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ENERGY–MASS BALANCE: COMMERCIAL BUILDINGS
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Energy Efficiency Opportunities

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Some hypothetical energy-using activities are used as examples. They are for illustrative purposes only and are entirely fictitious. Any resemblance to past or present organisations or individuals is coincidental and unintended.

CONTENTS

FIGURES

TABLES

1 INTRODUCTION

The energy consumption of commercial buildings, while not as intensive as some industrial operations, is nationally significant. Commercial buildings are responsible for 10% of Australia's greenhouse gas emissions, and between 1990 and 2006 those emissions grew by around 87%.[1]

There is significant scope for corporations registered with the Energy Efficiency Opportunities (EEO) program to improve the energy efficiency of their commercial buildings. While the concept of an EMB is most intuitive in manufacturing and thermal processing activities, the benefits of the EMB process are equally applicable to commercial buildings. This guidance document outlines the key considerations for, and potential approaches to, the development of an energy-mass balance (EMB) for a commercial building to meet the requirements of the EEO program as detailed in the EEO legislation.[2] This is one of a series of EMB guidance documents, including guides for transport and mining operations.

1.1 ENERGY EFFICIENCY OPPORTUNITIES REQUIREMENTS FOR EMBS

Key Requirements 3.2(d), 3.3(b) and 3.3(c) of the EEO Assessment Framework, which is at Schedule 7 of the Energy Efficiency Opportunities Regulations 2006 (and also outlined in the *Industry Guidelines*), require that:

- The data collection process includes 'The energy and material flows through the site/fleet (e.g. through using an EMB or similar technique)'.
- The energy analysis process includes 'Application of a range of methods of data analysis (e.g. EMB, review of graphs and charts) to explore relationships between energy use and variables that may influence it, using data collected at appropriate time intervals'.
- A comparison of performance to theoretical and actual energy use benchmarks be undertaken, at the relevant level (process, technology, site, or indicator). Where appropriate, other detailed numerical analysis or the application of indicators and other comparative techniques are used to fully understand energy consumption, including its variability.

Box 1 provides further detail of the requirements for EMBs in the regulations.

BOX 1. EMBs IN THE ENERGY EFFICIENCY OPPORTUNITIES REGULATIONS 2006

Regulation 1.3 defines an EMB as a method of accounting for:

a) the materials and energy entering and leaving a site or fleet and its processes, systems or equipment; and

b) the energy and material flows, energy conversions and energy use within the site or fleet and its processes, systems or equipment.

Note 1 To enable an appropriate coverage, an EMB should define, to an accuracy of ±5%, at least 80% of a site's energy use and all processes not already included in the 80% that use at least 0.1 PJ of energy per year.[3]

Note 2 An EMB should provide a thorough understanding of:

(a) the material flows and energy use through a site, its processes and systems, and items of equipment including items such as pipes and ducts; and

(b) the specific services and products the energy use delivers; and

(c) the energy conversion processes within a system, and identification of conversions that are essential and efficient; and

(d) the identification of energy waste and energy efficiency opportunities.

1 Department of the Environment, Water Heritage and the Arts, *Commercial buildings in Australia* [online], Commonwealth of Australia, Canberra, 2009, available at http://www.environment.gov.au/sustainability/energyefficiency/buildings/commercial/index.html.

2 The EEO program was established under the *Energy Efficiency Opportunities Act 2006*, and detailed requirements are outlined in the Energy Efficiency Opportunities Regulations 2006. The EEO *Industry Guidelines* provide a plain English guide explaining what participating corporations need to do to meet the requirements of the program.

3 0.1 PJ, or 0.1×10^{15} joules, is equivalent to 27,778 megawatt hours (MWh).

There is scope for error margins larger than 5% for some flows or items of equipment in a building, consistent with being able to prepare a business case with sufficient rigour to meet the overall assessment data accuracy requirement.[4] Accuracy requirements should not be seen as a disincentive to detailed investigation of processes in the EMB.

More broadly, Key Requirement 3 sets out requirements for data collection and analysis, which provide guidance for developing an EMB. Energy consumption and cost data is required for each energy source. Data should be entered at the frequency that bills and other records are received (typically monthly) for a total of 24 months. The accuracy of total energy consumption data must be within ±5%. A less accurate level may only be used if this was approved in the Assessment and Reporting Schedule (ARS).

For verification purposes, an EMB will be good evidence of having addressed key requirements 3.2(d) and 3.3. Assumptions, calculations, equations used and decision processes should all be documented and kept for at least seven years.

This document provides guidance on the level of detail and considerations required in an EMB (or similar approach) to satisfy these requirements, and it indicates the standard that industry should attain. The document complements the EEO *Assessment Handbook*, which outlines the complete EEO assessment process on pages 10–12. This EMB guidance also complements the *Energy Savings Measurement Guide*, which provides guidance on how to estimate, measure, evaluate and track energy and financial savings from opportunities.

1.2 WHAT IS AN EMB?

In principle, an EMB is an approach used to understand the efficiency of energy conversion and how other inputs are used to deliver goods and services. Box 2 explains the technical underpinnings of the EMB. Preparation of an EMB involves a number of steps that are discussed in Section 2.3.

BOX 2. TECHNICAL BASIS OF AN EMB

An energy balance is a mathematical statement of the conservation of energy, and a systematic accounting for energy flows and transformations in a system. The theoretical basis for the energy balance is the first law of thermodynamics, which states that 'energy cannot be created or destroyed, only modified in form'. Contrary to mass balances, a system can only have one energy balance that describes it, since different types of energy are considered, mathematically, to be interchangeable. Specifically, the change in energy for a system equals the heat transferred into the system minus the work done by the system plus the net energy input associated with mass flows. Mass flows carry enthalpy[5], kinetic and potential energies.

An EMB is a model, from an energy perspective, of how a process or system works. It helps to understand the energy flows, mass flows, and other factors influencing energy efficiency, to determine the efficiencies of processes and equipment, and to evaluate the effects of external factors. For commercial buildings, these may include the location of buildings, the work tasks performed within the building, occupant behaviour, external temperature and weather conditions and architectural design of the building. For example, if a building has a large area of north-facing windows, passive solar gain may reduce the amount of heating required in the winter. However, additional cooling or shading may be required during warmer periods to mitigate the effects of this heat inflow.

4 For example, the electricity and gas consumption at a commercial building should be known to within ±5% from billing data. By contrast, the heat released from pipes, ducts and people, and heat transfers through the building walls, floors and roof space might have higher error margins.

5 Enthalpy is a measure of the 'heat content' of a material, and is tabulated in engineering texts and handbooks. It equals the sum of the internal energy and the product of the pressure and volume of the material.

1.3 WHAT ARE THE BENEFITS OF AN EMB?

Thorough EMBs reveal significant energy and cost savings by identifying:

- how much energy is being used, wasted or lost—and where this occurs
- whether the systems and equipment are operating according to design and work schedules
- energy use variability and its underlying causes
- whether usable waste heat is being produced—or processes could be alternatively powered
- the efficiency of energy-using processes within the business.

EMBs also provide a structure for examining interactions between the different components of a business operation. For example, an EMB can be used to examine whether energy use adjusts to the demand for services. An EMB can also help to identify interactions between people, technologies and energy use, rather than looking independently at the technical performance of individual items of equipment. Accounting for these interactions and human factors helps to ensure that identified opportunities can be effectively and reliably implemented.

An EMB requires a company to look at its business or site as a whole system. This can provide the data required to question assumptions about existing patterns of energy use and production. In the process, an EMB can help to identify novel or innovative ways of producing products or services with substantially lower energy and resource inputs. The EMB can potentially incorporate other resource constraints such as water usage, use of non-renewable resources, waste, logistics and occupant behaviour.

As with other business improvements, the benefits from an EMB are dependent on the level of detail in the analysis involved. Experience with the EEO program to date suggests that detailed EMBs that analyse the way in which energy is used by specific processes, sub-processes and items of equipment deliver favourable benefit–cost ratios. By comparison, companies that merely develop high-level energy use breakdowns, limited, for example, to pie charts of energy end uses by technology, derive much less benefit from the process.

1.4 WHERE DOES AN EMB FIT IN THE ASSESSMENT PROCESS?

As noted in Section 1.1, an EMB is a major part of the data collection and analysis component of an EEO assessment. An EMB systematically collects and analyses data on energy use, and investigates where losses occur. It is therefore a useful input to background papers, workshops, meetings, specialist studies and other activities used to identify and investigate opportunities. Developing a first iteration of the EMB for opportunities identification workshops focuses the opportunity identification process on those areas with the greatest energy-saving potential.[6] This enables workshop participants to develop more rigorous ideas and opportunity savings estimates.

Once companies have identified an initial list of opportunities, the preliminary EMB should be improved to build up a detailed and accurate understanding of the energy and material flows through the fleet or site. The first iteration of the EMB should provide the highest accuracy obtainable with the available data and analysis tools, plus a clear plan to improve accuracy over time so as to better understand energy use and identify further opportunities. A detailed EMB will determine the energy use of specific processes, ancillary equipment, and the variables that influence energy use at all three levels.

In addition, a detailed EMB will be very useful for evaluating the opportunities already identified to an accuracy of 30% or better (as specified by Key Requirements 4.3 and 4.4 of the Assessment Framework). Thorough EMBs can be used to estimate energy savings and other whole-of-business costs and benefits for an opportunity. Following opportunity implementation, EMBs can also be used to measure the actual savings realised from implementing projects, and to examine interactions between different projects.

6 Providing a more detailed EMB for workshops will produce more realistic and feasible ideas and opportunities.

1.5 IS THERE A PRESCRIBED METHOD FOR A COMMERCIAL BUILDING PORTFOLIO EMB?

Under the EEO program, companies are required to analyse energy and mass flows sufficiently to satisfy the EEO requirements for an EMB or equivalent. Subject to this constraint, there is flexibility for companies to adapt the EMB or equivalent approach to their circumstances to meet program requirements efficiently.

In addition to physical factors, the EMB approach may be determined initially based on data/measurement availability as well as company organisation. The optimal approach for any company will depend on initial data availability, measurement systems and the personnel available for the EMB process. For verification purposes, companies should be able to justify the chosen approach to collecting and analysing energy and material flows and should make sufficient resources available to satisfy program requirements.

Corporations with large building portfolios may be able to adopt a 'representative assessment' approach. The EEO *Representative Assessment Guide* provides guidance on assessing energy usage and opportunities in multiple, similar operations, including statistical sampling techniques relevant to commercial buildings. Section 2 of this document presents a general approach to developing an EMB for a commercial building.

2 WHAT DOES AN EMB FOR A COMMERCIAL BUILDING LOOK LIKE?

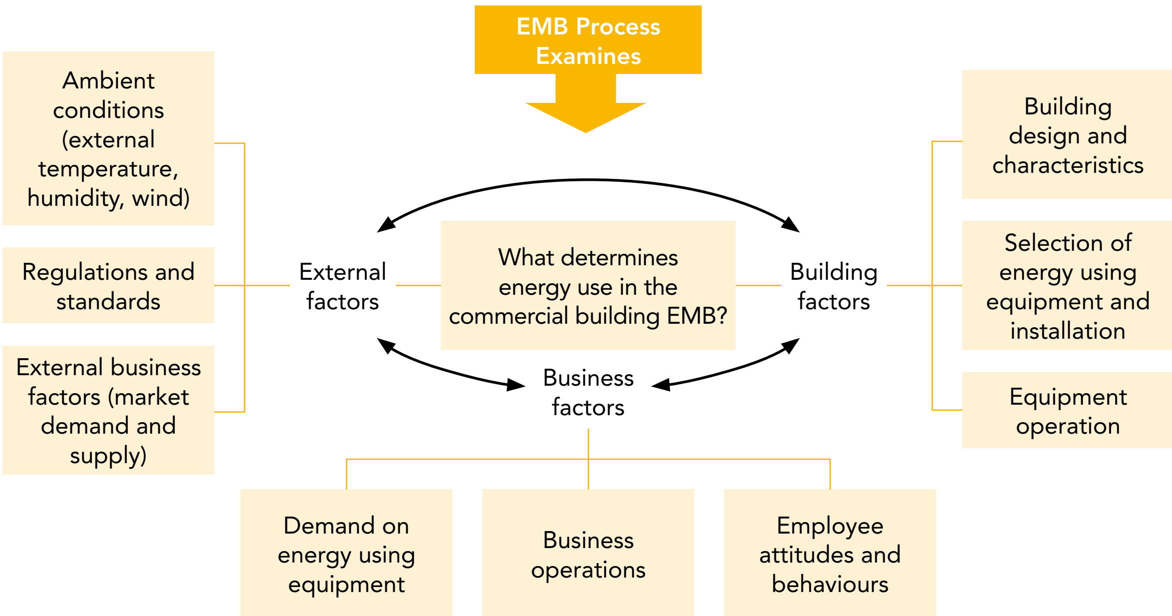
Energy use in buildings is influenced by a number of organisational, building-specific and external factors, many of which also affect productivity. The EMB process aims to identify and analyse the impacts of these factors on energy use and how these factors interact.

While the concept of an EMB is most intuitive in manufacturing and thermal processing activities, the benefits of the EMB process are equally applicable to commercial buildings. This document presents the key considerations involved in developing an EMB for a commercial building.

As a first step, it is recommended to map out the building portfolio so as to identify the key factors that influence energy use. This mapping is a brainstorming process that helps to identify how operational factors, external influences and building characteristics interact and contribute to energy use. Mapping these influences will help to establish which data need to be collected and may indicate which energy-using systems in the commercial building have the strongest interactions. Figure 1 presents a high-level schematic of a process map of factors affecting energy use in an EMB for a building portfolio.

