# CLOSING THE GAP BETWEEN DESIGN AND REALITY OF BUILDING ENERGY PERFORMANCE

Identification of operation phase factors

**Research Report 3 (May 2018; updated February 2019)**


**Research Team from Curtin University**

Professor Peter Newman and Lio Hebert


**Collaborative Universities**

Swinburne University of Technology
Curtin University

**Government and Industry Partners**

Australian Research Council
Aurecon, Victoria
Building Management and Works, Department of Finance, Western Australia
Department of Housing and Public Works, Queensland

Sustainable Built Environment National Research Centre

# Executive Summary

This project investigates the energy performance gap between the design intent and the actual outcomes in building energy retrofit projects, to discover faulty design assumptions, hidden construction errors and inefficient operation practices. Investment in energy retrofitting of buildings is one of the cheapest ways to reduce the nation's energy consumption. However, there is risk and uncertainty about the return on investments, as the retrofit projects do not always deliver the intended benefits.

While the first two parts of this SBEnrc/ARC research project looked at factors in the design and the construction stages that contribute to the performance gap between predicted and measured energy use of retrofitted buildings, this report looks at the factors in the operation phase.

For this purpose, the research assumes that all stages before handover have been ideally perfect, and concentrates on identifying factors that would find their origin in the operation stage of the building.

Factors have been considered under different categories related to the operation phase, involving the Facilities Management team, the tenants, the building owner, the external conditions, the building envelope, etc. However, feedback collected during interviews of professionals in Buildings Services and Facilities Management, as well as information found in the literature review, indicated that 'flaws' introduced during previous stages could come up in the operation phase and be mistakenly attributed to this phase. Since the resolution or prevention of these factors would be found not in the operation phase but in the previous phases, an additional category was created and called 'The grey area'.

Therefore, the factors have been considered under the following six categories:

1. Control of services
2. Efficiency of systems
3. Indoor and outdoor conditions (including occupant behaviour)
4. Building envelope
5. Stakeholders incentives to close the gap
6. The grey area

The identification and classification of these factors in this report provided strong foundations for the development of strategies to overcome the energy performance gap in the operation phase, which are addressed in Research Report 4: Strategies to address operation phase factors.

The results of this investigation show that two factors have a prominent influence on the performance gap between predicted and actual energy rating:

- The controls are the weak point of Building Services and are generally the reason for drift in energy use after the building has been tracking properly for a while after the start of occupancy. They represent the technology factor.
- An unpredicted usage profile of the building, often due to unexpected occupant behaviour, is the human factor contributing to the performance gap. In particular, the activities outside business hours have an unforeseen impact on the NABERS star rating.

# Contents

# 1 Introduction

Investment in energy retrofitting of buildings is one of the cheapest ways to reduce the energy consumption of developed countries (Balaras, 2001). However, there is risk and uncertainty about the return on investments, as the retrofit projects do not always deliver the intended benefits and, more particularly, a performance gap is too often observed between the predicted and the actual energy consumption. This SBEnrc/ARC research project aims to identify the factors that contribute to the performance gap in energy retrofitted buildings and propose solutions to mitigate them. This report contributes by investigating the factors that contribute to the performance gap in the operation phase of office buildings.

## 1.1 Background

With the rise in awareness of climate change since the late nineties that triggered the need to reduce the energy demand of our buildings, but also with the development of the internet and the 'connected world', Building Services have become greatly more complicated in the past twenty years and so has become the role of Facilities Management (FM) (Fedoruk, Cole, Robinson, & Cayuela, 2015). Whilst previously the main target was to achieve the intended comfort conditions in the building while minimising maintenance costs, the ever more stringent emission targets and increasing energy prices are now pressing Facilities Managers also to pursue energy efficiency targets. This is particularly true in the context of this research project where intended (predicted) energy savings can be used to support above-standard investments in energy efficient Building Services with the promise to bear a short payback period. While the two previous parts of this research project looked into factors in the design and construction stages of the retrofitting that contribute to the energy performance gap, this section looks particularly at the factors in the operation phase.

## 1.2 General assumptions underpinning the investigation

### 1.2.1 Focus on the operation phase

The operation phase is defined as the period starting with occupancy of the lettable areas of the building, and its performance is assessed using the data collected from the master meter and the sub-meters, via the Building Management System (BMS) and additional monitoring systems (e.g. analytics software). To ensure this section focussed on the factors attributed to, and only to, the operation phase, it is necessary to assume that:

1. The building retrofitting design and plans are correct, relevant to energy efficiency targets and relate to the existing situation (building envelope, location and orientation, etc.).
2. The building modelling (in relation to the energy modelling component) is an exact reproduction of the plans, and the energy simulation is an exact reproduction of the intended usage profile of the building and external factors.
3. The construction work is truly and entirely done according to the design plans and executed with flawless craftsmanship.
4. The retrofitted building is delivered 'as designed' and the commissioning is unbiased and without reserves.

