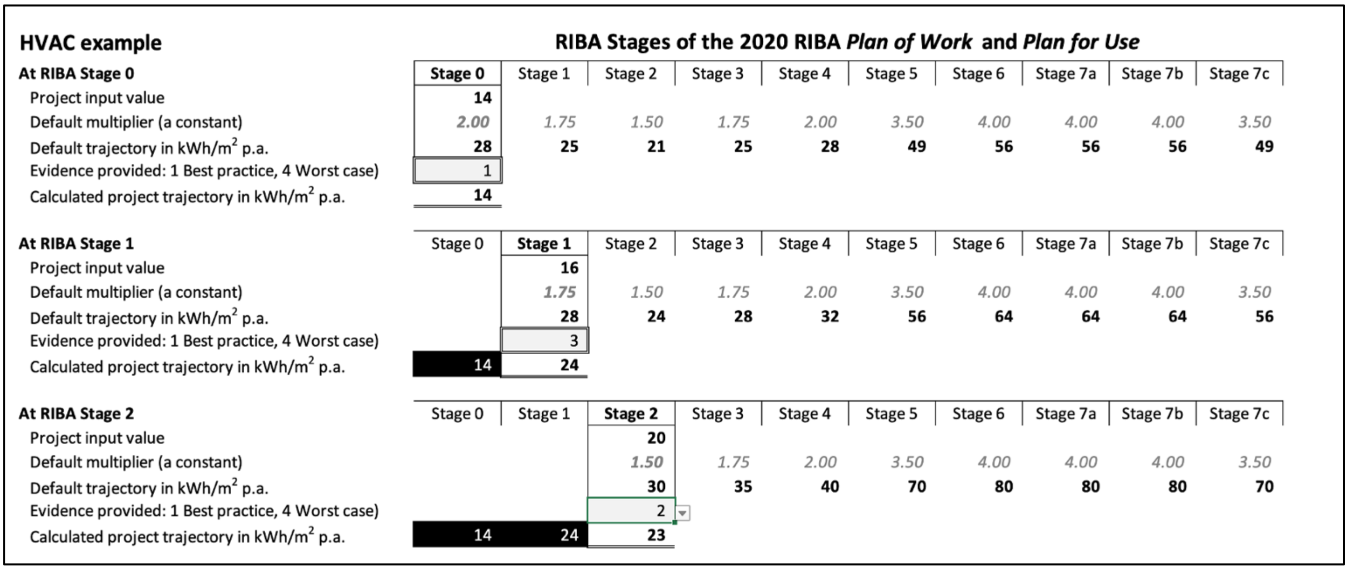


Topic	RIBA Stage 0	RIBA Stage 1	RIBA Stage 2	RIBA Stage 3	RIBA Stage 4	RIBA Stage 5	RIBA Stage 6	RIBA Stage 7a	RIBA Stage 7b-c
1		Specific fan power in W/l.s	Specific fan power in W/l.s	Specific fan power in W/l.s	Specific fan power in W/l.s	Specific fan power in W/l.s installed value	Specific fan power in W/l.s test value, with pressure drop as additional input value	SFP in W/l.s initial actual	TM22/OpEC POE validated values
2	Desired air change rates and notional volumes	Design air change rates and volumes for conditioned zones	Design air change rates and volumes for conditioned zones	Design air change rates and volumes for conditioned zones	Design air change rates and volumes for conditioned zones	Confirmed air change rates and volumes for conditioned zones	Commissioned air change rates and volumes for conditioned zones	Validated air change rates for conditioned zones	Re-commissioned air change rates for conditioned zones (Option for seasonal commissioning)
3	Notional outside air (fresh air) supply rates	Notional outside air (fresh air) supply rates	Notional outside air (fresh air) supply rates	Design outside air (fresh air) supply rates	Design outside air (fresh air) supply rates	Confirmed outside air (fresh air) supply rates	Commissioned outside air (fresh air) supply rates with air leakage test as a factor	Validated outside air (fresh air) supply rates	Changes to outside air (fresh air) supply rates
4	Required filtration standard/levels per zone	Notional filtration standard/levels per zone	Notional filtration standard/levels per zone	Design filtration standard/levels per zone	Design filtration standard/levels per zone	Confirmed filtration standard/levels per zone	Commissioned filtration standard /levels per zone	Actual filtration standard/levels per zone	Modified filtration standard/levels per zone