Having mapped out the various factors that influence energy use, the next step is to determine how best to organise the analysis and which parts of the building portfolio should be given priority. The proposed approach is to break down the portfolio into three broad levels for analysis, as discussed in Section 2.1.

Figure 1: Influences on a commercial building EMB



2.1 LEVELS OF ANALYSIS

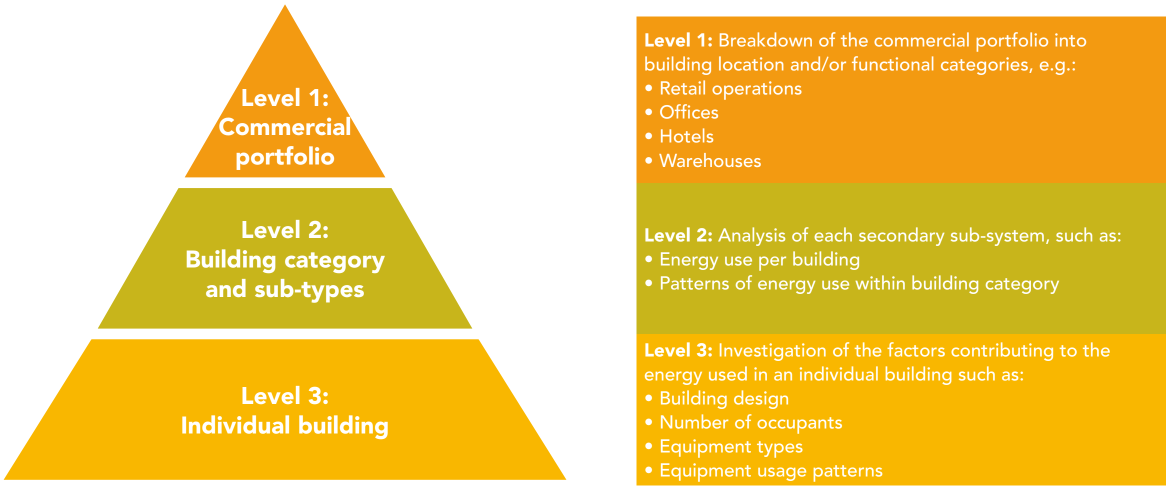
An effective commercial building portfolio EMB has three broad levels of analysis, each of which interacts to form a complete system. These three levels, illustrated in Figure 2, are described below:

- *Level 1.* At the top level, there is the breakdown of the commercial portfolio into building location and/or functional categories, such as retail, office or hotel. This high-level breakdown helps to identify priorities for further analysis, clarifies which parts of the portfolio should be included in the EMB, and indicates appropriate subsystem boundaries.
- *Level 2.* At the next level of the EMB there is the analysis of data and characteristics of each secondary subsystem, such as the energy use per building and the patterns of energy use within that building category. Such analysis may reveal the factors affecting energy use within the building

category as well as potential energy efficiency opportunities that may be implemented across the entire category.

- *Level 3.* The final level of the EMB investigates the factors contributing to the energy used in an individual building, such as building design and heating, ventilation and air conditioning (HVAC) system performance. Individual building models enable estimation of the benefits of implementing energy efficiency opportunities in an individual building. This includes investigating how the broad energy use factors identified in the level 2 analysis affect energy use at the individual building level. The model can also be used to estimate the effects and feasibility of implementing opportunities across a level 2 category, possibly as part of an approved *Representative Assessment* approach.

Figure 2: Three levels of analysis for a commercial building EMB



The guidance provided in this document concentrates on the EMB process at level 3, presenting techniques that can be used to break down energy consumption on an end-use and time-of-use basis for a commercial building. The EMB approach depends on the design features of the building and the configurations of energy systems installed.

2.2 MASS FLOWS AND EFFECTS IN COMMERCIAL BUILDINGS

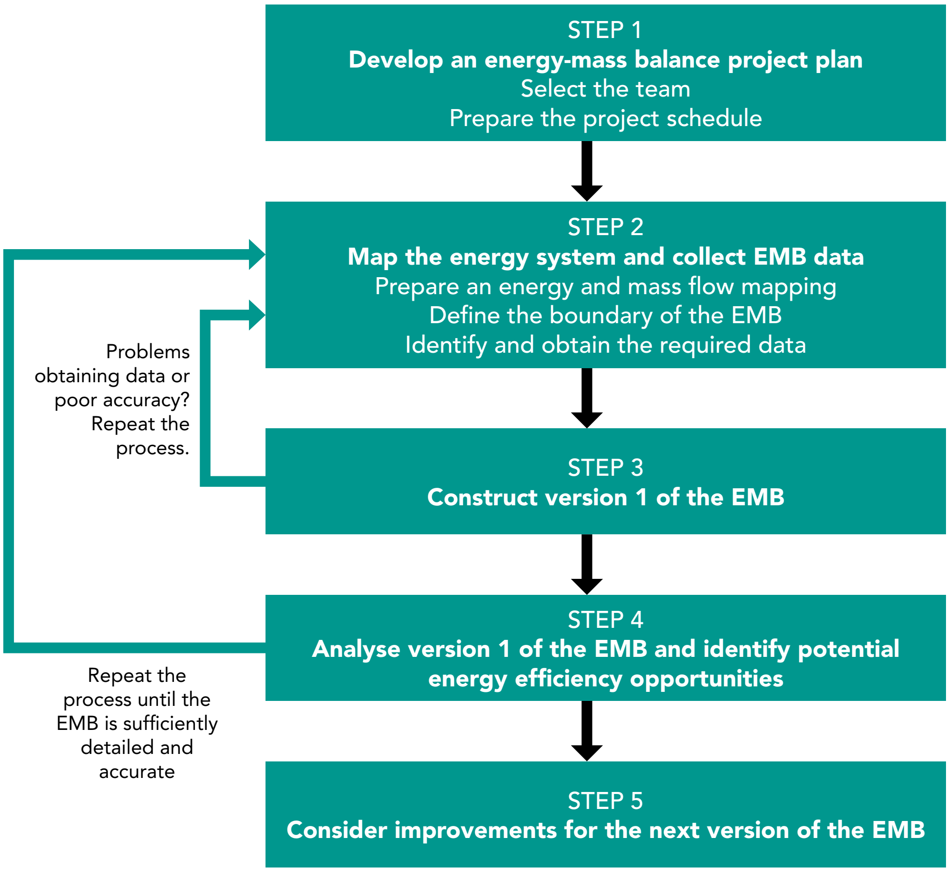
Accounting for mass 'flows' through a commercial building is necessary to gain an effective understanding of overall building energy use. The mass flows will depend on the type of business operations that are conducted within the building. Mass flows common to all commercial buildings include air, water, products and people. Mass flows that might apply to only some commercial buildings include food, meals and refrigerants in refrigeration systems.

An EMB can use a variety of modelling approaches, such as engineering calculations, regression analysis or direct measurement. These and other methods are described in Section 3.2 and detailed in the *Energy Savings Measurement Guide*.

2.3 STEPS IN DEVELOPING AN EMB FOR A COMMERCIAL BUILDING

Figure 3 illustrates the basic steps involved in developing an EMB for a commercial building. An EMB is an iterative process, and typically needs to be refined as the analysis progresses so as to obtain the required accuracy.

Figure 3: Basic steps to develop a commercial building EMB



2.3.1 Personnel and skill requirements

As outlined in step 1 of Figure 3, in order to develop an EMB, input from a range of people from the site and possibly external to the site will be needed to provide information and expertise to the process. In addition to the organisational skills required to ensure that the EMB process is planned and resourced appropriately, there is a need for staff with appropriate knowledge of the energy-using systems and business activities conducted within the commercial building. Table 1 outlines these skills and indicates which staff and other professionals may provide them.

Table 1: Skills and knowledge needed for a commercial building EMB

System	Skills and knowledge	Potential benefits	Suitable staff or external professionals
HVAC	Understanding of systems and technology	Identification of efficiency opportunities through operational, maintenance, control and commissioning issues and equipment upgrades	Mechanical engineers with HVAC experience for analysis, opportunity identification and design solutions HVAC maintenance staff and technicians for relevant data, field experience, specifications and implementation
Electrical equipment	Understanding of the operation and technology	Identification of opportunities through operational and control changes and equipment upgrades	Electrical engineers for analysis, opportunity identification and design solutions Building managers or electricians for information on circuits and system layout, and for implementation
Process operations	Knowledge of the operations conducted within the building	Identification of opportunities arising through changes to process structure and operation	Building facility managers Staff involved directly with the work process
Data	Ability to develop and manipulate relatively complex spreadsheets	Accuracy and speed of analysis, improved data manipulation, interpretation and presentation of results	Energy managers, mechanical/electrical engineers Project managers or building managers Data analysts, e.g. statisticians
Mass flows and environmental factors	Ability to model mass flows through the building, and other environmental factors affecting energy use, such as solar gain	Estimation and modelling of mass flows, energy process interactions and additional energy flows into the building, which are not paid for directly but which affect energy demand	Mechanical, chemical or systems engineers for the analysis and modelling of mass flows Energy efficiency specialists Process staff and building tenants for provision of data

2.3.2 The EMB project plan

An EMB requires effective project management to ensure that the process is completed within business and EEO program timelines. The project schedule should identify the main steps and milestones involved in developing the EMB, bearing in mind the quantity and quality of data available. Developing an EMB is an iterative process, so an EMB can incorporate data from additional measurement systems as they are implemented. An example project plan for a commercial building EMB is shown in Table 2. Further iterations of this plan may be required for subsequent stages of the EMB, in order to improve data accuracy.

Table 2: Example project plan for stage 1 of a commercial building EMB

Task	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Schedule tasks																					
Prepare energy system mapping																					
Identify systems to analyse																					
Identify required data																					
Conduct initial EMB analysis based on estimates and available data																					
Construct version 1 of the EMB																					
Analyse results to identify data and measurement gaps																					
Refine analysis and install any additional metering																					
Capture required energy and mass flow data																					
Construct revised EMB																					
Analyse results																					
Rectify any remaining data gaps and refine analysis																					
Analyse results of implemented opportunities																					
Collate revised results for public and government reporting																					

2.4 MAPPING ENERGY AND MASS FLOWS

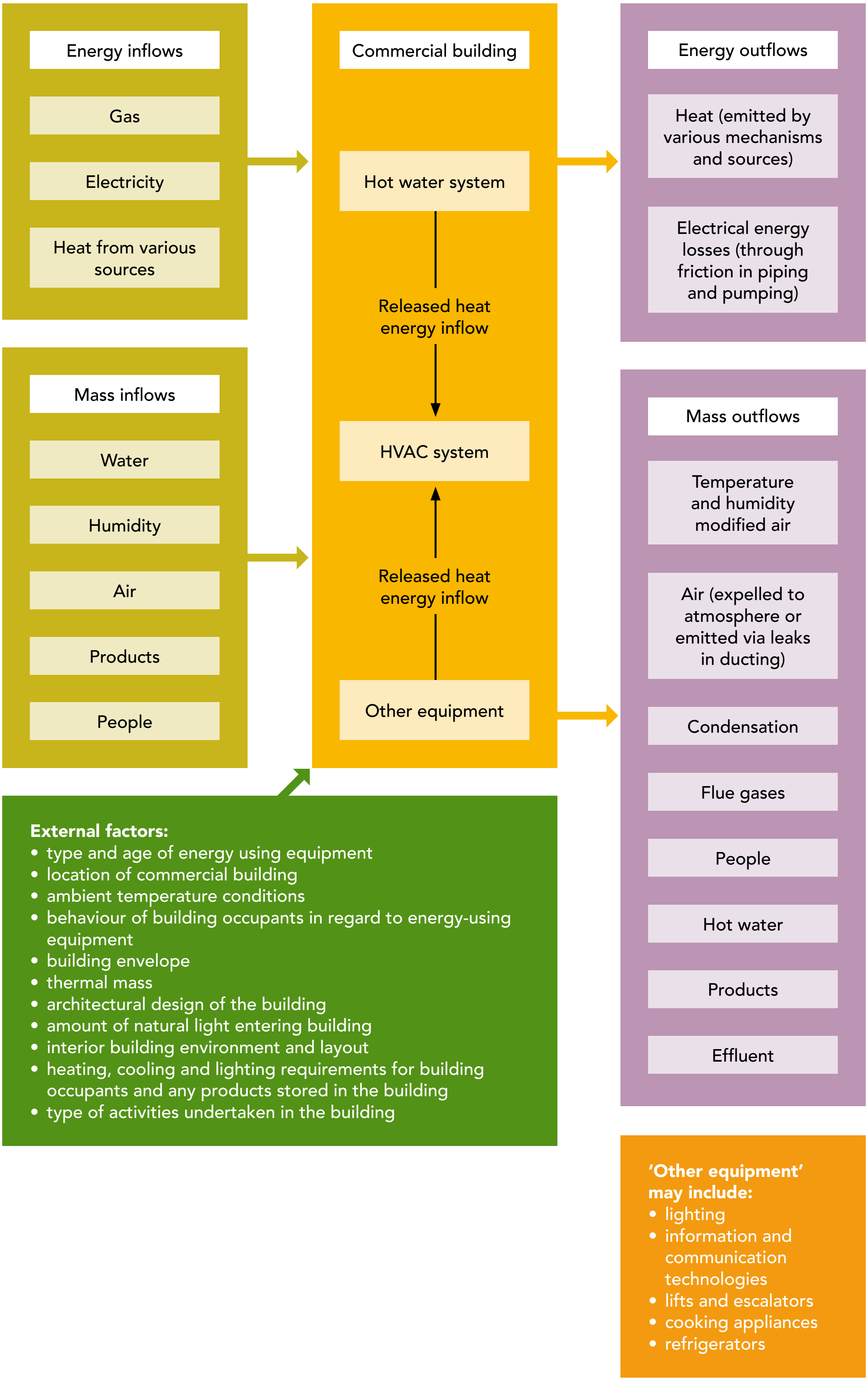
The aim of the EMB is to improve understanding of the energy system and to provide insights into potential energy efficiency opportunities. The first step in an EMB is to investigate the various factors that influence building energy use and to map these influences. Brainstorming the factors that influence commercial building energy use and their interactions helps to determine the appropriate way to break down the EMB and prioritise the analysis.