**Feedback from interviews**: *a performance gap can be observed in the first year of occupancy but more often happens when the building has been tracking as expected from the start of occupancy and suddenly goes off track.*

### 1.2.2 Reference method to assess the energy performance gap

To constructively discuss the gap between two assessed situations, it is generally necessary to use the same points of reference. In the case of this research project, to discuss the performance gap between the energy efficiency at the design stage (calculated or 'predicted' energy consumption) and the energy efficiency during the operation phase (measured or 'actual' energy consumption), it is necessary to use the same assessment method. Several frameworks exist, such as the ISO 50000 Energy Management Standard and the *International Performance Measurement & Verification Protocol* (IPMVP), also found under the *International Measurement & Verification System* (IMVS). They are both globally recognised and used frameworks to assess the savings from energy efficiency measures. However, to stay closer to the Australian context, the National Australian Built Environment Rating System (NABERS) was chosen in this report as the default framework for assessing the performance gap of building retrofits. This framework has several advantages compared to the IMVS, such as:

- It has been widely used to assess office buildings across Australia for more than 10 years.
- It is made mandatory, through the Building Energy Efficiency Disclosure Act 2010, for buildings leasing over 1000m$^2$ of Net Lettable Areas (NLA).
- It can be used for the base building or only the tenant (NLAs), or the whole building.
- It accounts for the level of occupancy of the building.

However, the NABERS framework is not perfect, and this report will point out some situations where the NABERS rating can be misleading or not sufficient.

**Feedback from interviews**: *NABERS accounting for the level of occupancy of the building helps to get a more realistic rating. However, it can still be misleading as energy consumption of building services is not proportional to its rate of occupancy.*

### 1.2.3 Building scope considered in the investigation

It is also important to define the scope of the energy consumption considered when investigating the energy performance gap. The Building Energy Efficiency Disclosure Act 2010 requires the disclosure of the NABERS rating of the 'base' building. As defined by NABERS[1], a "base building rating covers the performance of the building's central services and common areas, which are usually managed by the building owner". This includes the general air conditioning system to maintain fresh air and comfort temperatures across all area (HVAC) including the ones let to tenants (NLAs), but also the lights outside the NLAs, the lifts, etc. Therefore, all energy consumption supplied to NLAs via Tenant Distribution Boards (and sub-metered), such as tenant lights and General Power Outlets (GPO), are not accounted for when assessing the energy efficiency of a building using the NABERS base

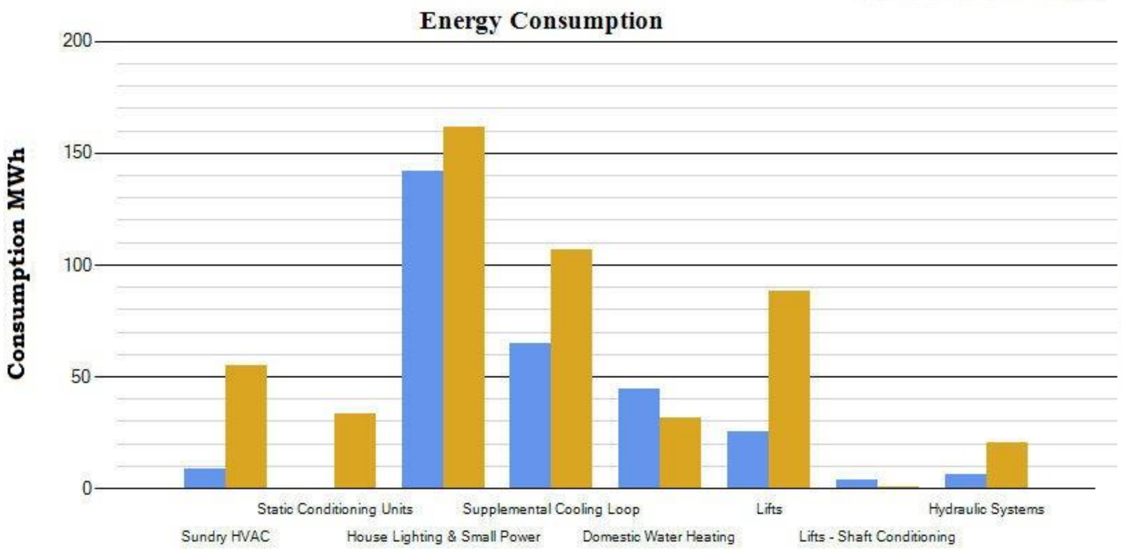
[1] https://nabers.gov.au/public/webpages/ContentStandard.aspx?module=10&template=3&include=Intro.htm&side=EventTertiary.htm

building rating, and thus are not contributing to the performance gap. Nevertheless, this does not mean factors from the NLAs will be omitted but only the ones that are having a direct or indirect influence on the performance of the HVAC will be considered.

**Feedback from interviews**: *Generally, tenants would account for the energy efficiency of a building (e.g. base building NABERS rating) only to make their initial choice but rare are the tenants following up on the rating's annual updates during occupancy or interested in actively monitoring and understanding the energy consumption of the area they are leasing (e.g. Tenancy NABERS rating).*

### 1.2.4 Services scope considered in the investigation

Office buildings are usually equipped with a set of systems for Heating, Ventilation and Cooling - also called Air Conditioning - all gathered under the name HVAC. The HVAC system is a complex system involving fans, pumps, motors, compressors, heaters and many types of controls and actuators. HVAC systems always use electricity, and some also use gas (for heating or for co-generation). In office buildings in Australia, the HVAC tends to take the larger share of the energy usage of office buildings, followed by the lighting systems.



