CLOSING THE GAP BETWEEN DESIGN AND REALITY OF BUILDING ENERGY PERFORMANCE

Final Industry Report, SBEnrc ARC Hub Project

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Preface

The Sustainable Built Environment National Research Centre (SBEnrc), the successor to Australia's Cooperative Research Centre (CRC) for Construction Innovation, is committed to making a leading contribution to innovation across the Australian built environment industry. We are dedicated to working collaboratively with industry and government to develop and apply practical research outcomes that improve industry practice and enhance our nation's competitiveness.

We encourage you to draw on the results of this applied research to deliver tangible outcomes for your operations. By working together, we can transform our industry through enhanced and sustainable business processes, environmental performance and productivity.

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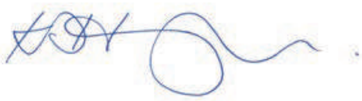

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Executive summary

The urgent need for energy conservation and greenhouse gas emission reduction in the building sector has been recognised at the highest levels of governments around the world and has led to the introduction of various strategies to deliver higher performance buildings. However, in most cases, buildings do not perform operationally at the level as intended and consume as much as three times the predicted energy consumption. This mismatch between the design and reality of energy performance is known as the "Building Energy Performance Gap" (BEPG). This research aimed to identify the root causes of BEPG in commercial buildings in Australia and develop strategies to close the gap, based on extensive literature reviews, interviews with experienced professionals and in-depth case studies.

The factors which drive BEPG can be found across the building life-cycle. During design, these factors include inaccurate design assumptions, poor design and uncertainties in simulation tools. During construction, these factors include value engineering, poor construction quality and materials, time pressure and incomplete commissioning. Other factors arise during building operation due to inefficient control of services, the inadequate knowledge and skills of facilities managers, degradation of system efficiency, complex occupant behaviours and extreme outdoor conditions. The lack of communication between stakeholders and the lack of accountability during the building life-cycle also contributes significantly to BEPG.

Based on the interviews of 28 experienced professionals and two case studies, two strategic frameworks have been developed to address the BEPG as shown in Figure 1.

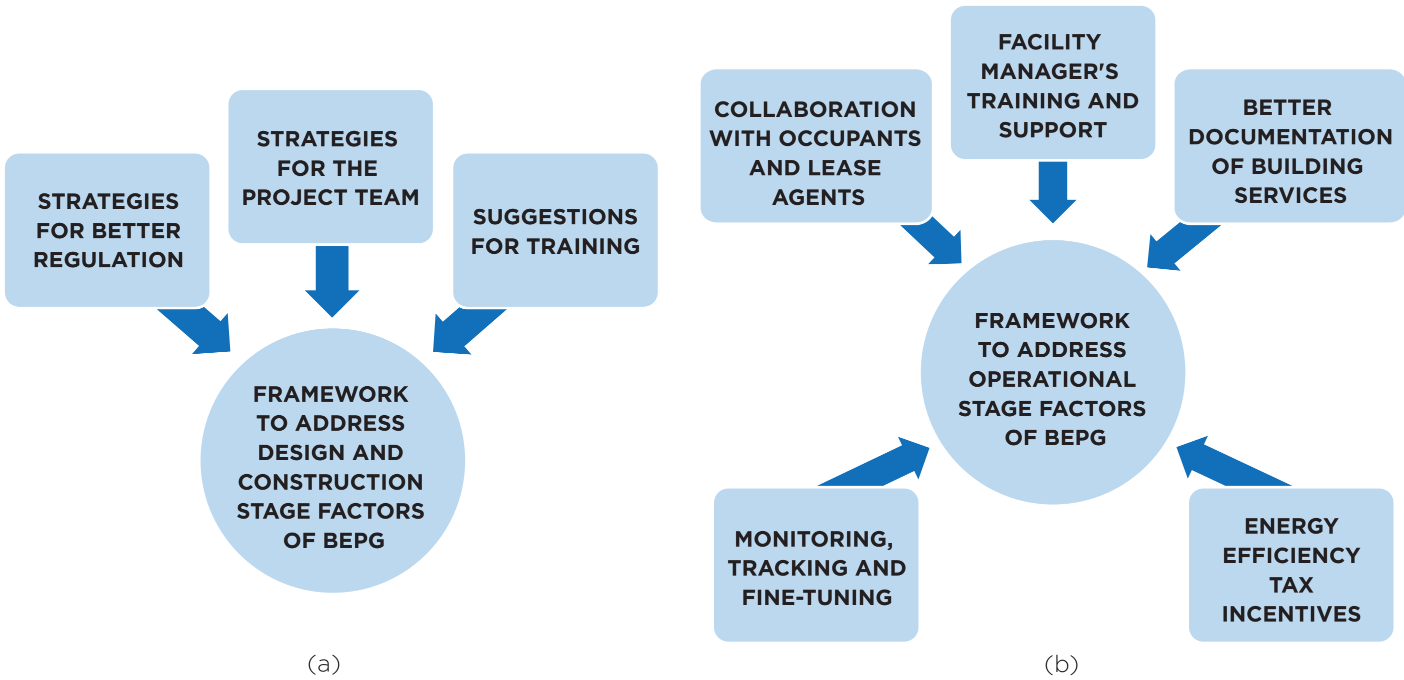

Figure 1 Framework of strategies to address (a) Design and Construction, and (b) Operational Stage factors of BEPG

The Design and Construction Stage framework has three contributing categories. Strategies for better regulation are focused on fostering more accountability in the industry. Strategies for the project team are directed towards enhancing industry practices to ensure effective communication among various stakeholders, as well as towards minimising the inaccuracy of energy models. Suggestions for training are aimed at educating the industry and upskilling designers, contractors, sub-contractors, tradespeople and other members involved in building projects. The Operational Stage framework looked at measures and strategies to prevent or overcome the gap in the post-occupancy period and had five contributing categories: 1) Monitoring, tracking and fine-tuning; 2) Collaborating with occupants; 3) Facility managers' training and support; 4) Documentation; and 5) Energy efficiency tax incentives.

Recommendations to close building energy performance gap

1) Implement the developed BEPG frameworks to address and mitigate those factors contributing to BEPG across the building life-cycle.

2) Adopt a "soft-landing extended aftercare" approach to ensure that the building is operating as designed. Building monitoring and tuning through effective collaboration between energy-related stakeholders (i.e. designers, main contractors, owners, facilities managers and sub-contractors) can significantly reduce BEPG.

3) Incentivise building owners need to champion and lead post-occupancy building monitoring and tuning activities. Inclusion of the as-built energy efficiency target as a condition in the funding agreement could help drive this.

4) Develop a mechanism to incentivise all stakeholders involved in monitoring and tuning activities.

5) Ensure seamless knowledge transfer between all stakeholders during monitoring and tuning activities.

6) Use a calibrated building energy simulation model to identify any sources of performance gap in building services operation and inform the facilities manager about the optimum operating conditions.