To map the system, start by considering:

- the building design and location
- activities undertaken in the building (e.g. office work or retailing)
- overall system configurations (e.g. the types of HVAC and lighting systems installed)
- any additional energy-using systems (e.g. refrigeration systems or kitchens)
- factors that define quality of output (these might be described in key performance indicators used by the organisation)
- the factors that influence overall energy efficiency.

An initial energy use and mass flow mapping is illustrated in Figure 4.

Figure 4: Overall energy and mass flow mapping for a commercial building



2.5 SPECIFIC SYSTEMS USED IN BUILDINGS

Sections 3 to 6 provide guidance on the key considerations for the assessment of energy and mass flows associated with four key energy consuming systems and elements within a commercial building. These are:

- HVAC systems (Section 3)
- lighting systems (Section 4)
- information and communication technologies (Section 5)
- other equipment, such as cooking appliances, hot water systems, refrigeration equipment and other miscellaneous electrical equipment (Section 6).

These sections apply the steps following the planning stage and the overall mapping of energy and mass flows, namely steps 2 to 5 set out in Figure 3. Sections 3 to 6 also discuss energy efficiency opportunities associated with each of these systems.

Since HVAC systems interact with other energy-using systems within the building and require fairly detailed analysis, Section 3 also discusses three different ways to quantify energy and mass flows: metering, building simulation and engineering calculations.[7] Methods presented in Section 3.2 can also be applied to other systems in a commercial building.

When determining which systems to analyse within a commercial building, in order to meet the EEO requirements outlined in Box 1, it is important to consider which systems consume the most energy as well as where potential inefficiencies are located and hence where greatest energy savings might be realised. A minimum of 80% of a building's energy use must be analysed in the EMB, which ideally should include all equipment and processes that consume more then 0.1 PJ across the corporation's building portfolio.

7 Section 3 draws extensively on BL Capehart, WC Turner, and WJ Kennedy, *Guide to energy management*, 4th edn, The Fairmont Press Inc, Georgia, 2003, chap. 6.

3 HEATING, VENTILATION AND AIR CONDITIONING SYSTEMS

HVAC systems in commercial buildings add or remove heat and moisture (humidity) to maintain the desired environmental conditions for employees, products or equipment. HVAC systems also filter and recirculate air to remove odours, dust, pollen and other undesirable air particles to provide acceptable interior air quality.

HVAC systems deliver temperature and humidity modified air to the interior of a commercial building via a series of pumps, motors, fans, ducts, controls and heat exchange units. Heat in a HVAC system is usually supplied by a boiler or furnace, with chillers or refrigeration units providing cooling. Because HVAC systems account for around 33% of energy consumption and associated costs for Australian commercial buildings,[8] they are an important part of commercial building EMBs.

Energy efficiency has not historically been a major consideration in the design and installation of commercial building HVAC systems. Existing systems were often designed to meet extreme load conditions, such as very hot weather, rather than to meet the typical demands placed on the system. Therefore, there are significant opportunities to improve the energy efficiency of existing HVAC systems and reap energy and cost savings.

3.1 EXAMINING THE BASELINE PERFORMANCE OF THE HVAC SYSTEM

Analysis of the energy and mass flows for the HVAC system of a building helps to determine the energy baseline model—how the system is performing based on the current systems and settings. This becomes the reference point or model from which to measure energy savings. Calculating the baseline may also reveal areas where the HVAC system is underperforming or where HVAC control system parameters are not well matched to building requirements. Changes in these areas may provide energy and cost savings while improving working conditions for occupants.

HVAC system energy use is strongly affected by ambient temperature and humidity. Instantaneous temperature and humidity measurements can be made using thermometers and hygrometers. However, for a more thorough analysis of the performance of the HVAC system, temperature and humidity data loggers should be positioned in different internal building zones and externally to the building for an extended period of time. Logging data over time provides data on the performance of the HVAC system at different times of the day and under varying external climatic conditions.

Variations in external temperature and humidity can then be compared to internal variations to gauge the effectiveness of the HVAC system at moderating these variables. The internal measurements can also be compared to applicable standards or system characteristics, to determine whether interior temperature and humidity levels meet requirements.

Measuring particulates in the air circulating within the building also helps to quantify the performance of the HVAC system. These measurements can be made using particle measuring systems or air particle counters and then compared to relevant Australian standards.

Staff attitudes and qualitative observations can be used to gauge the performance of the HVAC system. Staff surveys or observations can reveal occupants' experience with the performance of the HVAC system as external conditions change, and can identify critical aspects of the HVAC system requiring detailed investigation, such as excessive temperature differences between different zones in a building.

Comparing the measured volumetric or mass flow rates of air from the HVAC system to levels calculated or determined from specifications can also help to gauge the performance of the system. Such analysis may reveal potential air leakage within the HVAC system.

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8 A Pears, *Energy efficiency improvement in the commercial sector, draft*, Melbourne, 2006; cited in the Centre for International Economics, *Capitalising the buildings sector's potential to lessen the costs of a broad based GHG emissions cut*, prepared for the ASBEC Climate Change Task Group, Canberra, 2007.

3.1.1 Identifying mass and energy flows

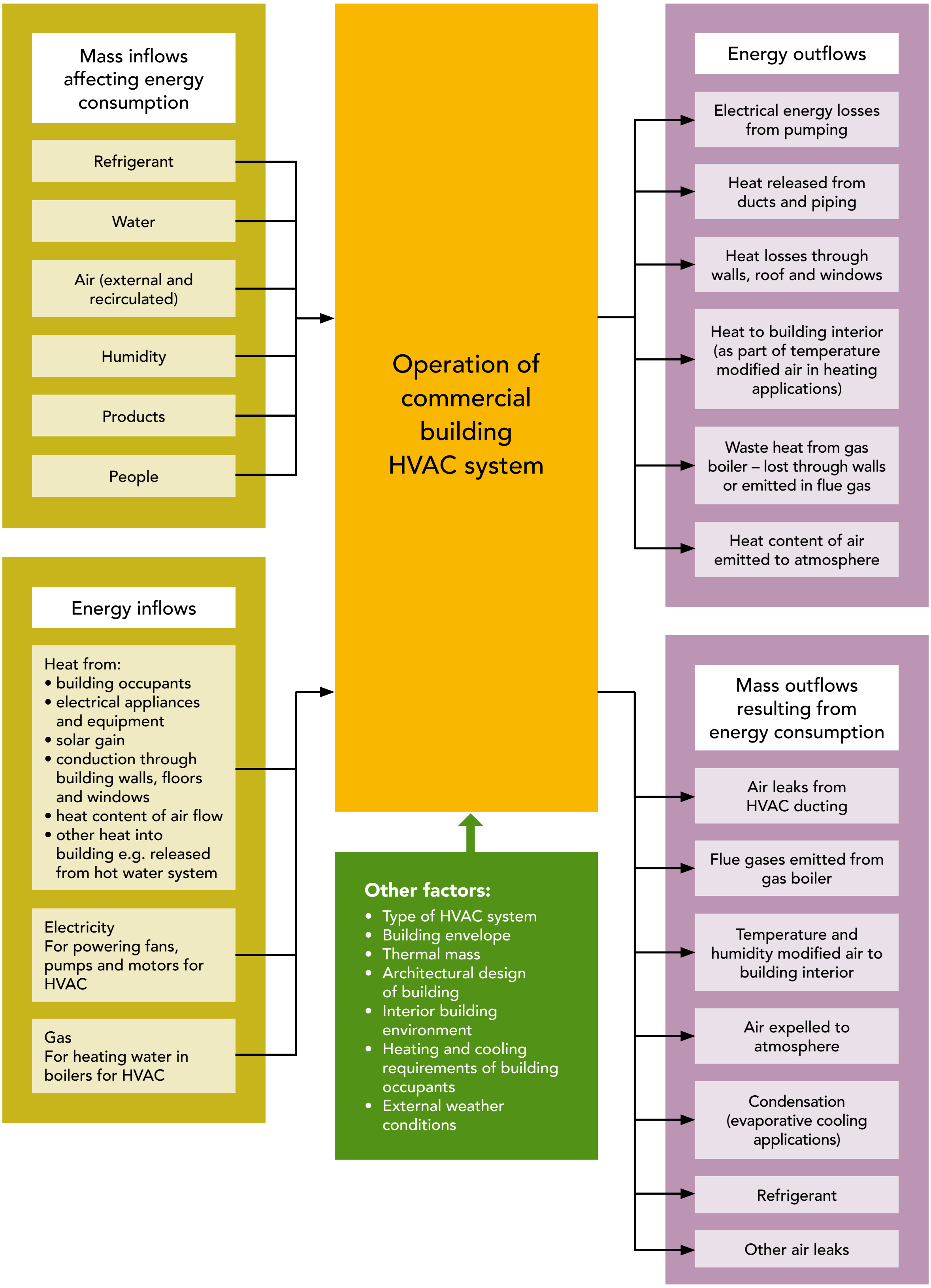
Energy flows for HVAC systems include not only the electricity and gas inputs required to operate the system, but also environmental heat transfers. Heat transfers occur via the three mechanisms of convection, conduction and radiation, and are always directed from hot to cold. Major heat transfers occur through building walls and as a result of solar radiation, mostly through windows. Within the building, heat is released by electrical and gas appliances, building occupants, hot water piping and hot air ducting. All of these heat transfers affect HVAC system demand.

The mass flows within a HVAC system are the air, vapour and fluid flows. These include air and humidity moving through fans and ducts, as well as refrigerants and other liquids in chillers, pumps and condensers. These mass flows carry embodied energy, including the latent heat required for phase changes. Energy is required to move fluids through pipes and air through ducting, and for compressors.

Indirect or external mass flows affecting the energy consumption of HVAC systems include not only water, air and humidity, but also products and people. The energy consumed by a HVAC system will often vary with the number of people who occupy the building. HVAC system energy consumption can also be influenced by products that are stored in the building, as some products will require the interior temperature to be regulated to maintain product integrity. Examples include food and beverage products stored in coolrooms, chemicals stored in laboratories or hot food in restaurants or hotels.

Figure 5 illustrates the energy and mass inflows that may affect the operation of a HVAC system, as well as the energy and mass outflows that result from the operation of the system. Air movement from entrances, exits, windows, exhaust outlets, roof openings and cracks in a building (if applicable) also affect HVAC system energy use. These indirect mass flows should be included in the EMB analysis, either as system parameters or requirements, depending on the flows.

Figure 5: Typical energy and mass inflows, external influences and resulting energy and mass outflows for HVAC systems



3.1.2 Design factors affecting HVAC system energy consumption

The degree to which the energy and mass flows illustrated in Figure 5 will affect energy consumption will depend on several other factors. These factors include the performance and type of the HVAC system, the architectural design of the building, the interior environment, the heating and cooling requirements of building occupants and the local climate. These factors should be considered when analysing a portfolio of commercial buildings in different locations or used for different purposes, as they may explain variations in HVAC system energy consumption.

The energy and mass outflows illustrated in Figure 5 are highly dependent on the age and operational performance of the HVAC system. If the ducting or piping used to direct air and water around the building has minimal or no insulation, HVAC system heat transfers would be greater. Likewise, if a gas boiler is used for heating applications, an older, less efficient and poorly insulated boiler would expel more heat and flue gases.

The age, type and quality of pumps and fans used in the HVAC system will also affect the electrical energy losses from pumping and air distribution. Pumps can suffer corrosion and deterioration from fouling, corrosion and cavitation. Choice of pump design and operating range can significantly affect efficiency and energy requirements.

The amount and composition of mass outflow will depend on the operational settings of the HVAC system (i.e. heating or cooling), the type of system and specific building requirements. For example a laboratory, workshop or specific storage area may require additional ventilation to ensure that any potentially harmful gases or substances are removed from the building. Heating and cooling requirements will peak at external temperature extremes, particularly during summer and winter periods.

3.2 METHODS FOR QUANTIFYING KEY ENERGY AND MASS FLOWS

Determining the baseline energy and mass flows for a HVAC system can be simple if accurate sub-metering is in place and good quality information can be obtained from the HVAC control system.

In the absence of metering, engineering calculations or building simulations can be used. Simple engineering calculations can provide a first-pass estimate which will indicate which energy and mass flows require more detailed examination and potential metering.

Quantification of the other energy and mass flows will be based on metering, building simulation or engineering calculations, as described in Sections 3.2.1 to 3.2.3.

3.2.1 Metering

If separate metering is available for the HVAC system within a commercial building, determining the electricity and gas consumption will be straightforward. If this data is recorded as part of the HVAC control system, instantaneous and cumulative data may also be available. Such data systems enable analysis of variations in energy consumption under different external weather conditions and at different times during the day and year.

Some buildings may have site-level metering but no sub-metering for individual pieces of equipment or work processes. Lack of metering will affect the accuracy and rigour with which an EMB can be carried out on a site or process. In the absence of metering, an initial EMB can be developed using estimates or simulation while arrangements are made to install metering equipment.