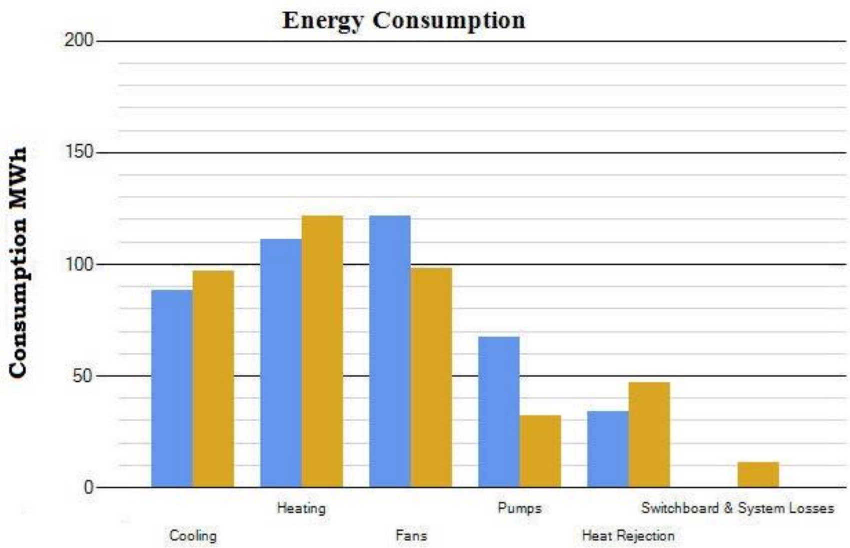




*Figure 1 Breakdown of energy consumption for an office building in Perth*
*(From iSynapse analytic software - Courtesy of Crabtree Engineering Software)*[2]

*Note: Yellow bars are the predicted energy and blue the measured energy.*

Figure 1 shows a common distribution of energy usage for a base building (used for NABERS rating), where HVAC and lighting take up by far the most energy. It is nice to see that, sometimes, buildings perform better than predicted.

When considering the whole building energy consumption, as shown in Figure 2**Error! Reference source not found.**, HVAC and lighting still make up the larger share, particularly if there is an underground carpark (with many lights).

[2] https://www.crabtreesoftware.com/

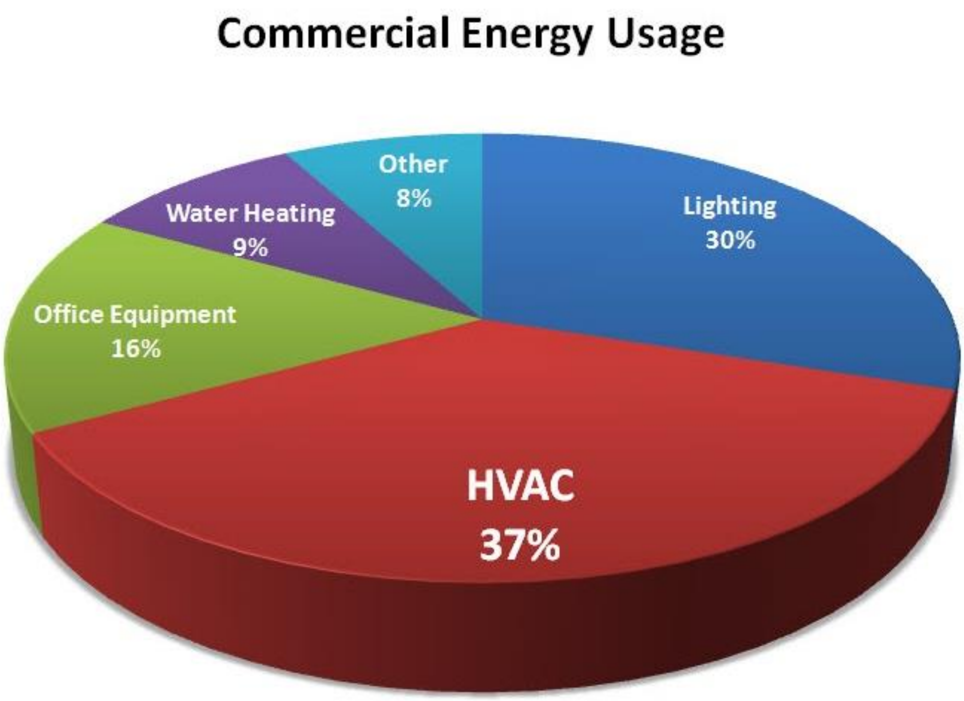



*Figure 2 Typical distribution of energy usage in an office building (whole building energy)*

Therefore, HVAC and lighting will be the focus of this part of the research as they are the services that influence most the energy efficiency rating of office buildings as well as the performance gap.

# 2 Literature review and interviews

The literature review carried out revealed that the operation phase is rarely a topic on its own when researching or reporting on the energy performance gap in buildings. The documents found are either looking at the reasons for a performance gap within all the phases or concentrating on the performance during the operation phase but without comparing it to performance predicted at the design stage. However, this did not prevent useful findings. Besides the literature review, the research team also interviewed a number of relevant professionals:

**Patrick Jeannerat** (MSc) is Sustainability Manager at Colliers International. Patrick has been working in sustainability roles within Australia's built environment for over 10 years, supporting design with ARUP, construction with John Holland and now operations with Colliers International. Patrick holds relevant professional assessor accreditations under the NABERS and Commercial Building Disclosure (CBD) programs and is an accredited professional under the Green Star Design, As-Built and Performance, and WELL building standard[3].