7) Use Total Facility Management (TFM) approach. TFM could be an integrated service, aggregating all services linked to the operation, provided to the owner for a fixed fee. It could also include a variable portion based on customer satisfaction or a percentage of the revenue from leases, in order to incentivise the service provider to drive the building not only towards energy efficiency targets but also occupants' comfort and productivity. The innovative shift would be from the current "action-based" contract to a performance-based contract.

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1 Introduction

1.1 INDUSTRY CHALLENGES

Buildings account for 32% of total global energy use and 19% of energy-related greenhouse gas (GHG) emissions making this sector the largest users of energy and sources of emissions. Due to population growth, growing urbanisation and lifestyle changes, building energy consumption is expected to double over the period by 2050 globally [1] which are prompting governments, corporates and investors around the world to adopt strategies to deliver higher energy-efficient buildings. One of the primary ways to achieve this is to incorporate energy-efficient technologies. However, despite the endorsement of green building regulations and incorporation of energy efficient technologies, buildings often fail to achieve the desired energy conservation goals, still consuming as much as three times that predicted [2]. This mismatch between the designed and actual energy performance is known as "Building Energy Performance Gap" (BEPG). Inaccurate predictions of building energy consumption and savings could result in a significant financial loss to the clients and investors. The existence of BEPG also poses a threat to achieving targeted GHG emissions reduction from the building sector to mitigate climate change. There is an urgent need to understand the sources and causes of BEPG and develop strategies to close the BEPG.

The research built on the findings of SBEnrc Project P1.43 Retrofitting Public Buildings for Energy and Water Efficiency.

1.2 RESEARCH AIMS AND OBJECTIVES

This research was developed in collaboration with industry partners to identify the root causes of BEPG in commercial buildings and propose strategies to close the gap. The specific objectives were to:

1. Identify critical factors driving BEPG in the design, construction and operational stages of buildings through literature reviews and interviews.
2. Conduct case studies to identify the root causes of BEPG and potential mitigation strategies
3. Develop a framework of strategies to close BEPG.

The research methods and phases shown in Figure 2 were used to achieve the research aim and objectives.

PHASE 1	PHASE 2	PHASE 3
• Conduct literature review • Interview experienced professionals from building life-cycle. • Identify key factors of BEPG in building life-cycle.	• Indentify strategies to close the BEPG from literature reviews and interviews. • Conduct two case studies to understand root causes of BEPG at sub-system level and potential mitigation strategies.	• Analysis of collected data using the qualitative data analysis software NVIVO. • Develop a framework of strategies to close the BEPG in design. • Develop a framework to close BEPG in operational stage.

Communication and consultation with project steering group and key stakeholders

Figure 2 Research methods and phases to achieve the research aim and objectives

Factors driving the building energy performance gap

Figure 3 presents the factors driving BEPG that were identified through literature reviews and interviews with 28 experienced professionals.

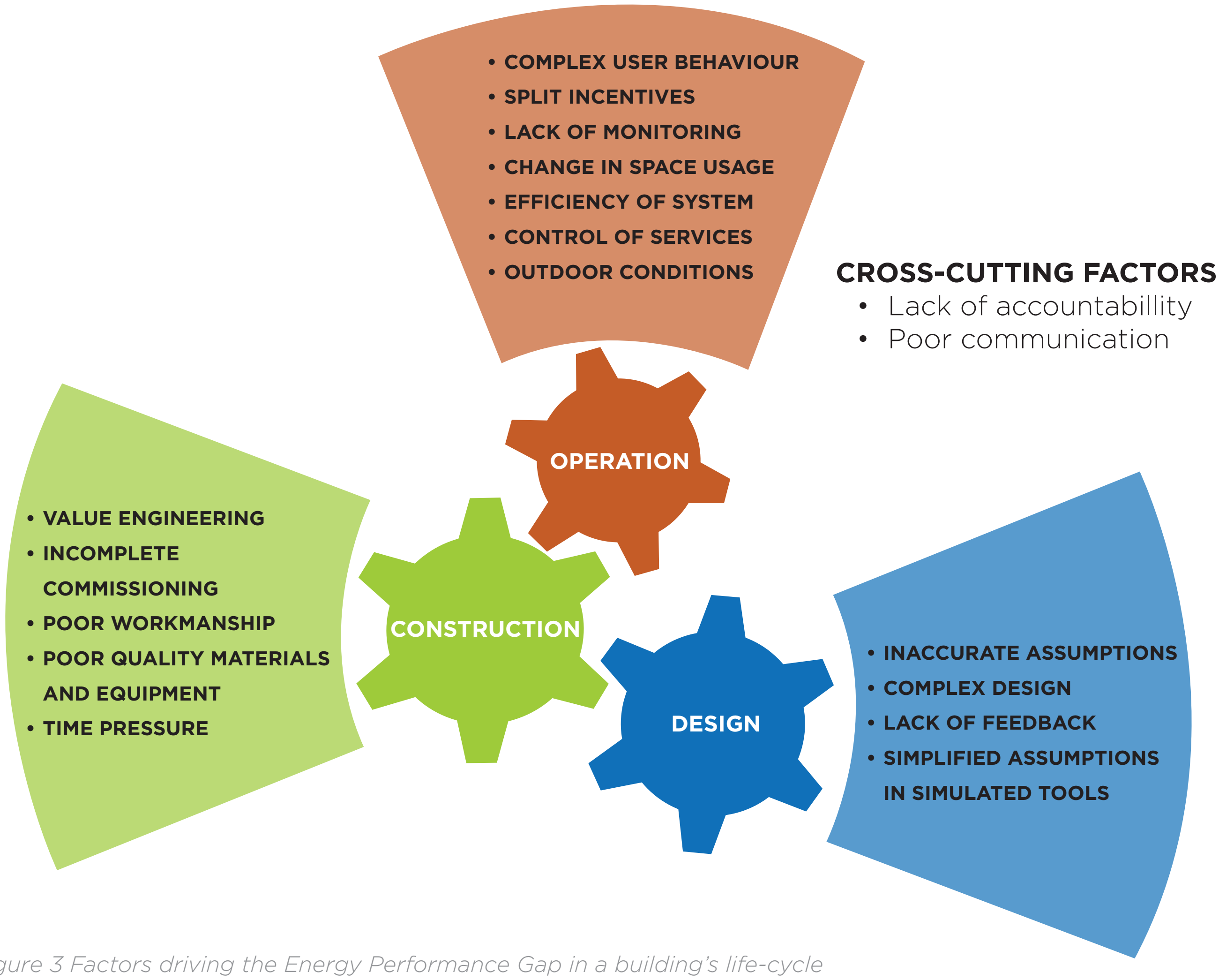

Figure 3 Factors driving the Energy Performance Gap in a building's life-cycle

2.1 DESIGN-RELATED FACTORS

Inaccurate assumptions: Designers usually assume that the control system is perfect and that the equipment will run as intended, but do not consider any inefficiencies that might occur during building operation. Moreover, plug-in loads are difficult to predict during the design stage. Erroneous assumptions about the usage and plug-in loads of different building types contribute to BEPG [3, 4]. Furthermore, in building energy retrofit projects, energy modellers have to make many assumptions regarding the performance of the building fabric and equipment. Finally, stochastic factors such as weather and occupant density fluctuate unpredictably over time, which results in uncertainties and errors in prediction [5].