Figure 3 shows the theoretical application of energy penalties to generate a live project trajectory against the high-energy default trajectory. The attribution of an energy penalty to a given load (e.g. fans, lighting) depends on the submission of evidence for four key questions (as Table 1) to justify an initial project input value at each RIBA Stage. The answers can only be captured by the visualisation tool based on uploaded evidence. That evidence could be modelling reports, correspondence, or other documentation that possesses a given degree of technical validity and/or contractual worth. It is the ambition of the OpEC visualisation team that submitted evidence be logged (and therefore auditable) in a Building Information Model (BIM).

In the theoretical example, at Stage 0 a user’s input value of ‘18’ kWh/m^2 per annum is justified on submission of all evidence by fulfilling the requirements of Question 1. The project score is thus lower than the default trajectory score of 20, based on a pre-defined default energy multiplier operating at Stage 0. This value becomes locked-in. At subsequent RIBA Stages 1 and 2, evidence of a lower quality has been uploaded, resulting in a penalty multiplier value. A theoretical emerging trajectory for RIBA Stages 0 – 3 is shown in Figure 4 against the default (high) energy trajectory.

The live project trajectory is subjected to the same multiplier factors as the Default Trajectory. A project team that fails to adopt best practice engineering and construction delivery procedures would see their project trajectory rise progressively during RIBA Stages to track closer to the default trajectory, unless interventions are made to keep their trajectory down.



HVAC example

RIBA Stages of the 2020 RIBA *Plan of Work* and *Plan for Use*

At RIBA Stage 0	**Stage 0**	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7a	Stage 7b	Stage 7c
Project input value	**14**									
Default multiplier (a constant)	*2.00*	*1.75*	*1.50*	*1.75*	*2.00*	*3.50*	*4.00*	*4.00*	*4.00*	*3.50*
Default trajectory in kWh/m^2 p.a.	**28**	**25**	**21**	**25**	**28**	**49**	**56**	**56**	**56**	**49**
Evidence provided: 1 Best practice, 4 Worst case)	1									
Calculated project trajectory in kWh/m^2 p.a.	**14**									

At RIBA Stage 1	Stage 0	**Stage 1**	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7a	Stage 7b	Stage 7c
Project input value		**16**								
Default multiplier (a constant)		*1.75*	*1.50*	*1.75*	*2.00*	*3.50*	*4.00*	*4.00*	*4.00*	*3.50*
Default trajectory in kWh/m^2 p.a.		**28**	**24**	**28**	**32**	**56**	**64**	**64**	**64**	**56**
Evidence provided: 1 Best practice, 4 Worst case)		3								
Calculated project trajectory in kWh/m^2 p.a.	14	**24**								

At RIBA Stage 2	Stage 0	Stage 1	**Stage 2**	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7a	Stage 7b	Stage 7c
Project input value			**20**							
Default multiplier (a constant)			*1.50*	*1.75*	*2.00*	*3.50*	*4.00*	*4.00*	*4.00*	*3.50*
Default trajectory in kWh/m^2 p.a.			**30**	**35**	**40**	**70**	**80**	**80**	**80**	**70**
Evidence provided: 1 Best practice, 4 Worst case)			2							
Calculated project trajectory in kWh/m^2 p.a.	14	24	**23**							

Figure 3 - A theoretical application of energy penalties to generate a live project operational energy trajectory against the high (default) energy trajectory. Black boxes denote fixed entries at the RIBA gateway.