3.2.2 Building simulation/modelling software

While simulation software is mostly used as part of the building design process, it can also be employed as a diagnostic tool for the EMB. To estimate energy use, simulation takes into account the complexities of the building and its local environment, as well as the characteristics of HVAC and other systems. An effective simulation provides a comprehensive benchmarking tool against which estimates and measurements can be compared. Simulation software also supports sensitivity analysis that can be used to explore energy efficiency opportunities, and provides numerical data for use in preparing business cases.

Building simulation and modelling software and HVAC control systems can simulate some of the energy and mass flows associated with the operation of the HVAC system. Such energy and mass flows may include:

- electricity and gas consumption
- external air inflow
- temperature and humidity modified air outflows
- return air outflows
- air leakage rates from ducting
- water flow rates and temperatures
- solar gain and heat conduction through building windows and walls
- heat emitted to the exterior environment after removal from the building.

3.2.3 Estimation using engineering calculations

If no metering of HVAC system components is available, then energy consumption may initially need to be estimated using instantaneous power ratings labelled on HVAC system components and other data that may be available from manufacturers. Energy use figures may be directly obtainable from the HVAC control system in some cases.

In practice, some of the EMB data will need to be estimated using engineering calculations, which will principally involve thermodynamics, heat transfer and fluid mechanics. These theories can be applied in simpler forms during the initial EMB, and refined in subsequent versions to improve accuracy. Note that actual energy requirements may differ from the manufacturers' data due to equipment degradation and the system layout. For example, the energy used by a fan will be affected by the layout of ducting, the amount of fouling on blades and the age and condition of motors and other components.

The following sections outline potential methods for estimating some energy and mass flows that are not directly metered.

3.3 HEAT EMITTED BY ELECTRICAL EQUIPMENT AND OCCUPANTS

The amount of heat that occupants transfer to the building will depend on the number of occupants and the activities they undertake. Table 3 details the heat given off by building occupants during different activities.

Table 3: Heat introduced to building interior by occupant, by activity

Activity	Heat emitted (W)	Heat emitted (kJ/h)
Seated at rest	100	360
Seated, light office work	120	432
Standing or walking slowly	145	522
Light physical work	250	900
Heavy physical work	470	1,692

W = watts; kJ/h = kilojoules per hour

Source: Adapted from American Society of Heating, Refrigerating and Air-Conditioning Engineers, *Handbook of fundamentals*, Atlanta, Georgia, 1989; cited in PS Curtiss, JS Haberl, J Huang, D Jump, JF Kreider, A Rabl, TA Reddy and M Sherman, *Handbook of heating, ventilation and air conditioning*, CRC Press LLC, Boca Raton, 2001, chap. 6.

The number of occupants will vary depending on the activities conducted within the building and the time of day. Ideally, HVAC system settings should be adjusted for the level of occupancy and the associated heat load. Electrical appliances and ICT (Section 5) energy use will also vary with occupancy.

Quantifying the number of people who enter and leave a building is a difficult exercise and one that may require different approaches before the preferable method is identified. Optical people counters may provide a means of obtaining this data, however other forms of metering may be required if current systems do not provide data of sufficient accuracy. Obtaining this data will inform analysis of the energy and mass flows within a building, and may also provide useful business information about customer behaviour for retailers or customer service centres.

The heat flows resulting from the operation of electrical equipment within a building can be easily approximated based on the assumption that all the energy supplied to the equipment will eventually be dissipated as heat.[9] However, it is important to remember that the energy consumed by electrical appliances, other than simple appliances such as lights, will not always match the labelled instantaneous power rating. Therefore, a usage factor may need to be applied to the power rating to determine the heat produced. It is preferable to use a digital power meter or data logger to accurately determine the power rating and subsequent heat emitted (see Section 5.4).

3.4 HEAT TRANSFERS

Heat inflows and outflows resulting from the three modes of heat transfer[10], conduction, radiation and convection of heat via building walls, floors and roofs, can occur over an extended period of time, as heat is absorbed by surfaces and then progressively released. The time over which this occurs depends on the thermal mass of the building. The thermal mass of the building depends on the materials used in construction, as well as the additional insulation that may be present in walls, floors or roofs.

The amount of heat transfer through building walls, floors and roofs depends on the heat transfer coefficient, or U-value, of the surface and the air temperature difference between the environments separated by the surface. The thickness and type of insulation will alter the U-value for the wall, floor or roof, affecting the rate of heat transfer and the load on the HVAC system.

Heat transfer rates and building U-values can be determined using building modelling software or engineering calculations. Further information about the calculation of heat transfer rates and insulation can be sourced from engineering handbooks.[11]

Heat transfers from the pipes and ducting will depend on the physical properties of the fluid, the air temperature in the area external to the pipe or duct, the volumetric flow rate or velocity at which the material travels, and the properties of the piping or ducting material.[12]

The mass flow rates for water and air can be directly measured using flow meters, or determined from data obtained from control systems or technical specifications. The physical properties of air or water can be obtained from thermodynamics texts or engineering handbooks.

Building or pipe and duct modelling software can be used to calculate the heat transfers associated with the flow of hot water or air through pipes and ducting. Engineering calculations for turbulent heat transfer in a tube can also be used to calculate these heat flows.

If substantial heat transfers are identified for various utilities in the building, then current levels of insulation may not be optimal and additional insulation may deliver energy and cost savings.

The waste heat outflow from a gas boiler can be determined from the combustion efficiency. The combustion efficiency represents the percentage of energy input that will heat incoming water, with the remaining energy being converted to waste heat and emitted as part of flue gases or lost through boiler walls. For example, if a gas boiler has a combustion efficiency of 85% and consumes 650 GJ of energy, then around 98 GJ of waste heat will be either radiated through boiler walls or emitted as a component of flue gases produced by the boiler.

9 BL Capehart, WC Turner, and WJ Kennedy, *Guide to energy management*, 4th edn, The Fairmont Press Inc, Georgia, 2003, chap. 6.

10 The mode of heat transfer that predominates will depend on the conditions and material characteristics. Conduction is the transfer of energy between materials or particles at different levels of excitement. Convection is the mode of heat transfer between a solid surface and an adjacent liquid or gas that is in motion. Radiation is the energy emitted by a material in the form of electromagnetic waves due to changes in the temperature of the material.

11 See, for example, F Kreith (ed), *CRC handbook of thermal engineering*, CRC Press LLC, Boca Raton, Florida, 2000.

12 Note that 'fluid' includes air and other gases.

3.5 SOLAR GAIN

The heat transferred through windows by sunlight, referred to as passive solar gain, is an energy flow that depends on the following properties of a commercial building:

- area and orientation of glass windows
- number and size of curtains or shade awnings on windows
- amount of shade that the building receives from either trees or adjacent buildings
- the location of the building.

In order to obtain a first-pass estimate of the magnitude of solar gain, the summer cooling load created by solar heat gain in commercial buildings can be approximated using the following equation:

$q = \sum A \times DSI \times SHGC \times CLF$, where:

- *q* is the daily cooling load in megajoules (MJ)
- A is the area of windows that have the same orientation, in square metres (m^2)
- DSI is the daily solar irradiation on a vertical plane measured in MJ/m^2. DSI values for Australia will vary based on the geographic location and orientation of the vertical plane (building window). These values, which can be obtained from the Australian and New Zealand Solar Energy Society's Australian Solar Radiation and Data Handbook[13], may need to be modified to reflect the amount of shading provided by eaves or trees at certain parts of the day, depending on the angle of incident solar radiation.
- SHGC is the solar heat gain coefficient, which varies between 0 and 1 and represents the fraction of heat from solar radiation that enters through a window.[14] SHGC can be obtained from window manufacturers and retailers.[15]
- CLF is the cooling load factor for glass, which accounts for the storage of heat from solar radiation that is transferred into the building at a later point in time.[16] CLF factors can be determined from engineering handbooks.

If this first-pass estimate indicates that solar gain will be a significant energy inflow, then solar gain may warrant further examination, potentially through computer-based simulation and modelling or the use of external consultants, to more accurately quantify this energy flow.

When calculating the solar gain, it is advisable to estimate annual values in at least monthly increments, as irradiation varies seasonally. Building modelling and simulation software can adjust for climatic factors, building design (which affects retention of the heat from solar gain) and types of glazing. It is also important to note that in commercial buildings the ratio of external surface area to floor area is often low, so solar gain may prove to be a minor energy flow affecting a HVAC system.

3.6 MASS INFLOWS AND OUTFLOWS

Data for some key mass inflows and outflows associated with the operation of a HVAC system should be available from billing or metering. These flows include products, water and occupancy. Quantifying these flows not only assists with the development of the EMB, but also with developing an understanding of occupant behaviour, water use, and logistical factors for buildings where product handling forms a major part of business operations.

13 See http://www.anzses.org/index.php?q=node/22 for more information. This reference material needs to be purchased from the Australian and New Zealand Solar Energy Society.

14 Building Energy Codes Resource Center, *What is a window SHGC?* [online], The United States Department of Energy, Washington, 2009, available at http://resourcecenter.pnl.gov/cocoon/morf/ResourceCenter/article//93.

15 Older windows might refer to the shading coefficient (SC) rather then SHGC. In this case the following calculation can be used to convert SC to SHGC: SHGC = 0.87 × SC. See Building Energy Codes Resource Center (2009), *How do I Find the SHGC for my Windows?* [online], The United States Department of Energy, Washington, available at http://resourcecenter.pnl.gov/cocoon/morf/ResourceCenter/article//101.

16 University of South Australia, School of Advanced Manufacturing and Mechanical Engineering, *Lecture 2—Heating and cooling load calculations* [online], University of South Australia, Adelaide, 2005, available at http://www.unisanet.unisa.edu.au/Resources/10767/Energy%20System%20Design/Lecture%202/Lecture-2-BW.pdf.

If refrigerant is used as a working fluid within a HVAC system, it must be considered as part of an EMB, even if fluids are cycled within a closed loop and their total mass is conserved. This is because the fluid circulation is related to energy use. Energy is required to compress and pump the working fluid, while phase changes involve latent heat. There may be scope to improve system efficiency by adjusting some components, such as condensors, radiators or pumps. The coefficient of performance of a system can indicate the scope for improvement relative to the more efficient systems available.

The rate of inflow of ambient air into a HVAC system and air flows delivered by the system should be quantifiable based on information obtained from the HVAC control system or using operating specifications combined with engineering calculations. Similarly, the air expelled from the HVAC system should also be quantified via the control system. The heat content of these air inflows and outflows can also be estimated, by multiplying the flow rate by the enthalpy of the air at a given temperature, as tabulated in engineering texts.

If the HVAC control system is unable to quantify the volumetric flow rate of air, as may be the case in older buildings, a potential option for measuring this mass flow could be to use an anemometer to measure air flow rates. Note that several measurements are required, under different operating conditions, so that the performance of the system can be compared to manufacturer's specifications.

If a gas boiler is used as a source of heat in a commercial building, excess air will be a mass flow expelled as part of the flue gases produced by the boiler. Excess air is defined as the amount of air that is supplied to a boiler, above the theoretical amount of air needed to achieve complete combustion of a given fuel. Some excess air is always required to ensure complete combustion and can be measured with a flue gas analyser. If the flue gas contains too much excess air, a qualified technician should adjust the boiler to reduce this mass flow and the associated heat flow.[17]

The amount of water used in evaporative cooling applications will vary between HVAC systems. For some systems, water used within a HVAC system may be treated in cooling towers to prevent legionnaire's disease, and subsequently reused within the HVAC system. In other cases, the water used as a heat transfer medium for the removal of heat from air may be completely expelled from the system, creating a greater mass outflow. HVAC control systems often collect data on these mass flows.

The extent of air leakage from the ducting of a HVAC system is important to determine as part of an EMB, as quantifying these leaks can reveal viable energy-saving opportunities. Modern HVAC systems are often designed to detect air leaks from ducting, so quantifying the mass flows associated with air leaks for modern buildings may be relatively straightforward. For older HVAC systems, quantifying air leaks may be more difficult. Installing sensors and upgrading the existing control system is one effective option. Another option is to estimate losses using the law of conservation of mass. Any difference between the mass flows entering and exiting a HVAC system must be leaking from ducting.

The other air leaks and infiltration which may occur through entrances, exits, windows, exhaust outlets, roof openings and cracks can also affect the HVAC system energy use. Quantification of these flows, through estimation or modelling, may reveal potential energy saving measures.

3.7 PUMPING AND FLOW LOSSES

The design of piping affects flow resistance in a piping system, affecting energy use. Larger diameter pipes with fewer bends use less energy. Similarly, fan design and ducting layout affect the amount of energy required to distribute air around a building. It is important to take a whole-of-system approach to analysing pumping systems, rather then examining individual pumps and components in isolation. Joint optimisation of the system will produce much larger savings than changes to individual components.[18]

17 This heat loss is essentially equal to the change in the enthalpy of the excess air; see Office of Energy Efficiency of Natural Resources Canada, *Energy efficiency planning and management guide*, Office of Energy Efficiency of Natural Resources Canada, Ottawa, 2002, p. 78.

18 See United States Department of Energy, *Improving pumping system performance* [online], 2006, available at http://www1.eere.energy.gov/industry/bestpractices/techpubs_motors.html and The Natural Edge Project, *Engineering sustainable solutions program: design principles portfolio—whole system design suite, Case Study 1: industrial pumping systems* [online], The Natural Edge Project, Australia, 2007, available at www.naturaledgeproject.net/Whole_Systems_Design_Suite.aspx.