Complex design: To achieve energy efficiency, designers overcomplicate the design, including multiple layers of a control mechanism which are difficult to understand and run.

Lack of feedback: Designers do not have the opportunity of studying the design outcomes, receiving post-occupancy feedback and verifying their prescriptions.

Simplified assumptions in simulation tools: Simulation software tends to over-simplify building and building systems [6, 7]. Modellers are constrained by the models due to only limited prescribed options being available within the model structure [8].

2.2 CONSTRUCTION-RELATED FACTORS

Value engineering: The need to reduce capital costs can lead to cost compromises in the building services or replacing certain components with a cheaper alternative [9] which could cause a substantial performance gap, because these alterations are rarely fed back into the energy model [7].

Incomplete commissioning: Proper commissioning and building tuning do not happen all the time due to contractual issues, budget issues and time pressures [10, 11].

Poor workmanship: Poor construction works could occur due to insufficient design details, inefficient use of a quality assurance plan, or lack of knowledge or care by frontline workers.

Poor quality of materials and equipment: Materials and products which are not compliant with standards could result in a performance gap [12].

Time pressure: Under time pressure, contractors may take shortcuts to finish works on-time. This could lower the quality of works and create defects in building components.

2.3 OPERATION-RELATED FACTORS

Inefficient control of services: This category accounts for increases in energy consumption due to two types of external factors affecting the controls:

1. The setting of the control has been modified intentionally (to achieve a necessary outcome different from energy savings).
2. The setting has been modified accidentally or tampered with.

Degrading system efficiency: During operation, system efficiency can be degraded by faulty programmed maintenance, loss of efficiency introduced during an intervention due to poor craftsmanship and lack of skills, and ageing of the systems.

Complex occupant behaviour: Occupants' lack of understanding about the operation of installed technologies and different requirements in thermal comfort influence their behaviour in terms of operating those systems, which may change the building energy performance.

Outdoor conditions: Variations in outdoor conditions from those assumed during modelling will impact the energy consumption of the building and create a gap.

Factors propagating from the design and construction phase: Flaws from the design and construction stage can be unknowingly transferred to the operation phase and become an unmanageable burden for the facility manager who unfairly takes the blame.

2.4 CROSS-CUTTING FACTORS

Lack of Communication: There may be a lack of communication among various inter-functional groups working on the same project. The lack of communication between designers and contractors results in inadequate information transfer from designer to contractors. With the lack of detail design information, the chance of construction being in accordance with the original design intent is low. Also, the designer might fail to communicate the level of management and vigilance expected from the users and building facilities staff [13].

Lack of accountability: There are no measures to hold the designers and contractors accountable if the buildings do not perform as intended.

3 Case studies to understand the root causes of BEPG at the sub-system level and potential mitigation strategies

To understand the root causes of BEPG and potential mitigation strategies, two case studies were carried out: 1) an educational building; and 2) an office building.

3.1 CASE STUDY 1: EDUCATIONAL BUILDING

Incorporation of latent heat thermal energy storage system with phase change materials (PCM) in buildings has recently received significant attention as a potential technology to enhance energy efficiency. In this case study, the energy-saving performance of an active PCM system installed in an eleven-story educational building in Melbourne, Australia was investigated. The operational parameters of the active PCM system were monitored for 25 consecutive months and the results were analysed to calculate its energy-saving performance.

According to the design document of this building, the PCM thermal storage tank was designed to reduce the daytime cooling load on the chiller by 33%. However, the analysed results revealed that the active PCM system reduced the cooling load on the chiller by 12-37% only during colder months, and remained dormant during the summer. The causes for discrepancies between predicted and actual energy savings of the active PCM system in the case study building are summarised in Figure 4. The factors that contributed to the performance gap of this system include poor communication between the designer and facilities manager, the mismatch between designed and actual operation, inefficient control, poor material quality, and limited knowledge of the facilities manager of this emerging technology. Refer to [14] for further details of this case study.

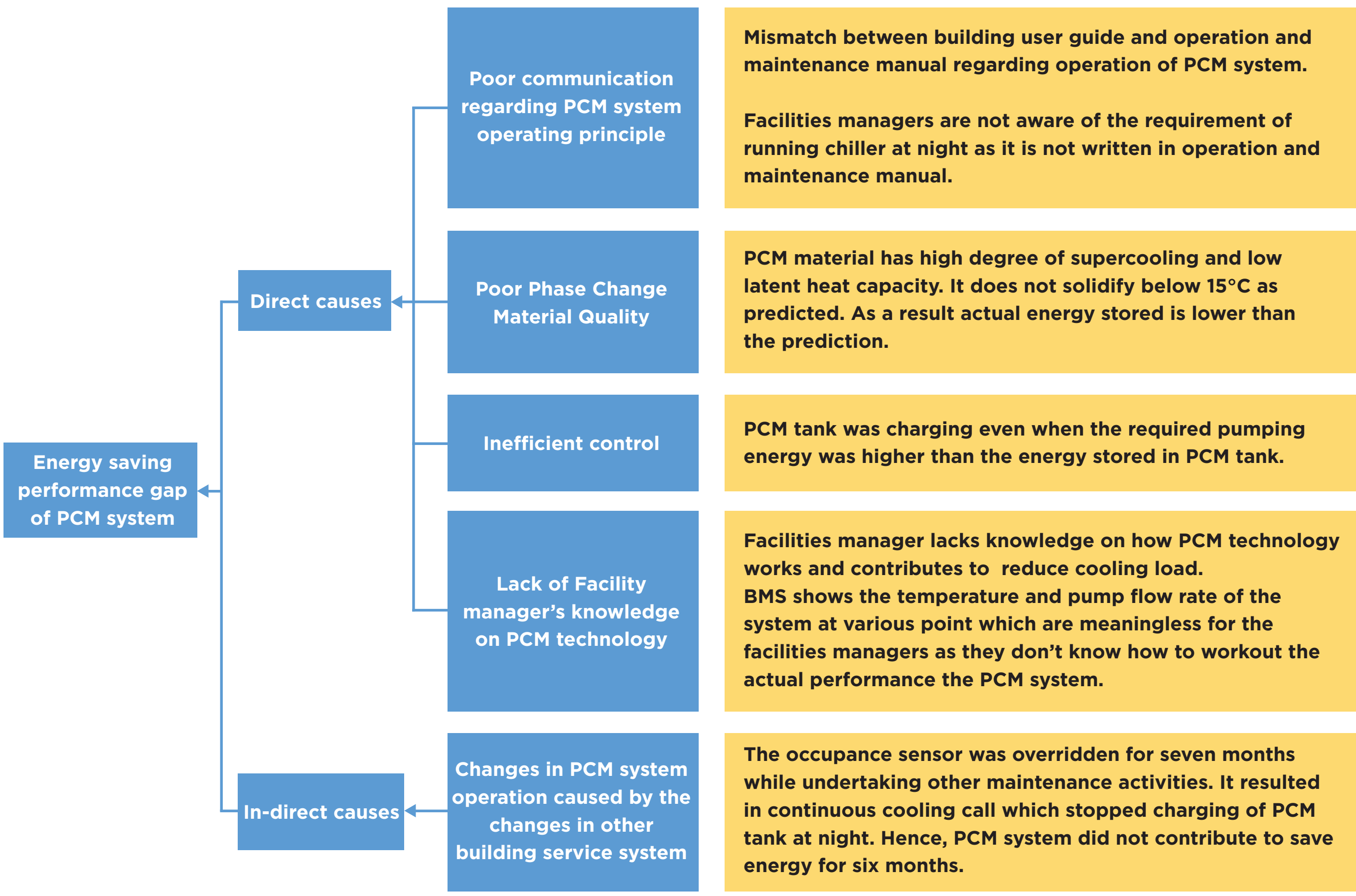

Figure 4 Factors affecting the energy saving performance gap of an active PCM system in a building[14]