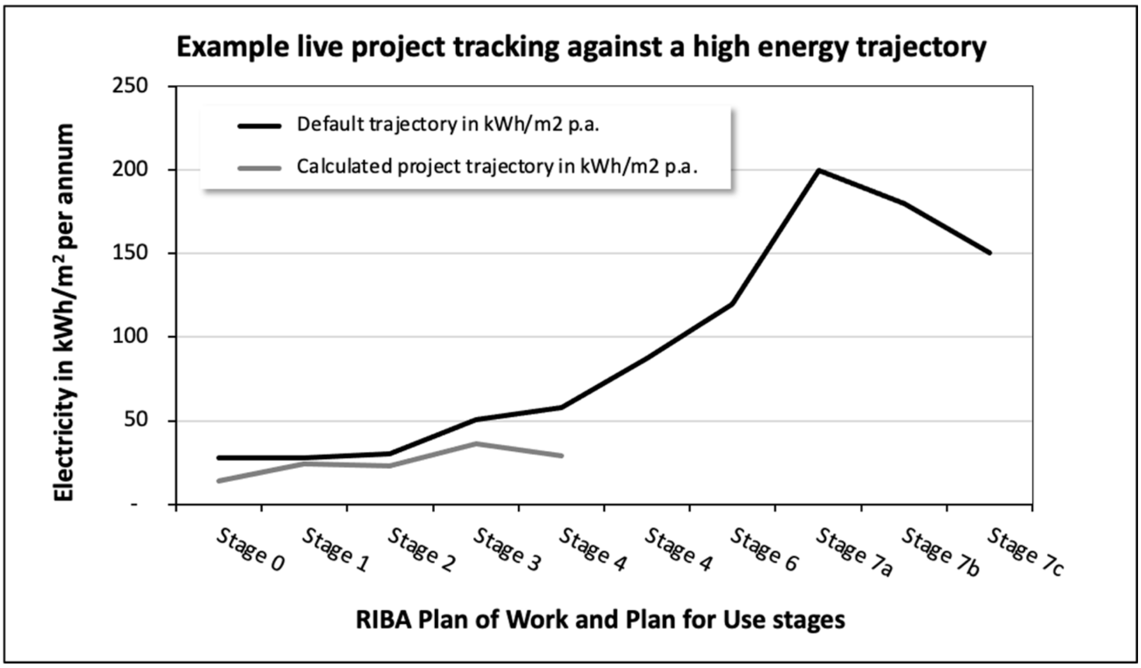
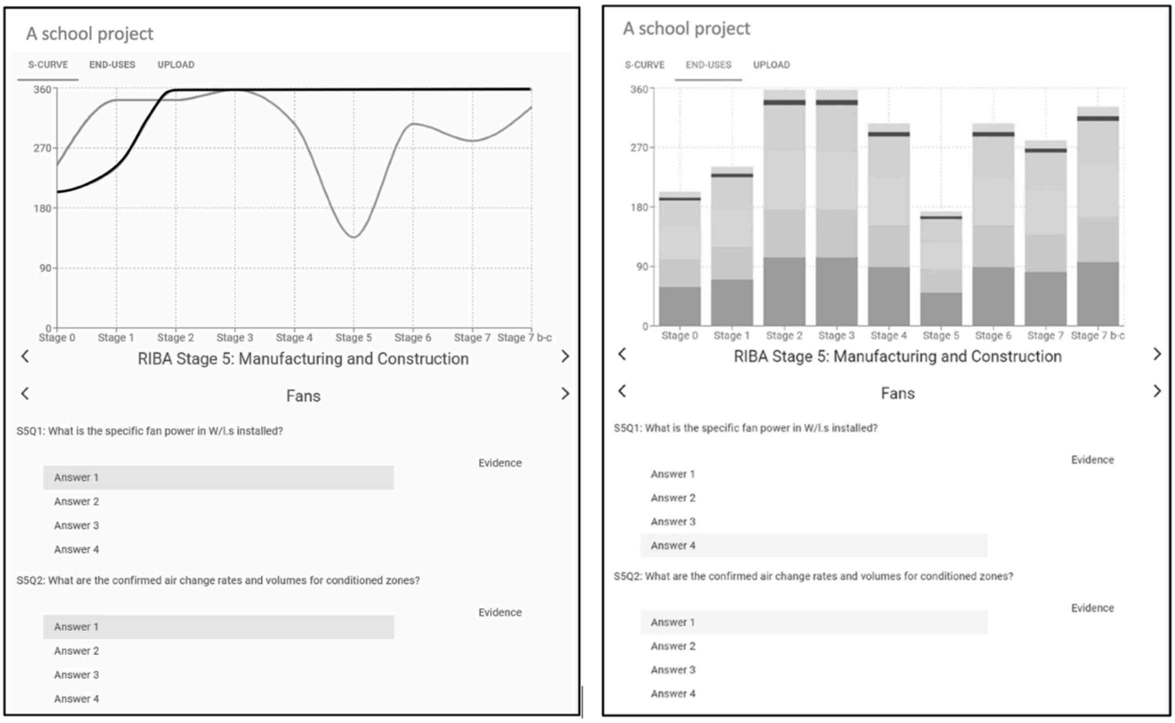