3.8 AREAS OF POTENTIAL ENERGY SAVINGS

When attempting to optimise the performance of a HVAC system, five key operational considerations should be examined[19]:

- *Temperature set points.* The system should heat to the lowest acceptable temperature and cool to the highest acceptable temperature. Unnecessary heating or cooling will result in wasted energy consumption. Adjusting control system parameters may offer very low cost opportunities.
- *Fixed energy use.* Avoid heating or cooling when not needed, such as when a building is unoccupied. Warehouses should not be heated or cooled unless they contain materials that are sensitive to heat or cold.[20]
- *Control system maintenance and operation.* Maintaining control systems so that they perform to specification is essential for the system to perform efficiently. For example, malfunctioning dampers can reduce HVAC performance and increase energy use. Ensuring that operators know how to operate control systems correctly will also promote efficiency.
- *Ventilation flow rates.* Ensure that indoor air quality standards are being met with the minimum amount of ventilation air. This can be achieved by altering the control system settings for ventilation or by changing and adjusting system components.
- *Powering down.* If heating, cooling or ventilation is not required, the HVAC system should be turned off; opening windows or blinds, for example, can provide natural sources of air and temperature control.

Designed heat transfer surfaces within a HVAC system are those surfaces where hot or cold fluids release heat to or absorb heat from their surroundings. To ensure the efficient operation of a HVAC system, these heat transfer surfaces must be appropriately maintained. In particular, ensuring that they are clean and not covered in grease, dust or other contaminants will maintain effective heat transfer. If these surfaces are fouled, heat transfer will be impeded and additional energy inputs will be needed to achieve the required heat transfer.

If it is established that different areas of a building have different heating or cooling demands, zone controls may be considered to provide for these different loads. Such controls will reduce unnecessary heating or cooling and ensure that areas deviating from the target temperature can be effectively heated or cooled.[21] Zone control systems should be considered as part of the development of HVAC systems in new buildings, but may be more costly to incorporate in existing systems.

If the energy and mass flow data for the HVAC system identifies significant heat transfers through walls, floors and roofs, installing additional insulation may need to be considered. Where existing insulation is absent or insufficient, reducing undesirable heat transfers will effectively reduce HVAC system loads and reduce energy consumption at relatively low cost.

Another more costly option for reducing the amount of ambient heat transfer is to install double glazing to windows. Double glazing involves either the addition of a second pane of glass or a clear membrane to the existing window to create a layer of trapped air that acts as insulation, reducing heat transfer.

If solar gain is found to be significant, adjusting this flow can reduce cooling loads and the energy consumption of the HVAC system. One option is to increase the use of blinds or external awnings, either fixed or adjustable, to prevent excessive sunlight entering windows. While the use of external awnings can be controlled, internal blinds will be operated by building occupants, so energy flow reductions may vary across the building.

If air leaks are detected within the HVAC system, repairing these leaks may reduce not only the amount of heating or cooling required to achieve the desired internal conditions, but also the energy required to circulate air around the building.

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19 BL Capehart, WC Turner, and WJ Kennedy, *Guide to energy management*, 4th edn, The Fairmont Press Inc, Georgia, 2003, chap. 6.

20 Radiant heating may be the best option for warehouses etc. where there are very large air losses.

21 Department of the Environment, Water, Heritage and the Arts, *Mandatory disclosure of commercial office building energy efficiency—regulation document*, Commonwealth of Australia: Canberra, 2009.

Ageing HVAC system equipment may be inefficient, and replacing components could result in energy savings. Payback periods for these replacements may exceed four years due to capital costs, but may be shorter if reliability and maintenance benefits are considered. For example, inefficient boilers often lose significant amounts of heat due to ineffective insulation and ageing components. Replacement of the boiler with a higher efficiency, better insulated unit may yield immediate energy and cost savings and improve HVAC system performance. Similarly, the replacement of chillers, if deemed necessary, will increase the efficiency of cooling operations.

It is worth noting that thorough analysis of HVAC system energy and mass flows may reveal low cost opportunities that can significantly improve performance. For example, changing pulleys and belts can be a low cost alternative to motor replacement.

An example of a potential energy saving measure associated with HVAC systems is provided in Box 3.

BOX 3. EXAMPLE OF HVAC ENERGY SAVING MEASURE

The temperature and humidity modified air provided to retail tenancies by a commercial building's HVAC system is heated (but not cooled) by hot water produced from a gas boiler. Air flows of 37.2 kg/s were provided to the tenancies at 18°C for 12 hours a day, 7 days a week.

Based on climate data for the commercial site, the energy required to heat the air to a temperature of 18°C was calculated at 329 GJ. This was calculated by reference to the climate data from the Australian Institute of Refrigeration, Air Conditioning and Heating handbook. Accounting for the efficiency of the boiler, rated at 78%, a heating load of 422 GJ was estimated.

The HVAC system operated at peak occupancy rates (800 people) and had not been designed to adjust output to occupancy levels. Average occupancy levels of 200 people suggested that the amount of air being delivered was excessive and potentially wasted up to three-quarters of the energy used in heating. Subsequent revision of the heat requirements resulted in heating estimates of 132 GJ, a 60% reduction on previous levels. Air mass flows were correspondingly reduced by 60%, from 37.2 kg/s to 14.9 kg/s.

Additional energy savings may also be achieved by replacing the existing boiler with a more efficient condensing boiler. This would reduce current gas consumption of 422 GJ by an estimated 56 GJ, assuming an increased boiler combustion efficiency of 90% and no change in current operating conditions.

4 LIGHTING SYSTEMS

Lighting systems contribute around 26% of commercial building energy use.[22] The amount of illumination required from lighting systems depends on the activities undertaken within the building, while the level of illumination provided by lights will depend on the design, quality and age of systems and the layout of the internal environment. This includes the shape of the room being illuminated, the amount of shading provided by walls and fixtures and the natural light that enters the building through windows.

Lighting system components can be separated into four basic categories[23]:

- light sources
- ballasts
- fixtures
- lighting controls.

Fluorescent tubes and incandescent lamps are the two main types of light sources used in commercial buildings, and their use is often dependent on the work undertaken within the building and the age of the lighting systems.

The commonly used fluorescent tube is categorised as a discharge lamp, as light is produced as a result of the gas contained in the tube being excited by an electric discharge. Fluorescent lamps have low electrical resistance, so a ballast—a device used to control the current—is required to limit current flow. The most common types of ballast used with fluorescent light sources are magnetic core coil and electronic high-frequency ballasts.[24] Box 4 discusses the advantages of alternative types of ballast.

Standard incandescent lamps have a filament, typically made of tungsten, which is heated by the flow of electricity to the point of incandescence (light production).[25] Low-voltage halogen dichroic lights (also called low-voltage downlights) are another type of lighting commonly used for architectural or effect lighting. Although they are low voltage, their wattage values can exceed 50 W, and they illuminate very small areas. As a general rule, low-voltage downlights are highly energy inefficient, as they deliver very poor illuminance relative to energy use (see Section 4.1).

Light Emitting Diodes (LEDs) are robust, energy efficient, compact lighting units with fast reaction times which can be used in a wide variety of applications.[26] LEDs involve the use of a semiconductor material to convert electric charges into electromagnetic radiation, which is emitted as light. The use of LEDs in commercial and residential applications has been limited due to their cost. However, new technology and cost reductions are making this technology an increasingly viable option to increase the energy efficiency of lighting systems.

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22 A Pears, *Energy efficiency improvement in the commercial sector, draft*, Melbourne, 2006; cited in the Centre for International Economics, *Capitalising the buildings sector's potential to lessen the costs of a broad based GHG emissions cut*, prepared for the ASBEC Climate Change Task Group, Canberra, 2007.

23 B Atkinson, A Denver, JE McMahon and R Clear, *Energy management and conservation handbook*, Taylor & Francis Group, LLC, Boca Raton, Florida, 2007, chap. 7.

24 Atkinson et al., chap. 7.

25 See Atkinson et al., chap. 7. Note also that the Australian Government, working with the states and territories, is gradually phasing out all inefficient incandescent light bulbs. See http://www.climatechange.gov.au/what-you-need-to-know/lighting.aspx for more details

26 Bosch (2007). Automotive handbook, 7th edn. Robert Bosch GmbH: Plochingen, Germany

BOX 4. BALLASTS FOR FLUORESCENT LIGHTS

Some fluorescent lamps require specific electronic high-frequency or magnetic ballasts. However, for many fluorescent lamps ballasts are interchangeable and upgrading the ballast can reduce energy consumption. Electronic high-frequency ballasts can increase light system energy efficiency, compared to the less efficient magnetic core coil ballasts.[27] Electronic ballasts also eliminate flickering of lights when initially activated, are lighter and operate with less noise than the magnetic alternatives.[28]

The installation of dimmable ballasts can also produce energy savings, by allowing the illuminance from fluorescent lighting systems to be reduced when natural light is available. Before replacing ballasts, consideration should be given first to whether current lamps are compatible with different ballasts, as well as the installation costs.

The purpose of the lighting fixture is to house and secure the light source and ballast, and to control the distribution of light to the building interior, without causing glare or discomfort to occupants. The more effective the fixture, the more light will be emitted to the interior environment.

Lighting control systems include electric switches, programmable timers, occupancy sensors, photo-electric sensors, dimmers and switchable or dimmable ballasts. These may be linked to a more complex communication and control system that combines lighting systems controls with the management of other energy consuming equipment in the building.

The nominal power rating of a lighting fixture is comprised of the nominal wattage of the light source and the power draw for the associated ballast. The power draw of the ballast generally corresponds to 10% to 20% of lamp wattage.[29]

4.1 DETERMINING THE PERFORMANCE OF LIGHTING SYSTEMS

The two main performance indicators used for lighting systems are the lighting power density and the illuminance. The *lighting power density* in W/m^2 measures the efficiency of lighting power consumption per unit of floor space, enabling comparison with similar commercial buildings. Measured in lux or lumens/m^2, the *illuminance* quantifies light intensity. Illuminance measurements can be compared to relevant Australian standards to determine whether the illumination provided is sufficient. If the illuminance exceeds the standard, energy savings may be readily obtainable.

Lighting power density can be simply determined by calculating the total instantaneous power rating (light source and ballast) for the light fixtures serving a designated floor area. An example calculation for the lighting power density is shown in Box 5.

BOX 5. CALCULATION OF LIGHTING POWER DENSITY

$$\text{Total number of light fixtures} = 20$$

$$\text{Each light fixture contains } 2 \times 36\text{ W Fluorescent tubes and } 2 \times 6\text{ W ballast}$$

$$\text{Therefore total instantaneous power rating for each fixture} = 84\text{ W}$$

$$\text{Total instantaneous power rating for lighting fixtures in floor space} = 20 \times 84\text{ W} = 1680\text{ W}$$

$$\text{Total area of floor space} = 80\text{ m}^2$$

$$\text{Lighting power density} = \frac{1680\text{ W}}{80\text{ m}^2} = 21\text{ W/m}^2$$

27 C Eley, TM Tolen, JR Benya, F Rubinstein and R Verderber, *Advanced lighting guidelines: final report*, prepared for the US Department of Energy, California Energy Commission, and Electric Power Research Institute, 1993.

28 See Atkinson et al., chap. 7.

29 See Atkinson et al., chap. 7.

Illuminance can be measured using a light meter. Where illuminance varies due to fluctuations in natural light, instantaneous measurements would not give an accurate measurement, so an average of readings should potentially be used. Lighting standards will specify a height, or working plane, at which the required illuminance should be provided. However, it is also recommended to measure illuminance on the surface on which work tasks are performed. For example, in an office environment additional light meter measurements should be taken on the surface of desks and at the height at which employees might view computer monitors.

It is also important to measure illuminance at different periods of the day and during different periods of the year—for example, in the morning and the afternoon, in both summer and winter. Accounting for variations in natural light will help to quantify potential efficiency opportunities associated with better use of natural light. If insufficient time is available, variations in natural light can be estimated using meteorological data and solar angles at different times of year, or using illuminance simulation programs.

4.2 MASS AND ENERGY FLOWS AFFECTING ENERGY CONSUMPTION

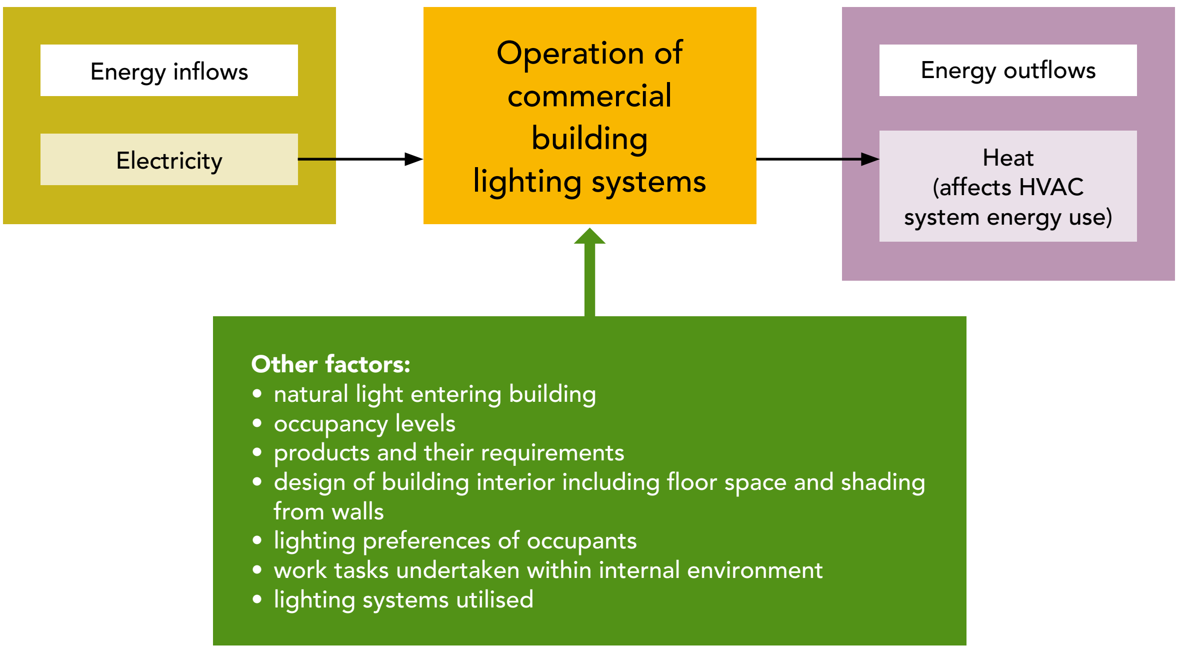
The only energy inflow that needs to be accounted for as part of an EMB is the electricity that powers the lighting system. Natural illumination entering through windows, skylights and atriums can reduce the need for artificial light and provide energy savings. The energy content of the natural light entering the building will have been considered when determining the solar heat gain (see Section 3.5).