3.2 CASE STUDY 2: OFFICE BUILDING

This case study aimed to understand the causes of BEPG at the building service component level and understand the importance and mechanism of collaboration required between energy-related stakeholders during the operational stage to close the gap. The selected case study is a 14-storey office building in Melbourne, Australia, with spaces occupied by public and private offices, a retail centre, car park, loading dock and end-of-trip facilities. The building was designed to achieve the 5.5 Star NABERS Energy for office – base building rating.

Since the start of the operational stage in January 2018, different energy-related stakeholders had been involved in a collaborative manner to achieve the targeted NABERS rating. This approach was very different from the traditional approach where the involvement of the Environmental Systems Design (ESD) team is limited to the design stage, and the service contractors are only involved in the construction and commissioning stages. The stakeholders include the ESD team, Main Contractor, Facilities Manager, Mechanical Service Contractor, Electrical Service Contractor, Building Management System (BMS) Service Contractor and Independent Commissioning Agent (ICA). Building Monitoring and Tuning meetings were held every two months involving all energy-related stakeholders, where they discussed the sources and causes of BEPG and possible intervention strategies to close the gap to achieve the desired sustainability target. Implementation of those intervention strategies resulted in a gradual decrease of BEPG from July 2018 to December 2018, as shown in Figure 5. In January 2019, the BEPG increased due to overriding of the HVAC pumps which was supposed to be a temporary to fix another operational problem. The contractor forgot to reinstate the automatic control which resulted in higher energy consumption. This phenomenon shows the importance of human interventions.

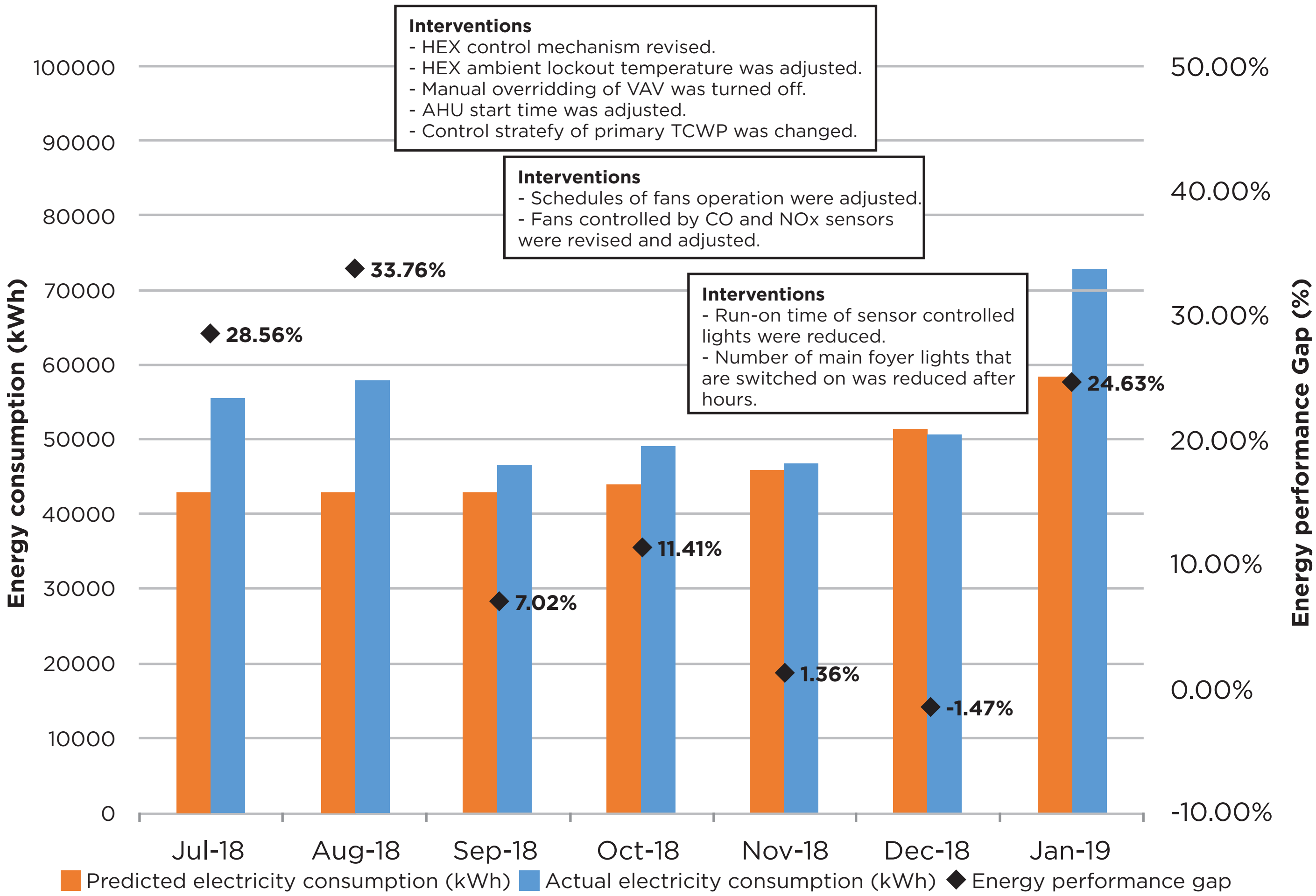

Figure 5 Monthly energy performance gap and adopted interventions in Case study 2 building

Based on Case study 2, a stakeholder collaboration framework has been developed to close the BEPG, as shown in Figure 6. Sitting at the outset are the drivers and incentives to motivate the involvement and participation of all key stakeholders. The four quarters of the innermost circle represent the four steps of the proposed framework: 1) Identification of BEPG sources; 2) Engagement of relevant service stakeholders; 3) Investigation of causes of BEPG; and 4) Solutions to close BEPG. The framework also shows the stakeholders associated with each step (in orange) along with their responsibilities (in yellow).