Figure 4 - An example of how responses on a live project generate a project trajectory could track against the default energy trajectory. The example shows electricity in kWh/m^2 per annum. The prototype visualisation will possess the functionality to toggle between electricity, fossil fuel, 'all fuels' and emissions in kgCO$_2$/m^2 per annum.

The Default Trajectory is a summation of individual system trajectories (e.g. fan power, lighting, heating and cooling) plus process factors (notably commissioning) that are known to contribute to outturn performance gaps. It is a time-based curve based on a set of typical overshoots for a given building typology, grounded in research evidence. The OpEC Visualisation will depict a single default (high energy) trajectory that consolidates all individual system and process influences on the operational energy consumption.

The values that make up the Default Trajectory, and the weightings applied to any particular energy end-use, are not data with a high degree of accuracy; rather they are realistic estimations based on empirical evidence from building performance evaluations. The primary purpose of the OpEC Visualisation is not precision energy modelling, but a way of motivating project teams to do better at each RIBA stage and to make improvement interventions they might otherwise avoid. In this way the OpEC Visualisation aims to be less of a modelling tool and much more a behaviour-change mechanism whereby people are encouraged to manage performance risks rather than ignore them. The tool and its underlying algorithms, however, will be developed with the capability to mine the data collated from projects using the tool and thereby progressively help to improve the accuracy of the uplift factors.



RIBA Stage 5: Manufacturing and Construction

Fans

S5Q1: What is the specific fan power in W/l.s installed?

- Answer 1
- Answer 2
- Answer 3
- Answer 4

S5Q2: What are the confirmed air change rates and volumes for conditioned zones?

- Answer 1
- Answer 2
- Answer 3
- Answer 4

RIBA Stage 5: Manufacturing and Construction

Fans

S5Q1: What is the specific fan power in W/l.s installed?

- Answer 1
- Answer 2
- Answer 3
- Answer 4

S5Q2: What are the confirmed air change rates and volumes for conditioned zones?

- Answer 1
- Answer 2
- Answer 3
- Answer 4

Figures 5a and 5b - The prototype OpEC Visualisation in development (December 2021). Users will be able to toggle between line trajectories and energy breakdown histograms. The former is easier for non-specialists to analyse.

5.0 Next steps

At the beginning of 2022, research work focused on the energy penalties of individual energy end-uses, identifying the influences on energy penalties, and determining how combinations may accentuate or supresses energy losses. While the research team has a lot of useful empirical data and engineering judgement will play an important role, some interaction effects will need to be modelled, particularly as the OpEC Visualisation migrates from proof-of-concept to a usable tool.

The project team is adopting a simplified approach: devise factors for a number of questions, give them equal weighting, and determine the scaling factors for each energy end-use at each RIBA Stage gateway. Ultimately the full extent of the energy performance gap will be characterised for the trajectories in Figure 1. The project will progressively improve its calibration, moving from engineering judgement, through modelling, and finally using feedback from to real-world data.