**Andrew Crabtree** (MSc) is the director of Crabtree Engineering Software and developer of iSynapse, an analytics and diagnostic software package for Building Services. Andrew has been working in different engineering and management roles in Building Services and Facilities Management since 1970 and was the Director of the commissioning management division of IBMS from 2007 to 2014.

[3] https://www.wellcertified.com/

**Peta Ealey** (BSc-Hons) and **Marc Atherden** (BSc) are Sustainability Consultants / Associates at Norman Disney & Young in Perth. Peta has an electrical engineering background and Marc a mechanical engineering background. They both have over 10 years' experience in sustainability roles within Australia's built environment and hold professional assessor accreditation under the NABERS program.

**Gary James** (BSc) is director at Jones Lang LaSalle in Perth and is responsible for JLL's Energy and Sustainability Performance Analytics (ESPA) platform to deliver cost, performance and brand benefits to their clients. Gary has 30 years' experience in Building Services and Facilities Management. Energy tracking and performance gaps in office buildings are one of his top priorities. Gary holds professional assessor accreditations under the NABERS and Commercial Building Disclosure (CBD) programs.

**Frederick Fontaine** (MSc) is Principal and Managing director at Atiane Energy, a consulting firm in Nice, France, specialising in renewable energy and building energy efficiency projects. More particularly, Frederick has been conducting energy efficiency audits to achieve the ISO 50001 certification.

**Lio Hebert** (MSc) is director of Sustainability Services at Wileo Consulting and PhD Candidate at the Curtin University Sustainability Policy Institute. Lio has been working in sustainability roles for the built environment for over 10 years, running a consulting firm in building energy efficiency, energy audits and renewable energy in France before moving to Australia where he continues working on Building and Energy related projects. Lio has relevant overseas accreditations such as LEED (Leadership in Energy and Environmental Design)[4].

The Literature review and the interviews revealed that factors in the operation phase contributing to the energy performance gap do not always have their origin in the operation phase: There are cases where the factors are first identified in the operation phase but are found to originate in the design, construction or commissioning phase. In this report, this has been called the 'Grey Area' as solutions to overcome these factors may involve stakeholders active before the operation phase and likely still be liable as part of a defects period or other regulatory and contractual obligations post completion.

# 3 Contributing factors in the operation phase

The factors in the operation phase contributing to the energy performance gap have been considered under six categories:

1. Control of services
2. Efficiency of systems
3. Indoor and outdoor conditions
4. Building envelope
5. Stakeholders incentives to close the gap
6. The grey area

[4] https://www.usgbc.org/help/what-leed

## 3.1 Control of services

All Building Services are subject to controls to ensure adapted and efficient operation. Most of them are self-adjusting and rely on sensors to adapt to varying conditions or needs.

Some have internal controls that can be only tuned by the manufacturer or local representative subcontractor (e.g. lifts), while others can be adjusted by the FM (e.g. heating and cooling).

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.

Increased energy consumption due to an internal fault of the controls will be dealt with in the category ‘Efficiency of systems’ further below.

NB: As noted in Section 1.2, in this part of the research on operation phase, it is assumed the design plans specified the appropriate sensor types and location (zoning), and the builder installed the sensors at the intended location, properly connected to the BMS and correctly calibrated and set.

Examples in this category are provided in Table 1.

*Table 1 Examples of factors in controls of services*

| CONTROLS | Purposely modified | Accidently modified |
|---|---|---|
| **Heating and cooling** | 1. Thermostat not set properly by FM.<br>2. Thermostat set to a different setting to respond to tenant complaints.<br>3. Temperature set by FM to 22.5C +/- 1C (Temperature which often appears in lease contracts of office buildings) while the design team used another temperature range such as that indicated in the Australian Standard AS 1837 – 1976 or the ISO 7730-1984.<br>4. If the range is set too narrow, many cooling/reheat conflicts might occur and stop/starts of the pumps.<br>5. Night/WE program incorrectly modified or even bypassed. | 1. Thermostat/temp sensor obstructed by the tenant.<br>2. Additional heating or cooling device installed in NLA which affects sensor reading.<br>3. Supplementary air installed by tenant for a room and not interfaced with the BMS of the base building. These are unmonitored equipment affecting the base building HVAC.<br>4. Thermostat or program incorrectly set by accident or through incompetence. |

| | | |
|---|---|---|
| **Ventilation** | 1. Fan speed set to a different setting to respond to tenant complaints such as a request to increase for odours or reduce for noise or for thermal discomfort (the challenge of air mixing prior to reaching the occupant, and the trade-off between very localised comfort provision next to air diffusers and actual temperature control across the NLA space). | 1. Fan speed not set properly by FM by mistake or incompetence.<br>2. Night/WE program bypassed by mistake/incompetence.<br>3. Economiser/damper tampered with (in buildings with an accessible rooftop) creating unintended pressure in the ducts. |
| **Lights** | 1. Incorrect setting of motion sensors (e.g. too sensitive). | 1. Night/WE general switch off program bypassed by mistake/incompetence.<br>2. Always-on mode activated when motion sensor was not satisfying some users (e.g. light turning off in a stairwell before the users manage to reach the exit). |

**Feedback from interviews**: *FMs are not always trained and skilled enough to understand the Building Services (and their controls) and to run them to their maximum efficiency. This is particularly true with older buildings. A 50 years old building in Perth CBD was running at 4.5 stars when the FM retired after working there for over 20 years. At the same time, the chillers were replaced with new high-efficiency units. The building first went down to 4 stars but eventually reached 5 stars after the new FM was upskilled and acquainted with the building.*

**Feedback from interviews**: *Controls of Building Services are the weak point of energy efficiency in office buildings and one of the top two factors contributing to the performance gap.*

## 3.2 Efficiency of systems

Electrical Services have intrinsic efficiency affecting their performance and therefore energy consumption.