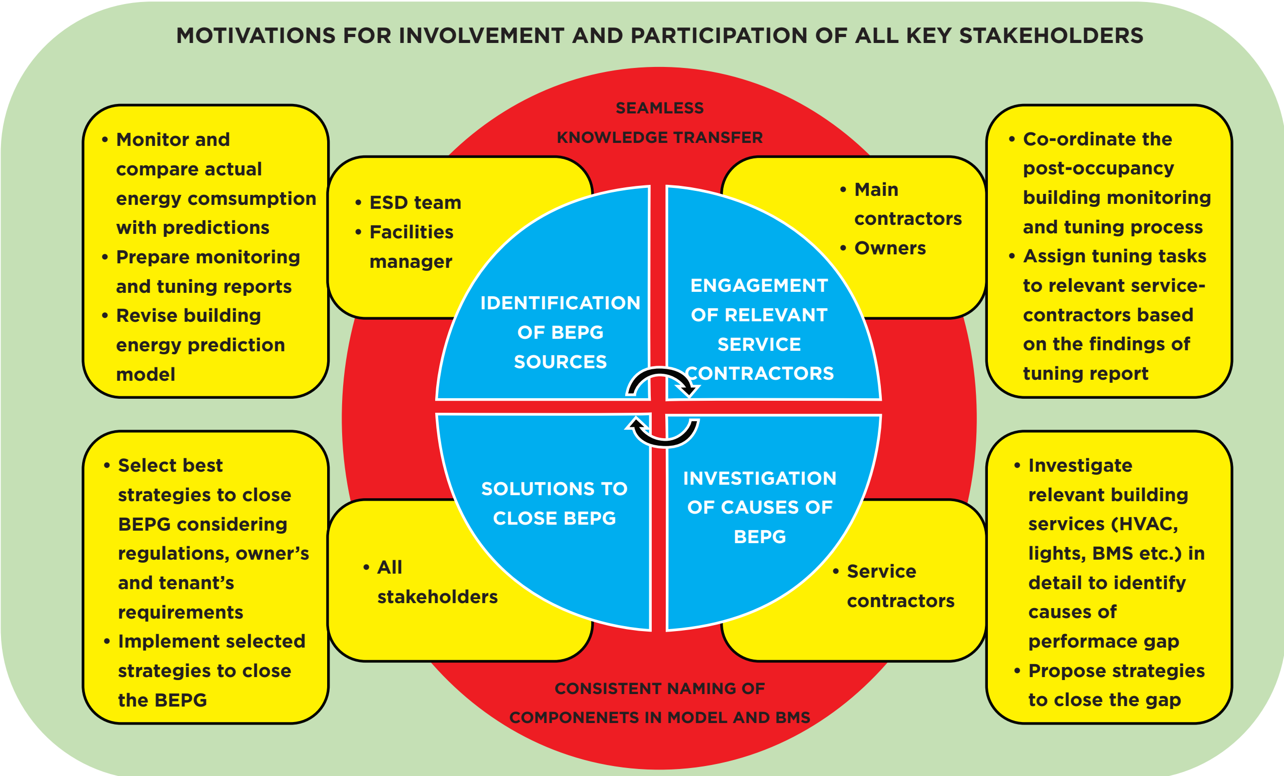

Figure 6 Stakeholder collaboration framework in the post-occupancy period to close BEPG

This approach is similar to the "extended aftercare" of the "soft-landing" approach and the case study demonstrates the importance of adopting such an approach in Australian buildings. The soft-landing approach has been successfully applied in several building construction projects in the UK. For example, The Living System Institute Building construction in the University of Exeter adopted a soft landing approach throughout the project lifespan from "conception" to "extended aftercare". The University facilities and maintenance team were fully engaged with the building project team from early on to develop maintenance strategies. The Enterprise Centre Building at the University of East Anglia achieved Passive House Classic Standard as designed using the soft-landing approach [15].

The construction of this case study building was funded by the Clean Energy Finance Corporation on the condition that the building should achieve 5.5-star NABERS which drove the owners to champion and lead post-occupancy building monitoring and tuning activities. However, to have effective collaboration, a mechanism to incentivise the design team and service contractors is needed. The owner had an extended contract with the ESD team to monitor building energy performance during the post-occupancy period and provide suggestions to close any energy performance gap. However, other service contractors (mechanical, electrical, BMS, ICA) were not contracted separately to take part in post-occupancy monitoring and tuning activities. They were involved in the process as a part of their 12 months post-occupancy building tuning service. There were no incentives for them to be involved in the monitoring and tuning process after 12 months. Moreover, seamless knowledge transfer between stakeholders is also essential to close the BEPG through stakeholder collaboration.

This case study also revealed that the building energy model has important ongoing value. The model should be used to inform the facilities manager about the optimum operating conditions and also updated regularly considering actual conditions to eliminate any uncertainties associated with the modelling assumptions and input parameters. The predicted consumptions of the updated model can be compared with the actual consumptions to identify the source of the performance gap. Refer to Project Report 6 for further details of this case study.

4 A framework of strategies to close BEPG in the design and construction stages

A framework of strategies has been developed to address the energy performance gap as shown in Figure 7. The framework has three categories: 1) strategies for better regulation (for better accountability); 2) strategies for the project team (for accurate energy models, better communication and improved expertise); and 3) suggestions for training (to address a lack of expertise) [16].

4.1 STRATEGIES FOR BETTER REGULATION

These strategies are policy and regulation-based and are concerned with replacing poor industry practices with better ones that foster better accountability in the industry. This study has identified three strategies for better regulation:

1) Regimented quality control process for procurement

a. *Ongoing Relationship with the Client:* A well-developed and ongoing relationship with the client in the transition from one project to another is conducive to greater accountability, as the employee's performance at the first job determines further employment.
b. *Developing Better Evaluation Criteria:* There is a tendency to make financial cost the highest-ranking criteria for the hiring process. There is not much incentive to perform well when all it takes to secure a job is to propose a good price.
c. *Certified Accreditation:* There is a need for a certified accreditation system, such as the Certified Measurement and Verification Professional and Energy Efficiency Certification Scheme from the Energy Efficiency Council, to provide evidence of assessors' competence.

2) Stringent standards for performance for project participants

a. *Stipulating Penalty and Rewards:* Stipulating rewards for meeting certain sustainability standards and penalties for failing to meet specified targets can drive designers and contractors to accept more accountability.
b. *Longer Warranty Periods:* Extending the current 12-month warranty period to a longer period would hold the manufacturers and contractors responsible if any system degrades and runs inefficiently soon after the brief 12-month warranty period.
c. *Stricter Targets in the Building Code for Air Tightness:* Putting in place stringent targets in the building code would require verification of building airtightness.
d. *Performance-based Contract with Savings Guarantee:* This would hold contractors accountable to the outcome, especially in large-scale projects where multiple contractors might be involved.
e. *Revising Commissioning Regularly:* When applying novel technologies, on-going commissioning is paramount to ensure everything is running optimally.

3) Aligning motivations of project participants to long term benefits.

a. *Investing in Detailed Energy Measurement and Verification:* It is important to ensure that the client or procurement manager invests in detailed energy measurement and verification while allocating enough budget for this, and preventing measurement and verification being value engineered.
b. *Tailoring Benefit to Core Drivers:* Identification should be made of the core motivators of the actors involved in a task and tailoring of the benefit of the task to their motivations in order to get them on board with the task.