There are no mass flows that must be included in an EMB for lighting systems. However, mass flows of people and products should be considered, as they affect lighting requirements. Mass inflows of people and products can be quantified using optical people counters and billing/logistical information, as outlined in Section 3.2. Quantifying these flows may identify areas of the building where higher lighting levels are required. Demand for lighting will depend on the nature of work tasks or activities undertaken within the building and storage/product requirements.

The only energy outflow produced from the operation of lighting systems is heat released by the lighting system, which influences HVAC system energy use. Lighting systems do not produce any direct mass outflows.

The energy flows and other factors influencing the operation of lighting systems are shown in Figure 6.

Figure 6: Energy flows and other influences on the energy consumption of lighting systems



4.3 DETERMINING THE KEY ENERGY AND MASS FLOWS

Quantifying the energy flows associated with the operation of existing lighting systems will be straightforward in buildings with sufficient sub-metering. If specific electrical meters for lighting systems are installed, the energy consumed by lighting systems can be simply quantified from measurements.

If lighting is not specifically metered, the energy consumption will need to be determined from first principles. The steps in this process are as follows:

- ***Step 1.*** Determine the power draw (wattage) of the light source(s) and ballast(s) used within each lighting fixture. This can be assumed to be the same as the wattage printed on the bulb/tube or ballast fixture, unless dimmers are in place.
- ***Step 2.*** Count the total number of lighting fixtures within the building or internal area being analysed.
- ***Step 3.*** Determine the operating hours for each lighting circuit. Lighting systems should be analysed for long enough to ensure that operating conditions during work days and weekend periods are included.
- ***Step 4.*** Multiply the calculated total wattage by the hours of operation to obtain the cumulative energy consumption in watt-hours (Wh).
- ***Step 5.*** Convert the energy consumption to gigajoules, in line with EEO program reporting requirements.

These five steps are illustrated in Box 6.

BOX 6. CALCULATING ENERGY CONSUMPTION FROM FIRST PRINCIPLES

Lighting fixtures within a commercial building contain two 36 W fluorescent light tubes. Each of the tubes has an associated electromagnetic ballast, which has a power rating of 6 W. Within the building there are approximately 1,100 of these light fixtures; of these, 900 fixtures are switched on for a 12-hour period from 7 am to 7 pm, with the remaining 200 fixtures left on over an entire 24-hour period.

The power rating for the individual light fixtures is:

$$\begin{aligned}\text{Power Rating} &= [(36\times 2)+(6\times 2)]\ \text{W}\times\frac{1}{1000}\frac{\text{kW}}{\text{W}}\\ &= 0.084\ \text{kW}\end{aligned}$$

The total energy consumption for the lighting fixtures within the building, over a 24-hour period, is calculated as follows:

$$\begin{aligned}\text{Energy Consumption} &= (900\times 12\ \text{h}\times 0.084\ \text{kW})+(200\times 24\ \text{h}\times 0.084\ \text{kW})\\ &= 907.2\ \text{kWh}+403.2\ \text{kWh}\\ &= 1310.4\ \text{kWh}\end{aligned}$$

Convert the result to gigajoules, noting that a watt is equivalent to a joule per second:

$$\begin{aligned}\text{Energy Consumption} &= 1310.4\ \text{k}\frac{\text{J}}{\text{s}}\text{h}\times 60\frac{\text{s}}{\text{min}}\times 60\frac{\text{min}}{\text{h}}\times\frac{1}{10^6}\frac{\text{GJ}}{\text{kJ}}\\ &= 4.72\ \text{GJ}\end{aligned}$$

Even if lighting electrical consumption can be determined from sub-metering, conducting the five-step procedure outlined above is still recommended. This procedure may reveal disparities between metering and calculated results. Differences can indicate potential deviations from electric circuit diagrams for the building, leading to potential efficiency gains and energy savings.

The heat generated by lighting systems can be estimated by assuming that all of the energy supplied to the lighting system will eventually be converted to heat within the building interior.[30] Therefore, the electrical energy supplied to the lighting system should be included as a heat input into the HVAC system EMB.

Measuring the illuminance provided by natural light is recommended to determine whether sunlight can potentially meet the requirements of the area being analysed during some periods of the day. Light sensors can be installed and linked into the control system so that lights only switch on when natural lighting is insufficient, thereby reducing energy consumption.

4.4 POTENTIAL ENERGY SAVING MEASURES

Having quantified the illuminance, power density and energy flows associated with lighting systems, the EMB can be used to analyse and estimate the potential energy and financial savings. Common lighting opportunities are outlined in subsections 4.4.1 to 4.4.5.

4.4.1 Replacement of inefficient light bulbs

Energy and cost saving can be made by simply replacing inefficient light bulbs with more efficient alternatives, such as replacing incandescent light bulbs with compact fluorescent lamps (CFLs). CFLs are up to four times more efficient and last up to 10 times longer than incandescent bulbs.[31] The capital cost associated with purchasing and fitting CFLs can be promptly recovered through energy and maintenance savings.

As the most common light sources used in commercial buildings are fluorescent tubes, a common approach is to replace fluorescent lamps with variants better suited to the lighting application and building interior. Common types of fluorescent lamp are, in order of increasing diameter, the T3, T5, T8 and T12. These tubes have varying technical specifications that are best suited to different applications and using the appropriate tubes for each application may yield energy savings.

Use of low-voltage dichroic lamps should be immediately re-examined and the lights potentially replaced. In order to achieve the required illuminance, these lights are often present in large numbers and consume an unnecessarily large amount of energy. Immediate replacement of these bulbs, or the alteration of current electrical set-ups (i.e. separate lighting into different sections or zones) are advisable energy efficiency measures.

In some applications using light-emitting diode (LED) lighting may be feasible. These lights can reduce energy consumption, but may be more complex and expensive to retrofit to some existing buildings due to the need to alter existing circuitry and fixtures. One potential use of LED lighting is to replace dichroic lights used for architectural or effect lighting.

4.4.2 De-lamping

It is common for lighting fixtures in commercial buildings to have two fluorescent light tubes and associated ballasts. If measurements show that the illuminance provided by lighting systems exceeds the relevant standard, then de-lamping may be an option to reduce energy consumption. De-lamping involves removing unnecessary tubes, while still ensuring that the required lighting levels are met. Removing excess tubes would effectively halve the power draw and energy consumption of the fixture, as the ballast will not consume the same amount of energy without a fluorescent tube installed.[32]

Before implementing de-lamping, it is recommended to ensure that the illuminance provided by the de-lamped fixtures still meets relevant standards. Investigation may involve localised tests with different combinations of complete and de-lamped fixtures to ensure that required levels of light output are maintained. Natural light levels should be taken into account when making these readings.

30 BL Capehart, WC Turner and WJ Kennedy, *Guide to energy management*, 4th edn, Fairmont Press Inc, Georgia, 2003, chap. 6.

31 Moreland Energy Foundation, *Energy efficient lighting* [online], Moreland Energy Foundation Limited, Sydney, 2009, available at http://www.mefl.com.au/documents/MEFL_FACT_SHEET-_efficient_lighting.pdf.

32 Occupational health and safety should also be considered when de-lamping.

4.4.3 Upgrading of lighting fixtures

Lighting fixtures that house the light source and ballast can also be upgraded to improve the efficiency of lighting systems. Commencing a regular maintenance program whereby light fixtures and sources are cleaned will ensure that the light generated can be effectively reflected into the building interior. This may potentially reduce the required wattage of light sources, as fixtures may have had unnecessarily high wattage tubes to compensate for soiled reflectors reducing effective light transmission.

When buildings are being built or refurbished, the choice of light fixtures may potentially yield energy and cost savings. One such example would be to replace a two-tube fluorescent fixture with a single fluorescent tube fixture, whose housing is made from a highly reflective material, and whose design ensures that the maximum amount of light is emitted to the building interior. Some light fixtures are able to reduce reflections on work surfaces and computer screens, making for a more comfortable work environment.

4.4.4 Control systems

Building occupants cannot always be relied on to switch off lights at the end of work shifts or when they are not required. Using automatic control systems to activate and deactivate lights when the building is vacant can therefore deliver energy and cost savings.

Occupancy sensors are a useful control system for those areas that are occupied only periodically, such as break rooms, toilet facilities and store/plant rooms. Once occupancy sensors have been installed, lighting systems will activate only when sensors detect people in the area. After the lights have been activated, they can be deactivated using a preset time switch. Time switches can also be used for lighting systems that are always on during working hours to ensure that they are switched off after hours.

Using a time control system to automatically switch lights on and off removes the potential wastage of energy from lighting systems not being switched off. However, a mixed control system that still allows building occupants to override time switches and exercise some discretion over the operation of lighting systems may be appropriate for those buildings where occupants do not always work consistent and predictable hours.

Photo-electric sensors are an applicable control system for areas illuminated by natural light entering through windows, or indoor/outdoor areas such as car parks, for which natural light may be sufficient to meet daytime lighting requirements. Photo-electric sensors, once installed in the appropriate location, will deactivate lighting systems when sufficient natural light is detected. Internal blinds may affect natural light levels and interfere with sensor operation. It is also important to ensure that the natural light which triggers the sensor aligns with Australian lighting standards.

Where natural light is almost sufficient, a dimming switch or dimmable ballast could be used to combine natural and artificial light in order to meet requirements, while still reducing energy consumption. Since dimmed lights do not always operate at full power, estimating their energy use is more involved and requires additional measurement compared to other lighting systems.

To obtain a first-pass estimate of the percentage of energy savings obtainable by using natural lighting, the following formula may be used[33]:

$$f_d = b[1 - \exp(-a\tau_w A_w / A_p)]\frac{A_p}{A_f}$$, where:

- f_d is the percentage saving on artificial illumination
- A_w/A_p is the ratio of window area to perimeter floor area (the perimeter is the area of floor space that receives appropriate illumination from natural light)
- A_p/A_f is the ratio of the perimeter to the total floor area

33 M Krarti, P Erickson and T Hillman, 'A simplified method to estimate energy savings of artificial lighting use', *Daylighting Building and Environment*, vol. 40, 2005, pp. 747–754; cited in M Krarti, *Energy management and conservation handbook*, Taylor and Frances Group, LLC: Boca Raton, Florida, 2007, chap. 4.

- τ_w is the transmissivity of the windows, obtainable from manufacturers
- *a* and *b* are coefficients that depend on the location of the building. For example Melbourne *a* is 19.96 and *b* is 67.72.

If the initial estimated savings are significant, further analysis of these opportunities may be warranted, perhaps using building simulation software. In some cases switching off lights automatically may create safety issues (e.g. in stairwells). Undertaking a risk assessment before installing sensor lights is therefore recommended.

4.4.5 Other potential measures

An electrical transformer is a device that can either upgrade or downgrade the voltage of an electric current to that required by the equipment being powered. Transformers have a constant power draw and can be significant energy consumers over time. Reviewing the transformer set-up for lighting systems may provide efficiency gains.

For areas of a building without direct natural light, there may still be an opportunity to use skylights to reduce energy consumption. Skylights will be most practical for areas that have exposure to the roof space of a building, such as the top floor of a multi-storey building. Whilst skylights will probably have payback periods over four years based on energy savings, they may improve working conditions for occupants.

4.4.6 Overarching rules

When determining the most efficient operating conditions for lighting systems it is important to remember that the right light sources should be chosen, positioned in the correct location and used only when needed[34], and that illuminance should meet, but not exceed, Australian Standards.

4.4.7 Example of lighting system energy-saving opportunity

The lighting power consumption in the lobby of a commercial building was made up of three types of lights, all operating 24 hours a day:

- 20 × 50 W low-voltage halogen dichroic lights with 15 W transformers
- 25 × 18 W compact fluorescent lamps
- 10 × 36 W linear fluorescent lamps with 6 W ballasts.

This equated to 2.17 kW of electricity demand, or 25 W/m² across the 87 m² lobby and an annual energy consumption of approximately 19,000 kWh per year.