The overall efficiency of the Building Services is the result of the efficiency of the core of the equipment (electric motors, heat coils, light bulbs), the efficiency of the auxiliaries and other components of the system (ducts, pipes), and finally the balance between equipment (Fedoruk et al., 2015).

At the design stage, when energy consumption is being calculated (predicted), the efficiency of the systems is estimated using manufacturers' data and engineering calculations to account for the rest of the system. Here, we assume the calculations are correct; the systems are installed using the correct components and in a proper way; and measured system efficiency at commissioning is similar to predicted efficiency.

During the operation phase of the life cycle, system efficiency can be degraded by three factors:

1. Faulty programmed maintenance (skipped, or incorrect, or incomplete, or late maintenance).
2. Loss of efficiency introduced during an intervention due to poor craftsmanship and lack of skills.
3. Ageing of the systems (including premature ageing).

Examples in this category are provided in Table 2:

*Table 2 Examples of factors in efficiency of systems*

| EFFICIENCY | Faulty maintenance | Introduced issues | Ageing |
|---|---|---|---|
| **Heating and cooling** | 1. Incorrect refrigerant gas charge.<br>2. Heat exchangers not cleaned often enough. | 1. Tenant installs an individual cooling and heating unit that conflicts with Building HVAC systems. | 1. Failed sensors or economiser, snap discs that cannot be calibrated or adjusted, and broken wires. |
| **Ventilation** | 1. Air filters not cleaned/replaced often enough, creating drag in the ducts and increasing the load on the fans.<br>2. $CO_2$ sensors not calibrated or replaced as required. Applied to the indoor sensors and more importantly to the outdoor sensors (in underground carparks) because of the important volume of air recycled. | 1. Tenant dislikes the air draft and blocks the air outlet. | 1. Loss of synchronisation of fan motor inducing high reactive power. |

| | | | |
|---|---|---|---|
| **Lights** | 1. Bulbs not cleaned regularly (dust or, for outdoor lights, spider webs holding leaves, etc.), leading to the use of additional lights, not modelled during simulation. | 1. Bulbs replaced with more powerful ones than intended.<br>2. Occupants keep the blinds shut even after the sun has moved away.<br>3. Obstruction of the light path by something installed after commissioning, that reduces lighting and forces user to use a secondary light source. | 1. The luminaire diffuser may age over time, becoming more opaque and letting through less light. Particularly typical for old-style prismatic diffusers. |

An example of an incorrect adjustment (unintentional) introduced in the BMS, is delaying the start of operation of the HVAC system of an office building. As seen in Figure 3 below, the Variable Air Volume (VAV) terminal unit starts 1.5 hours after the time of normal occupancy (pale blue area), while other systems such as the damper are still programmed correctly. Starting late, as in this scenario, may lead to occupant complaints; while starting too early would lead to unnecessary running time and greater energy consumption than predicted.

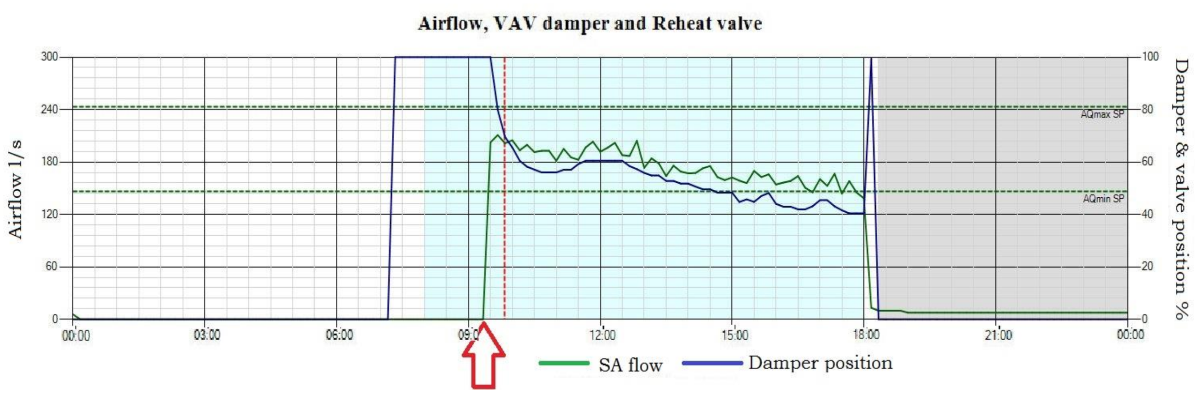



*Figure 3: VAV terminal unit analytics in an office building*
*(From iSynapse analytic software - Courtesy of Crabtree Engineering Software)*

| |
|---|
| **Feedback from interviews**: *At the moment, only high-profile building owners and high-profile tenants are really concerned with the NABERS star rating. That can explain why there are many factors contributing to the performance gap and not many measures put in place to close it.* |

## 3.3 Indoor and outdoor conditions

During the modelling of the building, to predict the post-retrofit energy performance, assumptions are made about the indoor and outdoor conditions within which the building will operate.