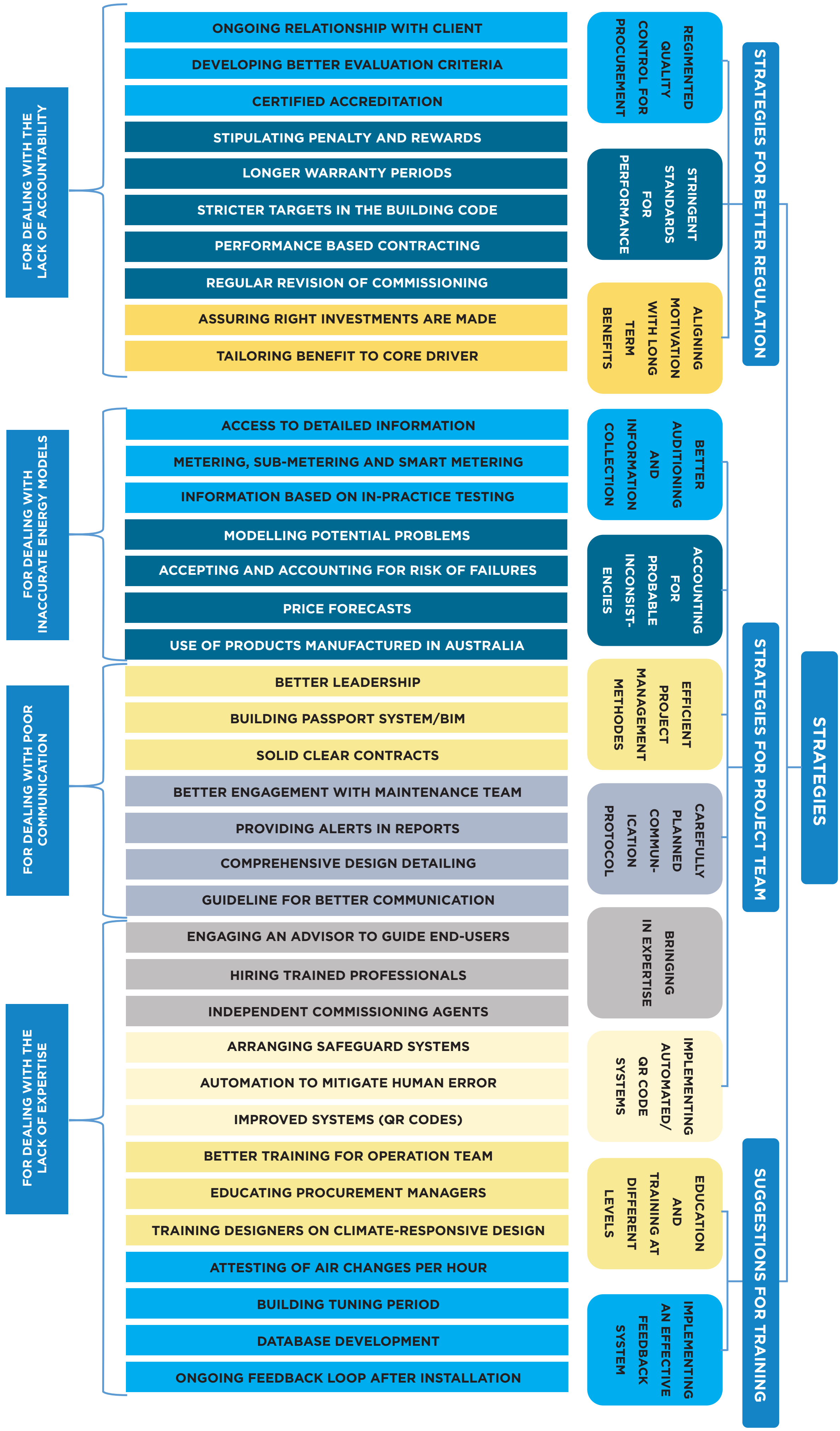

Figure 7 Framework of strategies to close BEPG in the design and construction stages

4.2 STRATEGIES FOR THE PROJECT TEAM

Strategies for the project team are directed towards enhancing industry practices so as to ensure effective communication among various stakeholders, as well as towards minimising the inaccuracy of energy models.

1) Better auditing and information collection: The more detailed the information, the fewer assumptions that need to be made in the energy model. Investing in metering generates more accurate information about the building's pre-performance and facilitates the identification of opportunities for energy saving.

2) Accounting for probable inconsistencies

a. *Modelling Potential Problems:* Follow the NABERS commitment agreement approach where the designers are required to conduct off-axis modelling in addition to a base model to test the building's ability to reach the targeted energy rating with changes in operating patterns.
b. *Accepting and Accounting for Risk of Failures:* Risk of failures should be accepted and taken into consideration when estimating energy savings, particularly for novel technologies.
c. *Price Forecasts:* Conducting comprehensive price forecasts is important to generate more relevant payback estimations.
d. *Use of Products Manufactured in Australia:* Products that are manufactured in Australia tend to comply better with Australian regulations.

3) Using efficient project management methods

a. *Better Leadership:* It is crucial to keep track of the project as a whole to make sure all parts are properly coming into place and to aid individual teams in working together.
b. *Building Passport System/ BIM:* Implementing this system would ensure that everyone involved in the project is on the same page, without letting modifications go unnoticed.
c. *Solid Clear Contracts:* This ensures the accountability of everyone involved in projects.

4) Carefully planned communication protocol

a. Better Engagement with Maintenance Team: This would encourage designers to engage with the existing maintenance teams to get an understanding of the intricacies of the systems that might cause issues. Similarly, in new builds, a "soft landing" approach is used where the design team remain engaged during the operational stage to ensure targeted building energy efficiency.
b. Providing Alerts in Reports: A detailed section should be provided in reports that warns the project team that any changes to certain design parameters would have a material impact on energy consumption and result in an uncompliant building.
c. Comprehensive Design Detailing: The provision of more comprehensive design detailing would show how certain criteria can be achieved. For example, constructing an airtight building.
d. Develop Protocol or Guideline for Better Communication: A communication protocol should be developed, tailored for every team, outlining what information is expected of them at which points in the project, as well as what information they should be seeking from which party.

5) Bringing in expertise

a. *Having an Advisor to Guide End-users:* This person would support the end-user in the use of new technology.
b. *Hiring Trained Professionals:* Appointing optimisation experts to oversee complex systems, who stay updated with technology and preferably do not sell products, generally yields the best advice.
c. *Independent Commissioning Agents:* These would ensure that building systems function properly as designed.

6) Implementation of automated and QR code systems

a. *Arranging Safeguard Systems:* Having prediction systems in place would facilitate timely detection of defects in operation and apt restoration.
b. Automation to Mitigate Human Error: Removing occupant's control of temperature settings and automating HVAC settings would minimise the impact of uncertain occupant behaviour.
c. Improved Systems: Intelligent systems could be used to minimise errors. For example, stamping QR codes on key products to ensure that they are installed and maintained correctly as designed.

4.3 SUGGESTIONS FOR TRAINING

These strategies focus on the gap caused by human error, lack of expertise and experiential learning.