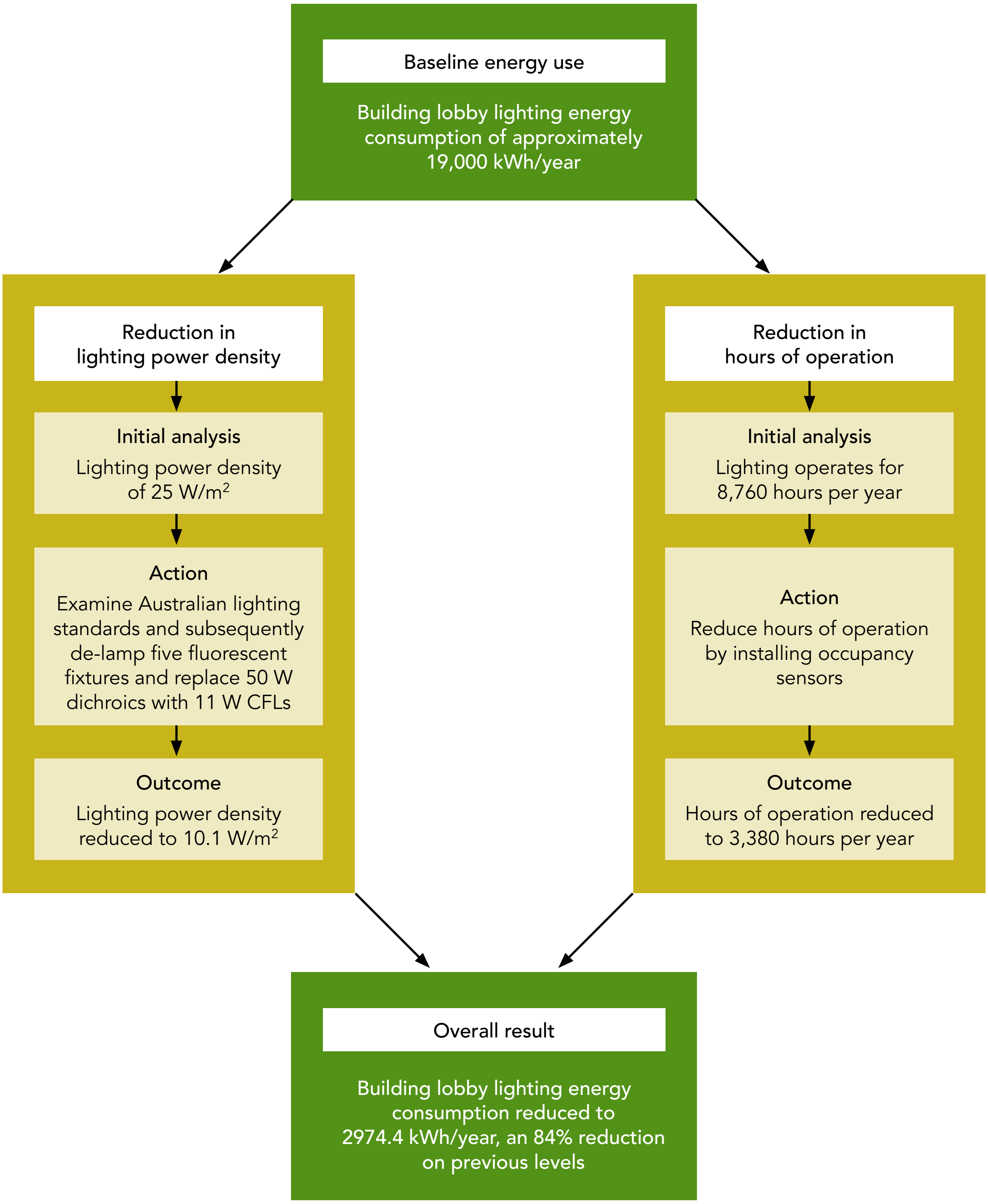
The first energy-saving measure involves the replacement of the 50 W dichroics and associated transformers with 11 W CFLs and the removal of five linear fluorescent lamps, as part of a de-lamping procedure. This measure was determined to be acceptable following examination of Australian lighting standards and reduced the lighting electricity demand to 0.88 kW and the power density to 10.1 W/m².

The other energy-saving measure was identified by examining the hours of operation. The lobby is constantly occupied for around 12 hours per weekday (10 hours peak), with limited to no occupancy over the weekend. Therefore, lighting levels could be reduced to a minimum during periods of low occupancy using occupancy sensors. Allowing for continuous lighting for safety and security reasons, minimum hours of service, with all lights in operation, were re-estimated at 65 hours per week.

The combination of these two energy efficiency measures reduced the total power draw of the lights to 0.88 kW and the total yearly hours of operation to approximately 3,380 hours. This results in a new energy consumption of 2,974 kWh per year (10.71 GJ), saving approximately 16,026 kWh per year (57.7 GJ), an 84% reduction on previous levels. The efficiency improvement process for the lobby lighting is illustrated in Figure 7.

34 United Nations Environment Programme, *Cleaner production—energy efficiency manual: guidelines for the integration of cleaner production and energy efficiency*, United Nations, New York, 2004.

Figure 7: Lobby lighting efficiency improvement process



5 INFORMATION AND COMMUNICATION TECHNOLOGIES

5.1 INFORMATION AND COMMUNICATION TECHNOLOGIES IN COMMERCIAL BUILDINGS

Information and communication technologies (ICT) are an important energy user in many commercial buildings. The percentage of total building energy consumption that can be allocated to ICT will depend on the activities undertaken.

ICT within commercial buildings may include:

- computer systems
- printers
- photocopiers
- telephones
- fax machines
- cash registers
- logistics and product processing equipment
- other critical infrastructure housed in data centres, including servers.

The need to maintain the operating temperature of ICT places additional demand on HVAC systems. This demand is highest in data centres due to the increased density of ICT. Therefore, ICT energy efficiency measures may also reduce the cooling load on the HVAC system.

Sections 5.2 to 5.5 assume that the HVAC system for use in server rooms or data centres is considered separately (see Section 3).

5.2 MASS AND ENERGY FLOWS ASSOCIATED WITH ICT

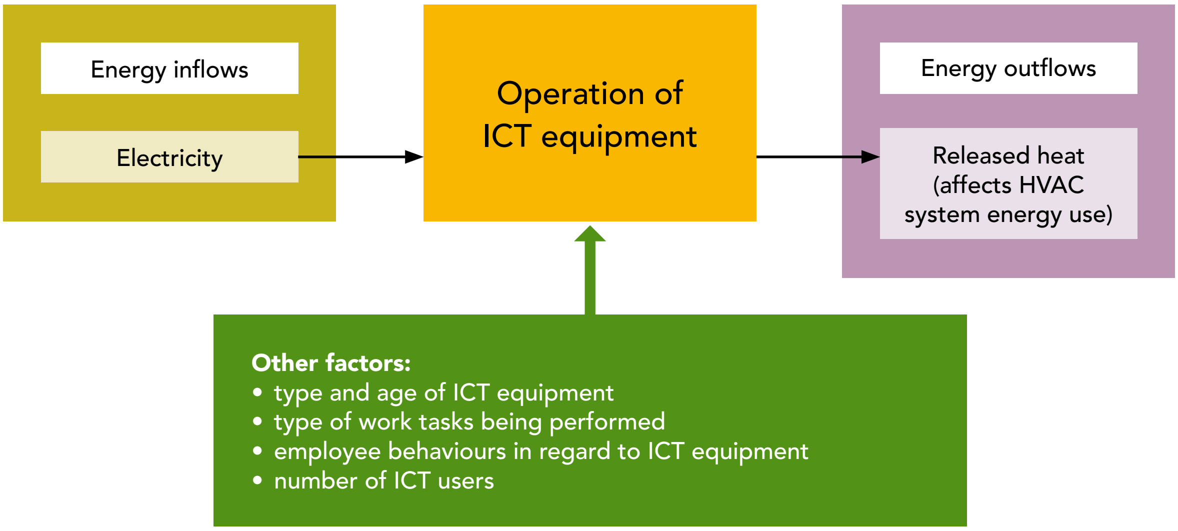
Electricity will be the only energy inflow associated with ICT. The heat released from the equipment will be the only energy outflow requiring consideration due to its effect on the HVAC system. Tracking building occupancy in relation to ICT energy use can indicate potential gains from shutdowns.

There are no mass flows that must be included in an EMB for ICT. Examining ICT use patterns as part of the EMB can also indicate excess printing, with wastage of paper and toner.

There may be opportunities to use ICT to save energy and reduce costs, for example, by using teleconferencing or video-conferencing to conduct meetings, thereby reducing energy-intensive and costly business travel. While the indirect energy use by travelling employees and used in paper production are not required to be included in an EMB, cost savings may be significant.

Figure 8 illustrates the energy flows associated with ICT.

Figure 8: Energy flows and other influences on the operation of ICT equipment



5.3 OTHER FACTORS AFFECTING ICT ENERGY CONSUMPTION

Other factors have a significant impact on the energy consumption of ICT. The type and age of equipment has a large bearing on energy consumption, with older equipment typically being less efficient for a given performance.

The type and complexity of work tasks performed will also have a bearing on energy consumption. Certain tasks, such as activities requiring very high computer processing power, may require additional equipment, creating additional energy demand.

Employee behaviour also affects ICT energy consumption. Such behaviour includes whether they switch off computers at the end of working days, whether they switch off monitors during the day when they are not using them, and the amount of printing they do. Conducting staff surveys may help to gauge employee attitudes towards the performance of ICT, and also indicate how ICT is used. Behavioural changes may be a potential method of reducing ICT energy use.

Surveying staff can also reveal costly adaptations by employees working around system deficiencies. For example, long system start-up times may discourage switching off computers at the end of a shift. Employees may also print excessively to compensate for an unreliable system or a lack of audiovisual facilities in meeting rooms. Lack of electronic document management systems can lead to a reliance on paper filing systems, requiring additional building space and creating large document search and retrieval costs.

5.4 DETERMINING THE KEY ENERGY FLOWS

The electricity consumed by ICT can be accurately quantified based on metering data. However, in the absence of specific sub-metering, digital power meters could be used to determine and monitor the energy use of a sample of ICT, which will provide a more detailed picture of energy consumption than estimates based on assumed loads.[35] The benefit of using power meters to analyse electrical equipment is that it provides data on the wattage of electrical appliances at various stages of operation. This is valuable because most electrical appliances have varying wattage depending on their state of operation.

35 Digital power meters measure the instantaneous wattage of the electrical appliance(s) being analysed, as well as the cumulative energy consumption and in some cases greenhouse gas emissions created. These meters are typically plugged into the mains power supply, with the appliance(s) then being plugged into the power meter. Multiple electrical appliances can be analysed on the single digital power meter using a power board.

The instantaneous wattage for ICT increases rapidly during start-up, is low during idling and varies during use depending on the work tasks being undertaken. Quantifying the wattage and cumulative energy use from ICT outside operating hours will indicate potential energy efficiency measures. Measured data can underpin a more attractive business case for effective investment proposals.

Digital power meter data from a sample can potentially be extrapolated to represent the population of similar appliances, pending introduction of metering. The EEO *Representative Assessment Guide* provides advice on sampling techniques and achievement of the required accuracy.

5.5 POTENTIAL ENERGY EFFICIENCY OPPORTUNITIES

The scope for improvements to ICT energy efficiency will vary depending on the amount and type of ICT equipment and the purpose for which it is used. Ensuring that the correct equipment is chosen for each application can yield efficiency and productivity gains. For example, some employees may require large or multiple monitors, whilst for others smaller monitors may be sufficient[36].

It may be possible to merge faxing, scanning, photocopying and printing applications into the one machine. Such a measure may not be appropriate if there is a high demand for these separate applications. However, where demand can be met by a single multipurpose item of ICT, energy savings may be significant.

As with lighting, occupants cannot always be relied upon to switch off idle ICT. Although modern ICT has energy saving modes that moderate standby energy use, consumption can be further reduced by encouraging occupants to switch off equipment at the end of each day. Staff awareness initiatives can also foster general energy efficiency awareness.

Power or software management systems can also be used to automatically switch off equipment at a set time or after a period of idling. Similarly, idle photocopiers and printers could be automatically switched off after a pre-defined period of inactivity or at a set time of day. Care must be taken to ensure that the time of deactivation reflects the working hours of building occupants, and that necessary software updates can be performed.

The workloads placed on servers within a data centre can vary significantly, especially where physical servers perform specific tasks and potentially remain idle for extended periods of time. Idling creates inefficiencies due to the continued need for energy to operate the server and for HVAC systems to control temperature. This inefficiency can be reduced by using server virtualisation, in which multiple virtual servers are configured and operated from a single physical server[37]. Server virtualisation may reduce the number of servers within a data centre, subsequently reducing the associated energy consumption. Server virtualisation may also increase the complexity of the information technology environment, which should be considered.

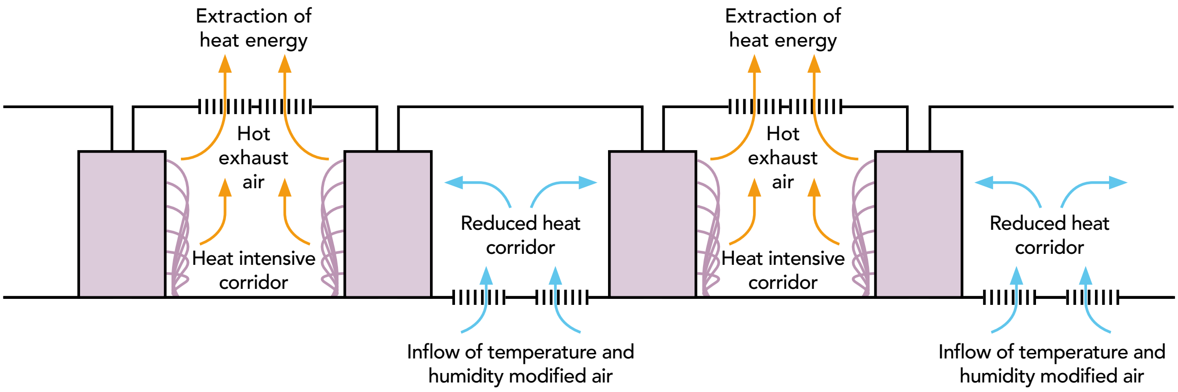
Laptop computers combined with wireless networks can provide energy use reductions within an office environment. Replacing PCs and conventional wired networks with laptops and wireless networks has additional cost and logistical requirements that should be considered before proceeding, including the disposal of redundant PCs. However, the potential energy and work flexibility benefits that can be achieved may be significant. The selection of laptop technology is an important consideration, as battery life varies between models. Laptops with longer battery lives will require less recharging and therefore offer potentially larger energy savings. Battery recharge could potentially occur after hours, taking advantage of off-peak electricity pricing, if battery life allows. Other considerations include the costs of ergonomic aids such as keyboards, mice and screen raisers.