6.0 Conclusions

The development of the OpEC Visualisation prototype comes at a time when clients and project teams are grappling with delivering the next generation of buildings (net zero). Although the climate change imperative is deeply concerning, its virtue is that everyone in the project team – from client down to sub-contractors – are increasingly being forced to focus on the same objectives. There are fewer excuses for not paying attention to aspects of construction that compromise intended standards of energy efficiency and contribute to sustaining performance gaps. The OpEC Visualisation intends to provide additional leverage to ensure performance risks are made visible and properly dealt with before the failings become embedded and potentially insoluble after handover.

The project team is aware of potential pitfalls. The means of data entry does not make an OpEC Visualisation immune from gaming, whereby a user could play around with input answers to generate the best score before locking-in the values at a given project stage gateway. In this respect the OpEC Visualisation will offer no greater security than that offered by commercial environmental rating schemes, where users tactically trade-off credit opportunities against each other. Its advantages, however, include a longitudinal approach to building performance and its evolving nature at in key gateways of project delivery, and a transparent and visualised approach to managing emerging operational energy risks.

Note that the tool will be designed for use by project teams rather than for building managers. As such it will be defined by the scope of the RIBA *Plan for Use*, which includes a three-year post-completion Soft Landings phase (RIBA Stage 7a-c). However, it is appreciated that many performance changes occur outside of this framework. Facilities teams may make changes to a building that may not follow the original design intent. This can lead to energy performance penalties. For example, night-cooling strategies in naturally ventilated buildings may be forgotten or misunderstood, and consequently abandoned. This may motivate recourse to mechanical ventilation and consequential fan energy penalties that did not previously exist.

Although the visualisation tool as intended is not designed to cope with post-handover alterations, the OpEC workbook that underpins the OpEC visualisation could easily be used to demonstrate to a client/property manager the penalties that may occur if energy-saving features are abandoned. A project team cannot, in practice, do much more than raise awareness. They cannot control for what happens once they have left site for good. However, they can be held responsible for making systems and controls strategies clear, inherently robust, and simple to operate.

It will be vital to keep the OpEC Visualisation tool agile and usable as a project moves through the RIBA Stages. More elements will need calculating for their effects on outturn energy performance. The number of performance-critical factors will increase as concepts move into detailed design and finally into installed systems. The trick is keeping input data manageable. Live projects cannot be overwhelmed with factor analysis in a misguided attempt to either measure everything, and/or to measure things in minute detail. It must be borne in mind that the ultimate purpose of the OPEC visualisation tool is not to be numerically accurate at a high level of resolution, but to motivate project teams to stay on a low energy trajectory – and provide auditable proof to justify a project's position on its trajectory.

In terms of being motivational, it may be advantageous to add an optional third curve to the OpEC Visualisation: that of a theoretical best-case project curve indicating to a project team where they could be if they made the right decisions and interventions. A toggle for a best-case trajectory could both taunt and inspire a project team to show what they could do if they tried. However, the primary purpose of the OpEC Visualisation Default Trajectory is to serve as a warning to clients and their advisors to constantly question the rationale and evidence for claims of best practice energy performance, given that they do not want a nasty surprise when the building comes into operation. It is not unreasonable to suppose that clients could include contractual penalty clauses for falsifying or otherwise over-promising the performance values. Equally they could offer incentives to motivate honest data inputs.

In due course the project team intend to refine the source data to improve the accuracy of the visualisation equations. That source data may derive from post-occupancy evaluation data conducted during Soft Landings, and from the POEs conducted on public sector Government Soft Landings (GSL) projects (e.g. school new build and refurbishments). Government capital expenditure programmes that are mandated to adopt GSL will be primary users of the prototype OpEC Visualisation. The project is liaising with government departments via the host of GSL: the Centre for Digital Built Britain (CDBB).

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