Indoor conditions of the building are defined by the 'usage profile' of the building and consequently the loads during the operation phase. The profile of occupancy can change between the design and the operation phases due to uncertainties of occupancy information at the design stage and drift in the profile of the occupant activities during the operation phase (Niu, Pan, & Zhao, 2016) (Bonte, Thellier, & Lartigue, 2014) (Zhang, 2018).

Outdoor conditions are the variations (mainly meteorological) of the environment around the building that affect the operation and therefore how the Building Services are used.

Variations in these conditions from the conditions assumed during modelling will impact the energy consumption of the building and create a gap between predicted and measured performance.

Variation in the Usage Profile can be broken down into two components: Amount of load, and frequency and duration.

1. The amount of load can be the number of occupants on a tenant floor or the activity of these occupants, for example being more numerous and with higher activity than predicted and modelled at the design stage. An unexpected usage profile affects the base building consumption by impacting the HVAC system, the lifts, etc.
2. The frequency and duration refers to how long and how often these loads are using energy. This is, in the majority of cases, related to unexpected after-hours activity by the tenants, but also services such as cleaning and security.

Examples in this category are provided in Table 3:

*Table 3 Examples of factors in Indoor and outdoor conditions*

| ENVIRONMENT | Outdoor | Load amount | Load freq & time |
|---|---|---|---|
| **Heating and cooling** | 1. Unexpected climate (temperature, solar radiation, humidity, wind).<br>2. Unexpected overshadowing by new adjacent buildings or tall trees; i.e. causing a problem in winter where the design model may have relied on | 1. Number of occupants or activity of occupants changed since design (e.g. tenant hosts more employees and many meetings).<br>2. Tenant installs more computers than expected (including data centres, or general ICT infrastructure such as meeting room screens, videoconferencing equipment, and booking | 1. Hours/days of occupancy different from design scenario.<br>2. ICT equipment staying on permanent standby therefore creating a load outside business hours that was not |

| | | | |
|---|---|---|---|
| | passive heating from the sun through the windows. | systems) generating more heat.<br>3. Tenant brings excessive plants or water features inside which changes the indoor humidity level and affects the efficiency of the HVAC. | expected during modelling. |
| **Ventilation** | | 1. Number of occupants or activity of occupants changed since the design stage; requiring more fresh air provision.<br>2. Unforeseen indoor conditions such as the cleaning team not using HEPA filters in their vacuum cleaners and clogging up prematurely the filters located centrally near the air handling units. | 1. Hours/days of occupancy different from design scenario. |
| **Lights** | 1. Obstructed natural light (e.g. due to vegetation growing or new next-door building casting a shadow). | 1. Number of occupants or activity of occupants changed since design (e.g. tenant hosts more employees and many meetings). | 1. Hours/days of occupancy different from design scenario.<br>2. Cleaning team and security patrol triggering a significant amount of lights after hours. |

**Feedback from interviews**: *Unpredicted occupant behaviour, and more particularly tenant activity happening outside 'design' hours, is one of the top two factors contributing to the performance gap*.

In the particular case of *tenant activity happening outside 'design' hours ('normal occupied' hours)*, the energy performance gap is not only due to a difference between design (and modelling) and actual conditions. It is emphasised in the way NABERS expresses energy use: The NABERS rating

calculations take a whole week's worth of energy use and expresses it in regards of business hours and number of occupants, using a level rating (represented by stars). When activities[5] in the building happen outside these business hours, not only do they trigger Business Services such as HVAC and lights but their related energy use is expressed in regards to the same 'official' number of business hours; hence impacting, even more, the star rating. The outside-business-hours load is called the Baseload of the building, and any difference between predicted and actual baseload has an important impact on the difference between predicted and actual star rating.

## 3.4 Building envelope

The 'building envelope' is the 'shell' within which the Building Services are working. In an office building, the main aspect of the building envelope that can explain a performance gap during the operation phase is degradation over time of airtightness.

The term 'air infiltrations' is used loosely here to account for two different sorts of change in the building airtightness from how it was modelled to predict the energy consumption:

1. Doors and windows left open.
2. Air tightness of the building envelope that deteriorates with time.

NB: Doors and windows can also fall under CONTROL OF SERVICES if they are automated but are considered here as manually operated.

Examples in this category are provided in Table 4:

***Table 4 Examples of factors in building envelope***

<table>
<tr><th>BUILDING ENVELOPE</th><th>Doors and windows</th><th>Deteriorated airtightness</th></tr>
<tr><td>Heating and cooling</td><td>Doors and windows left accidentally or intentionally left open may induce an excessive air exchange with the outdoor environment that was not anticipated during energy simulations =><br>1. HVAC works harder to maintain set temperature.<br>2. Sensors are fouled.</td><td>Doors and windows left accidentally or intentionally open may induce an air exchange with the outdoor environment that was not anticipated during energy simulations =><br>1. H&C work harder to maintain set temperature.<br>2. FM needs to adjust the thermostat to compensate for discomfort due to draft.</td></tr>
<tr><td>Ventilation</td><td colspan="2">1. Draft creates an unbalance of the system.<br>2. In windy conditions, a higher than normal pressure may occur in part of the building against which the ventilation system must fight.</td></tr>
<tr><td>Lights</td><td>N/A</td><td>N/A</td></tr>
</table>

[5] Outside-business-hours activities happen before-hours and after-hours. They can be tenant activities (employees working late or working during non-business days) or can be activities related to the base building such as the cleaning team, security patrols and maintenance staff.