1) Education and training at different levels

a. Better Training of Operation Team: Training and upskilling exercises should be provided for the building facilities managers to operate the building services systems efficiently.
b. Educating Procurement Managers: This would help avoid important energy efficient technologies being removed from the project during value engineering.
c. Training Designers on Climate-responsive Passive Design: Adequate training on the principles and techniques of passive design would reduce dependency on technology and avoid overcomplicated designs.

2) Implementing an effective feedback system for designers

a. Attesting of Air Changes Per Hour: A robust practice should be established for measuring airtightness once the construction is complete.
b. Building Tuning Period: Buildings change over time, and so do their needs. Equipment often goes out of tune and demands tuning informed by active monitoring of the building on a continuous basis.
c. Ongoing Feedback Loop after Installation: A "Soft-landing" approach, where the design team is involved during the operational stage, should be adopted. This provides the designers with a chance to identify the errors in their assumptions, learn from their mistakes and apply new techniques in their future projects.

5 Stakeholders incentives to close the gap

The previous sections covered the factors that would keep a building from performing as designed in an ideal situation where the facility manager, the tenants and the building owner are motivated by lower energy consumption. This section takes a step back and looks at the incentives for each stakeholder to close the performance gap during the operation phase.

The facility manager's primary objective is to ensure the building provides the work conditions as per the lease contract (i.e. everything works as intended) and the tenants are satisfied (e.g. adequate thermal comfort and enough fresh air are provided to keep the staff productive). The other objective is to satisfy the landlord (his employer) by keeping expenses as low as possible, rather than to think about the long-term value of the property. This includes the energy bills of the base building that are recharged to the tenants.

The tenants have a direct and indirect financial incentive to lower the energy consumption of their floor and of the entire building. Indeed, they pay directly the bills for the electricity used in their area (lighting and general purpose outlets) and they pay indirectly for the energy cost of the base building, either through their gross lease (Eastern states of Australia) or more directly through the "outgoings" (Western Australia). Therefore, a second issue is that individual tenants are not responsible for how the base building operates nor do they participate in the decision to invest in replacing or upgrading the equipment servicing the building (including their floor). Nevertheless, they are the ones paying for any lack of efficiency and poor performance.

The building owner passes the energy cost of the base building onto the tenants, so there is no direct financial incentive to lower energy consumption (including to close the performance gap between predicted and actual consumption)[1]. To the contrary, even if capital investments for replacing or upgrading old building components are tax-deductible, the reward (lower energy cost) really goes to the tenants, particularly in net leases. Therefore, the only, or at least the most common, incentive for the landlord is to advertise a low energy cost lease, and possibly a lease area with high thermal comfort, in the hope of attracting premium tenants.

6 Measures and strategies to close BEPG at the operational stage

Solutions, measures, feedback and advice were collected from the literature as well as from interviews with professionals from Buildings Services and Facility Management, to identify the existing strategies to prevent or overcome the performance gap. The research also looked at existing frameworks such as the "Soft Landings" methodology and the "nDeep" framework to enrich the findings. The identified strategies have been considered under the following five themes, and brought together in the framework in Figure 8:

1. Monitoring, tracking and fine-tuning
2. Collaboration with the occupants
3. Facility management training and support
4. Documentation
5. Energy efficiency-related tax incentives

[1] Exception: when the tenant is a government agency, the landlord must keep the building to a minimum performance of 5 stars in NSW and 4.5 stars elsewhere in Australia

6.1 MONITORING, TRACKING AND FINE-TUNING

Continuous monitoring of the building's energy consumption and the use of analytic tools to track the performance are necessary to ensure the building is operating as designed [17]. Feedback from interviews: Too often, the Building Management System (BMS) that monitors and controls the operation of the building, does not have the capability to analyse the data recorded finely enough. Consequently, the facility manager who is willing to track the performance of its building to be reactive if it drifts must spend precious time extracting and interpreting a variety of meter readings and other system(s) data. Building performance analytic software can help the facility manager better appreciate the level of importance and urgency of alarms triggered by the BMS.

6.2 COLLABORATION WITH THE OCCUPANTS

Energy simulations assume occupants will have a very standardised and passive behaviour but human behaviour is complex and heterogeneous [18]. It is particularly the case when a tenant moves (or moves back) into an office building that has been retrofitted and its staff is not briefed on the specificities of this "new" environment. It is therefore important to inform the occupants on the (new) building services and controls, encourage them to engage with the facility management and make them aware their behaviour can impact their energy bills as well as the energy cost of the base building [19]. The Green Lease guide offers an interesting insight into the suggested collaboration.

6.3 FACILITY MANAGERS' TRAINING AND SUPPORT

As building services are continuously becoming more efficient and adaptive, they are becoming more complex and more difficult to understand [19]. Therefore, there is a need for more education about energy efficiency to enable facility managers to better understand the systems [20]. Moreover, one of the important measures to maintain the efficiency of the building and avoid a performance gap is to require the design and the construction team to remain involved in the operation phase to support the facility management team during a longer period than the contractual Defect Liability Period of 12 months. Facility managers also have the challenging task to please the tenants and please the building owner, each having their own perception and expectation of energy efficiency. The required training should, therefore, not only be about the technical operation of the building but also about advocacy (and communication) on energy efficiency to owners, contractors, users and other stakeholders [21].

6.4 BETTER DOCUMENTATION OF BUILDING SERVICES

The documentation related to the building services and the operation of the building is not a measure in itself to minimise the performance gap, but rather a measure to support other strategies. The research found the future of documentation should be fully digital, multi-sourced and shared, which is now becoming possible with the (slow) uptake of BIM (Building Information Modelling) that will help facility management understand and better maintain and operate their building.

6.5 ENERGY EFFICIENCY-RELATED TAX INCENTIVES

Section 2.3 revealed that many operational factors that contribute to the performance gap are linked to the motivation of the building owner to close this gap and offer a more energy efficient workplace to the tenants. However, the tenants are paying the energy bills (directly for their leased area and indirectly for the base building), so the building owners are only interested in the energy performance of their building from a marketing perspective.

Feedback from interviews: It is interesting to observe how landlords start caring about the (disclosed) energy efficiency of their building when it becomes a competitive advantage to attract tenants during economic slowdowns. This period is also the best time to implement significant HVAC and lighting upgrades when the building has vacancies (when whole floors are vacant). Unfortunately, it is also during that period that the cash flow is the lowest for the landlord.

One strategy to alleviate this variation and to encourage building owners to care more consistently about the energy performance of their buildings is to create an economic link between energy consumption and the owner's bottom line. The tax system is a solution that many countries are using and more particularly the accelerated depreciation of capital investment in eligible replacement or upgrade of building components contributing to its energy efficiency.