## 3.5 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** (FM'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 (such as adequate thermal comfort and enough fresh air 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 (Ernst & Young, 2015). This includes the energy bills of the base building that are recharged to the tenants.

In some cases, the FM can be asked to manage the building in a way that makes it perform to a certain energy efficiency level, most likely measured in NABERS stars, but the primary purpose of this effort is for promotion of the building to attract premium tenants. This brings up a first issue: In general, FMs are contracted to deliver an action – or reaction – when something does not work properly in the building, and not to deliver a result or a performance.

**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 GPO) and they pay indirectly for the energy cost of the base building, either through their gross lease (Eastern states) 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); however, 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)6. 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 most common incentive for the building owner is to advertise a low energy cost lease, and possibly a lease area with high thermal comfort, in the hope of attracting premium tenants, even if 'enhancing the buildings appearance' has often been a higher priority (Ernst & Young, 2015).

> **Feedback from interviews**: *Long hold investments have capital budgets but many landlords of lower grade buildings focus on the short term and do minimum compliance maintenance, hoping to pass on the big difficult work to the next owner.*

The 2015 Ernst & Young report adds "*Unless the equipment is about to break or there is a concerning high level of vacancy that is affecting his rental income, some owners lack motivation to do anything to*

[6] 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

*improve their building. This is especially the case if the building is not their core or highest-earning business.*"

Many different opportunities to support energy retrofitting of office buildings exist in Australia, mostly involving funding, knowledge raising, or a combination of both, but the motivation, the incentive, is lacking.

## 3.6 The grey area

### 3.6.1 Factors from the design and modelling phase

The assumptions about perfect design, modelling and simulation made used in this part of the research (see Section 1.2.1) are utopian, since even with all the goodwill, current modelling tools and calculation engines cannot accurately simulate an existing building.

Therefore, a few 'flaws' from the design and modelling stages can be unknowingly transferred to the operation phase and become an unmanageable burden for the FM who unfairly takes the blame.

This is typically the case of the airtightness and the thermal bridges of the building. Airtightness and thermal bridges are not yet fully considered in the Australian construction industry, and they are unpredictable in retrofitted buildings without an air leakage test for the former and a detailed analysis of the building envelope for the latter.

As identified in Section 3.4 above, air leakage can create discomfort for the occupants who either pressure the FM to adjust the air conditioning settings (to the disadvantage of energy efficiency) or install their own device. In both cases, the conditions divert from the initial assumptions and potentially induce imbalance in the HVAC system and consequently increase energy consumption (and the gap) even more. Nevertheless, if Section 3.4 was considering air leakages due to the ageing of the building envelope, it is the airtightness level that was underestimated during modelling. The same factor (underestimating building envelope quality during the design stage) is applicable to thermal bridges, which similarly creates thermal discomfort to occupants and induces the consequences seen above.

### 3.6.2 Factors from the construction phase

The building industry is a fragmented sector, involving a large number of actors (Fedoruk et al., 2015), with different perspectives and goals and often working in silos (Niu & Pan, 2016; van Bueren, 2009). According to the interviewees, the transition between construction and operation is the most strategic step, both for new and retrofitted buildings. Some examples are given below.

The 'official' commissioning process used in Australia is not robust, and the 'actual' process can be quite slack. For one, the commissioning by the builder themselves (i.e. self-assessing their own work) is permitted, while other countries have made it mandatory to have this critical assessment done by an independent third party. The latter, providing unbiased but costly quality control (by means of an ICA – Independent Commissioning Agent), is strongly recommended by GreenStar to, exactly, minimise the risk of hidden defects that will later impact the energy performance of the building negatively and widen the performance gap. The official process allows for early ICA involvement from early design stages and extends over the construction and commissioning phases into the Defect Liability period during which the building can be occupied and the Services tested and verified. In reality, the building is rarely occupied directly after the handover, and usually only occupied (and tested under load) after

the Defect Liability period is long over, leaving the owner (and the FM) with a building difficult to operate as intended during the design stage.

Overall, the HVAC system control strategy may not have been considered when tweaking individual system components during construction and commissioning to suit actual operating needs. For example, a fan may be cranked up, or a pump, increasing the energy use of that component by the power of 3, whilst it might have been wiser to simply modulate supply temperature at the power of 1 or power of 2. Optimal system performance needs to be ensured for any operating schedules and requires specialist support or clear guidance for the FM for most common scenarios.

Construction/retrofit defects can take longer to be identified and even longer to be rectified. Meanwhile, the occupants' discomfort and above-predicted energy usage are blamed on the FM team.

**Feedback from interviews**: *FM typically don't have a contract that makes provision for comprehensive Defect Management but nevertheless the expectation is there that FM do address and manage defects at least in the form of supervising the builder's lead approach to defects. Result is often that the builder bullies the FM until defects are over, forcefully 'cleaning away' any identified issues under the carpet.*

## 3.7 Summary of factors and identification of responsible stakeholders

The above factors that potentially contribute to the energy performance gap in the operation phase are shown in Figure 4Figure 4 below.