Item #	Category	Sub category	Measure	Comments
1.1	Monitoring, tracking and fine-tuning	Monitoring	Use software analytics	Use software analytics to complement the BMS and better understand the sourtce of the performance gap
1.2		Tracking	Adjust the operating conditions of the reference	Adjust the operating conditions of the reference (NABERS) to better gauge the performace gap
1.3		Fine-tuning	Run secondary commissionings	Run one of several commissioning in different climate conditions (different seasons) to ensure that weather-sensitive BA are working as designed
1.4			Understand the complexity and the overall target before fine tuning	Understand the relationship between BS equipment and elements, and what is the overall target to achieve before starting fine-tuning in isolation
2.1	Collaborating with the occupants and lease agent	Leasing terms	Let the FM assist the leasing agent in the negotiation with the tenants with atypical use of their space	Some atypical occupant behaviour or use of tenacny spaces (floors) may not be compatible in the capacity of the Building Services and will result in a performance gap. The FM should be involved in the negotiation of leases particularly when the use of tenancy spaces don't comply with the House Rules.
2.2		Share the aspiration	General information meeting for the occupants	Organise a general meeting soon after the start of occupancy to sensibilise the occupants on the aspiration of the retrofit, why it is beneficial also for them and how they can play a part
2.3			Monthly FM newsletter	Send a monthly newsletter with information about efforts of the FM to satisfy occupants, answer to questions from other occupants.
2.4		Inform occupants	Add signs and notes next to controls of BS.	Instruct occupants on the proper operation of services can be done in person during the general meeting but is best achieved by adding signs and notes next to controls of BS.
2.5			Monthly FM newsletter	The newsletter can also be useful here to give some tips on how to best operate the BS.
2.6		FM/occupants relations	Invite occupants to meet him/her to discuss	Ideally, the FM would have an office in the building where occupants can meet him/her. If not, the FM could organise to be onsite once a week to meet occupants in group.
3.1	FM training & support	Technical knowledge	Involve the FM in all stages of the retrofit, from Design to commissioning	This is to give a sense of ownership to the FM and gain insights from engineers and contractos
3.2		BMS	Extensive induction to Building Management System	BMS relies on meters and sensors to monitor performance and alert BS failures or BS going off-track. Knowing where are these meters and sensors and what they really tell is as important to use the BMS to its full capacity.
3.3		New technologies	Upskill FM to new technologies in BS and monitoring.	Building services may look the same and perform the same service, the technology behind them may have evolved. Making sure the FM has caught up with the new versions will make him/her more efficient when dealing with fine-tuning or failures.
3.4		Social communication	Train up the FM advocacy and social communication skills	This is important to enable and support measures mentioned in the "Occupant Behavious" category
3.5		Support	Support from Design and Construction teams	To help the FM understand the BS
4.1	Documentation	For the FM	An Operation and Maintenance Manual for the FM	Document created by the designer for the operator (the FM). This manual would cover at minimum the elements of the building that have been modified and improved.
4.2			A logbook for the FM to record activities and outcomes (performance)	Besides recording the performance, the logbook is also a summary of a building services' controls strategy, predicted energy performance and the means to monitor it.
4.3			Asset register	Gather useful information on BS such as short description mentioning location, primary functions/use and expected performance
4.4		For the occupants	A user manual for the occupants of the building	A document to communicate how the building has been designed, how it is intended to work, and how to operate the local control facilities for heating, lighting, ventilation, etc.
4.5			A tenancy fit-out guideline	A document to ensure tenants do not modify the building in a way that affects the overall performance (or the performance of the base building)

Figure 8 Framework for closing the energy performance gap at the building operation stage

7 Conclusions and recommendations

The key factors influencing BEPG in the design, construction and operational stages have been identified and a framework of strategies developed based on extensive literature reviews, interviews with experienced professionals and in-depth case studies. The factors identified in the design stage include inaccurate design assumptions, poor design and uncertainties in simulation tools. In the construction stage, value engineering, poor construction quality and materials, time pressures and incomplete commissioning are found to be the leading contributors to BEPG. In the operational stage, performance gaps arise from the control of services, efficiency of systems, complex occupant behaviour, outdoor conditions and factors propagating from the design and construction phase. The lack of communication between stakeholders and the lack of accountability also contributes significantly to BEPG.

The case studies revealed that BEPG could be reduced through effective collaboration between energy-related stakeholders (i.e. designers, main contractors, owners, facilities managers and sub-contractors) during the operational stage. This is similar to “extended aftercare” in the “soft-landing” approach. To have effective collaboration, the building owners need to champion and lead post-occupancy building monitoring and tuning activities. However, there is a need for a driver for the owner to introduce post-occupancy building monitoring and tuning activities. A mechanism to incentivise the design team and service contractors is equally important. Furthermore, the building energy model has important ongoing value in optimising building operation and should not be abandoned once the building is constructed.

Two frameworks of strategies have been developed to close the energy performance gap and each strategy is reinforced by implementation suggestions that can practically guide project teams in taking the necessary steps to address the BEPG. The design stage framework has three categories: 1) Strategies for better regulation; 2) Strategies for the project team; and 3) Suggestions for training. Strategies for better regulation is focused on fostering more accountability in the industry. Strategies for the project team are directed towards enhancing industry practices so as to ensure effective communication among various stakeholders, as well as towards minimising the inaccuracy of energy models. Suggestions for training aim to educate the industry and upskill designers, contractors, facility managers and other members of the industry that they rely upon. The operational stage framework has five contributing categories: 1) Monitoring, tracking and fine-tuning; 2) Collaborating with occupants; 3) Facility managers’ training and support; 4) Documentation; and 5) Energy efficiency tax incentives.

All the solutions, measures, strategies or frameworks that can overcome the performance gap are useless, if there isn’t a change in mentality in the construction industry, accountability of the actors and/or stricter control of compliance by the authorities. Perhaps it is time to rethink building regulations and create a new kind of contract that would require a new and more complete approach to facility management services. This could be called Total Facility Management (TFM).

TFM would be based on a business model where the building owner would be provided with the peace-of-mind of efficient building operation for a fixed fee. TFM would be an integrated service, aggregating all services linked to the operation of the building. The TFM contract would also include a variable portion based on customer satisfaction or a percentage of the revenue from leases, in order to incentivise the service provider to drive the building not only to achieve energy efficiency targets but also occupants’ comfort and productivity, and ultimately make the building attractive to premium tenants. The innovative shift would be from the current “action-based” contract to a performance-based contract. If this voluntary application of a TFM contract does not get taken up, then governments would need to step in and create the policies to make it happen. Thus, a set of regulations could support Total Facility Management becoming a mainstream exercise in managing buildings. This could be done through the Council of Australian Governments (COAG) agreeing on such a strategy and enabling legislation in each Australian State and Territory.

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Acronym list

AHU	Air Handling Units
BEPG	Building Energy Performance Gap
BMS	Building Management System
BMSSC	BMS Service Contractor
DX	Direct Expansion Heat Exchanger
ESC	Electrical Service Contractor
ESD	Environmental System Design
GHG	Greenhouse Gas
HVAC	Heating, Ventilation and Airconditioning
HEX	Heat Exchanger
ICA	Independent Commissioning Agent
MC	Main Contractor
MSC	Mechanical Service Contractor
NABERS	National Australian Building Energy Rating System
PCM	Phase Change Materials
TCWP	Tenant Chilled Water Pumps
TFM	Total Facilities Management

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