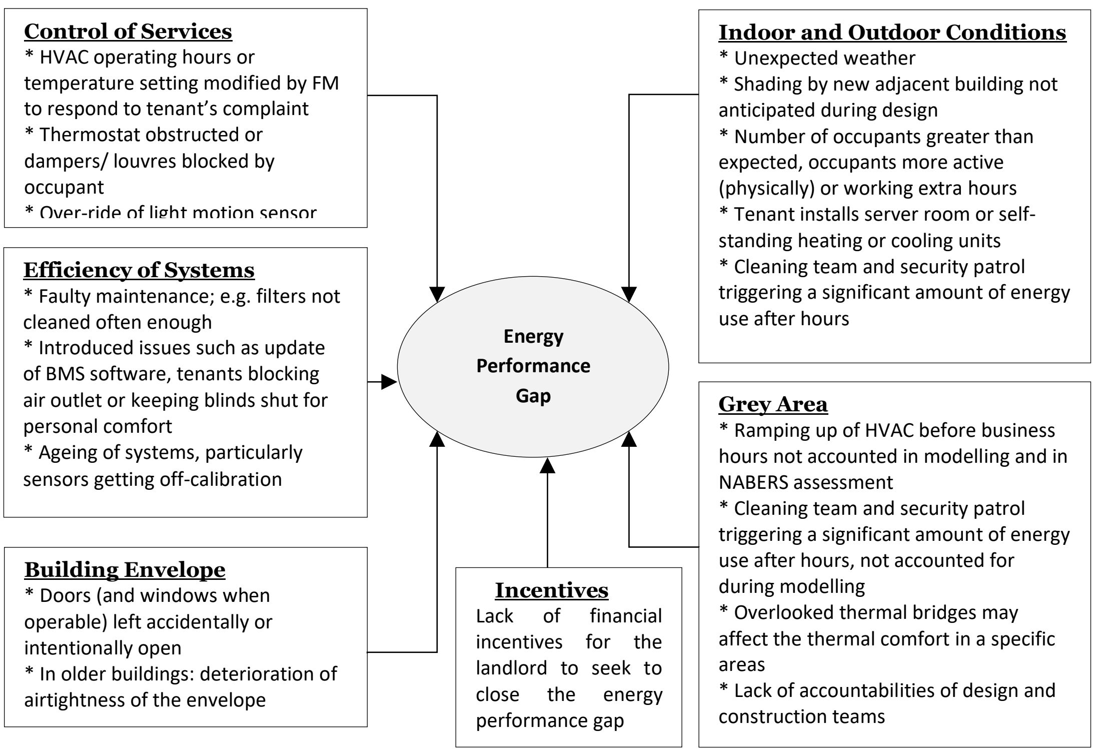



*Figure 4 Factors in the operation phase that contribute to the energy performance gap*

Most of the factors identified previously are the responsibility of the FM team or the tenants. However, other actors can have a role in the performance gap attributed to the operation phase:

**The design office**: may have difficulty in efficiently retrofitting older buildings and in modelling the specificities of older buildings properly. Older buildings can have an internal architecture (floor plan and floor-to-ceiling height) making difficult the design of efficient HVAC air ducts. The installation can look fine on paper (and when calculating the efficiency of the system) and can be installed exactly according to the design plans, but may not behave linearly or have sufficient zoning (control). It may be very difficult to control by the FM, who ends up sacrificing energy consumption for thermal comfort of the tenants and taking the blame for poor control and/or excessive energy consumption.

Airtightness and thermal bridges are not yet fully considered in the Australian Construction Industry and are overlooked in both design and construction phases.

**The builder and the sub-contractors**: may intentionally overlook or unintentionally miss defects in the Building Services which consequently underperform or are difficult to control by the FM. The most common case is a modification in the partitioning of tenant floors that affects the air balance and the flow of return air. This is the responsibility of the tenant's fit-out contractor who may not do the air balance properly (or at all), and the limited competence of the FM does not allow them to catch that.

**The real estate agent**: may not be strict enough with the limitations of NLAs (limitations defined in the design intent of the building and used during modelling), or may not anticipate the tenant's specific needs and work with the FM to find solutions that do not disrupt the balance of the whole system before the tenant moves in. Consequently, for the purpose of pleasing the customer (the tenant), additional loads are then accepted on the base build side (increasing HVAC load).

**The building owner**: may overdo compliance with the general lighting system rather than energy efficiency. The CBD program requires the disclosure of the nominal lighting power density for each separate office suite, and landlords are often advised to install (inexpensive) powerful general lighting systems to ensure the lighting density is achieved in all of the NLA. This choice leads to unexpected energy use for lighting and the HVAC system that has to overcome an unexpected heat load in summer.

# 4 Conclusion

The issue of the energy performance gap in retrofitting buildings poses a significant threat towards voluntary investments in energy efficiency measures, as their economic benefits are not often enough delivered. Factors in the operation phase, or at least identified as originating from the operation phase, do play an important role in this situation and have been identified in this report. They have been classified into six different categories offering a strong foundation for the identification and development of strategies in the Research Report 4, to overcome the energy performance gap during the operation phase. Two factors have been identified as preponderant and will be the centre of attention in Research Report 4:

The controls are the weak point of the Building Services and are generally the reason for drift in energy use after the building has been tracking properly for a period after the start of occupancy. They represent the technology factor.

Unpredicted usage profile of the building, often due to unexpected occupant behaviour, is the human factor contributing to the performance gap. In particular, activities outside business hours, such as staff working late, the cleaning team and security patrols, have unforeseen impacts on the star rating.

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