36 The Natural Edge Project, *Energy efficiency opportunities in large energy using sectors*, Lecture 5.3, 'Opportunities for energy efficiency in the IT industry and services sector', CSIRO: Australia, 2007.

37 P Johnson and T Marker, *Data centre energy efficiency product profile*, prepared for Equipment Energy Efficiency Committee [online], Pitt and Sherry, Australia, 2009, available at http://www.energyrating.gov.au/library/pubs/200905-data-centre-efficiency.pdf.

Physical servers give off substantial amounts of heat, which places a load on HVAC systems. Analysis and relocation of servers within a data centre can produce possible energy savings. One example of efficient positioning is illustrated in Figure 9, where servers have been arranged such that the hot exhaust air from one item is not transferred directly to the intake of another item. Sufficient space has been left between equipment to allow air flow and prevent an excessive build-up of heat, and air vents are located to optimise cooling for the entire data centre. Other mechanisms to reduce the cooling load can include placing the most heat-intensive and heat-tolerant equipment at the top of the racks where temperatures are highest and selecting appropriate locations for data centres away from external heat sources and using insulation mechanisms (as outlined in Section 3.8) to reduce heat flow.[38]

Figure 9: Optimised ICT placement in data centre to reduce heating load



Source: Adapted from Rumsey Engineers, *High performance data centers: a design guidelines sourcebook* [online], Pacific Gas and Electric Company, 2006, available from: http://hightech.lbl.gov/documents/data_centers/06_datacenters-pge.pdf.

5.5.1 Energy saving measure example

Within a commercial office building there are 1,200 computer systems operating during an average working day. The components of these systems and their instantaneous wattages at various stages of operation are summarised in Table 4.

Table 4: Computer system components and power draw

Component	Status	Power rating (W)
LCD Monitor	Standby	0.6
	Start-up	27.1
	In use	26.6
Computer Hardware	Standby	67.5
	Start-up	125.0
	In use	70.0
Keyboard		
Mouse		

38 The Natural Edge Project, *Energy efficiency opportunities in large energy using sectors*, Lecture 5.3, 'Opportunities for energy efficiency in the IT industry and services sector', CSIRO, Australia, 2007.

An examination of the use of computers after hours (between 7 pm and 7 am) revealed that out of 1,200 computer systems, 700 were left idling overnight, with the remaining 500 systems completely switched off. All computer systems within the building were switched off over the weekend. The energy consumption of the computer systems between the hours of 7 pm and 7 am could then be calculated, noting that 1 W=1 J/s:

$$\begin{aligned}\text{Computer System Idle Energy Consumption} &= (\text{LCD monitor standby wattage} + \text{computer hardware standby wattage}) \times 12\text{ hours}\\ &= (0.6\text{ W} + 67.5\text{ W}) \times 12\text{ hours}\\ &= 68.1\text{ W} \times 12\text{ hours}\\ &= 0.8172\text{ kWh}\\ &= 2.94\text{ MJ}\end{aligned}$$

For the 700 computers left idling overnight, the cumulative energy consumption was calculated as follows:

$$\begin{aligned}\text{Computer System Cumulative Idle Energy Consumption} &= 2.94\text{ MJ per computer} \times 700\text{ computers}\\ &= 2058\text{ MJ}\end{aligned}$$

The 50 printers/photocopiers located in the building were all idle between 7 am and 7 pm and over the weekend. Following analysis of digital power meter readings it was observed that the wattage of these printers/photocopiers when idle was not static. Rather, measurements showed a surge in the power draw every 15 seconds to keep the printer ink drum warm. Cumulative energy consumption measurements for the printer/photocopier showed 0.96 kWh or 3.46 MJ of energy consumption per printer/photocopier over the 12 hours from 7 am to 7 pm. For all 50 items this equates to 172.8 MJ of energy consumption. Over the weekend period (five 12-hour periods from 7 pm Friday to 7 am Monday) this idle energy consumption was calculated to be 864 MJ. The total weekly idle out-of-hours energy consumption was calculated as follows:

$$\begin{aligned}\text{Total out of hours energy consumption} &= \text{weekend consumption} + \text{weekday consumption}\\ &= 864\text{ MJ} + (4 \times 172.8\text{ MJ})\\ &= 1555\text{ MJ}\end{aligned}$$

Estimated daily energy use for the 1,200 computer systems during the working hours of 7am to 7pm, on Monday to Friday, was calculated as 5,016 MJ and 33,311 MJ weekly. For the printers/photocopier units the daily 7am to 7pm, Monday to Friday, energy use was calculated at 264.6 MJ, amounting to 2,878 MJ weekly. From this the total estimated energy consumption of the computer systems and printers/photocopiers was estimated as 36,189 MJ.

An energy-saving opportunity was identified that involved introducing a switch-off system for all computer systems and printers/photocopiers within the building between the hours of 7 pm and 7 am. The switch system was designed so that it allowed employees to override the system and activate a smaller area across the office, and also enabled software updates when required. Once implemented, the deactivation system yielded the weekly energy savings outlined in Table 5.

Table 5: Summary of ICT energy saving after installing mass switch-off system

Component	After hours energy use pre switch-off system (MJ)	After hours energy use after switch-off system (MJ)	Energy saving per week (MJ)	Savings as a % of weekly subsystem energy use
Computer systems (Monday–Thursday)	2,058 per day	17.35 per day	8,163	24.5
Printers/photocopiers (Monday–Thursday)	172.8 per day	10.37 per day	649.7	22.6
Printers/photocopiers (Weekends: 7 pm Friday – 7 am Monday)	864	34.4	829.6	28.8
Total			**9,642**	**26.6**

The energy use of ICT after the switch-off system was implemented was not zero, due to some periodic after-hours use of this equipment, which, as outlined, is permitted by the system.

6 OTHER ENERGY AND MASS FLOWS

6.1 OTHER ENERGY AND MASS FLOWS IN A COMMERCIAL BUILDING

Other types of energy-using equipment which will need to be analysed as part of a building EMB include:

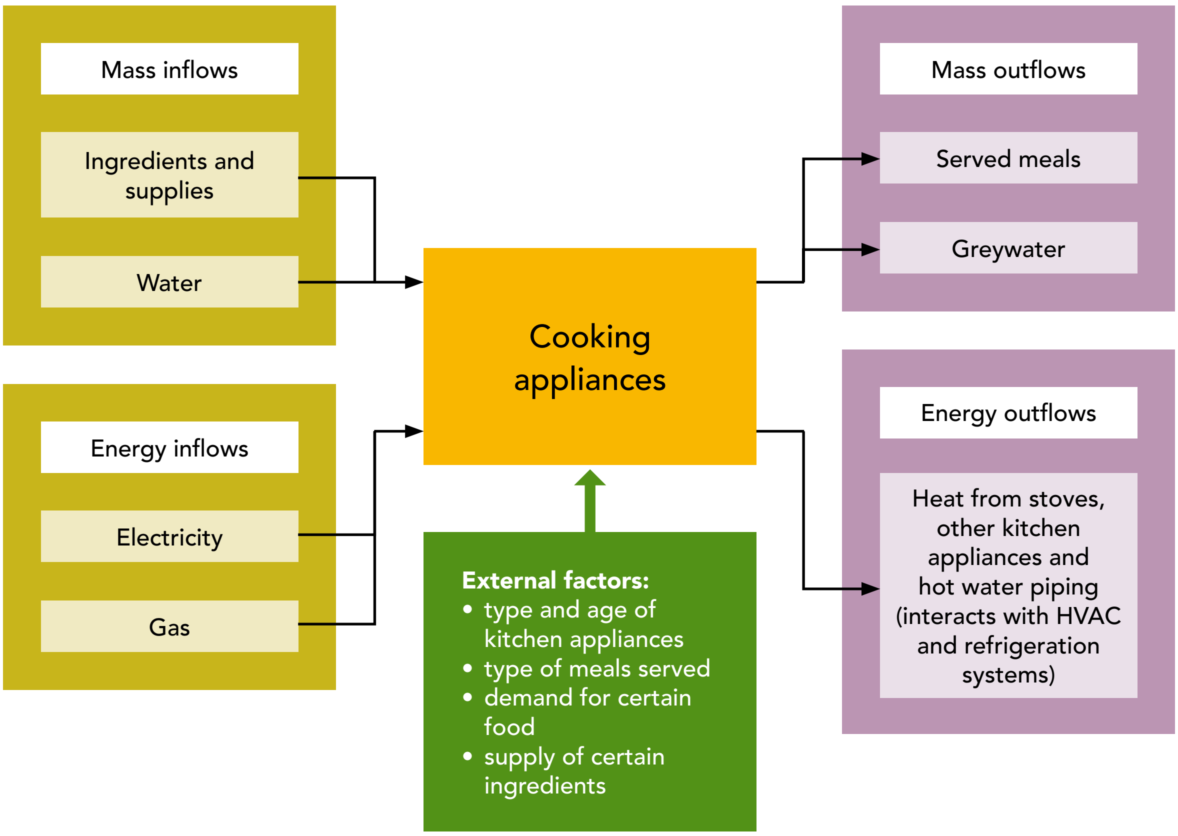
- lifts
- escalators
- cooking appliances (ovens, stoves, microwaves etc.)
- refrigerators
- washing machines
- dryers
- vending machines
- water heating systems
- other miscellaneous energy-using equipment (such as pumps and equipment used for hotel swimming pools).

The significance of these items of equipment will depend on building characteristics and the activities undertaken. For example, in multistorey offices or in retail buildings, lifts and escalators would consume a large amount of energy due to the requirement to move a significant number of people or products. Similarly, in some retail applications, such as restaurants and laundromats, cooking appliances, refrigerators, washing machines and dryers will be substantial users of energy.

6.2 MAPPING THE OTHER ENERGY AND MASS FLOWS

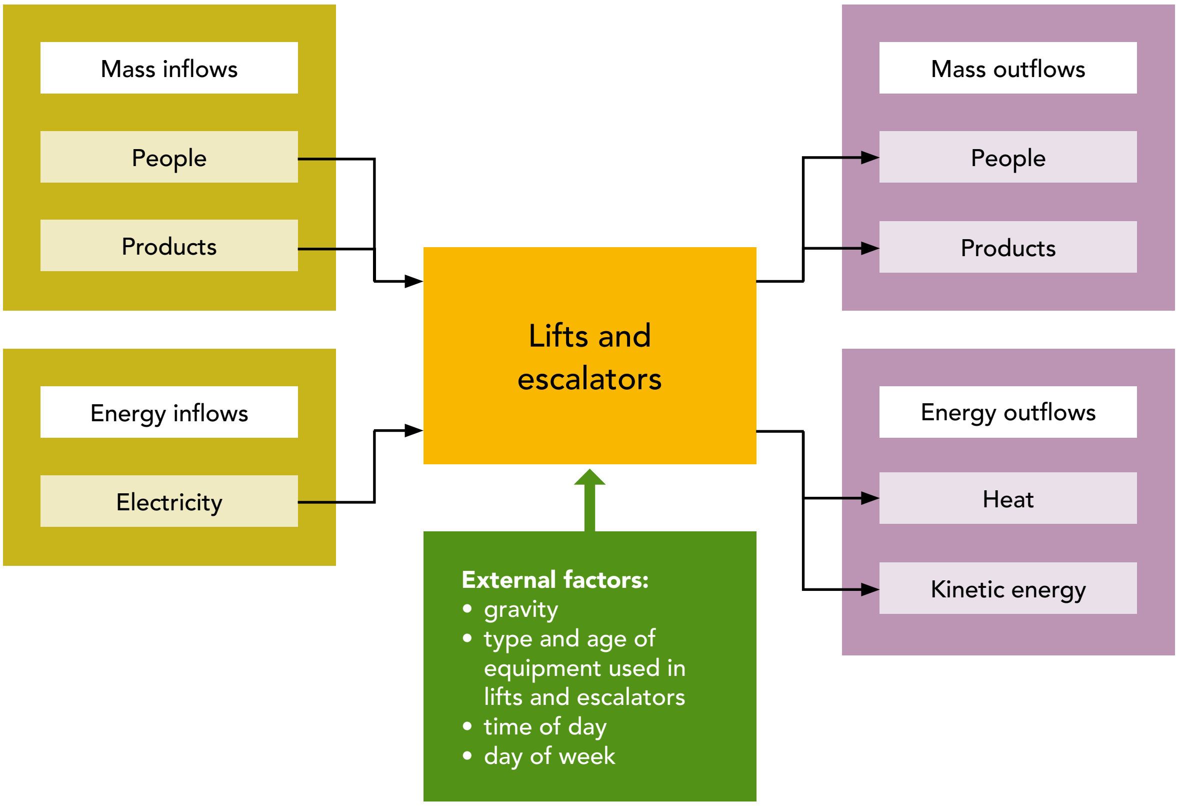
Figure 10, Figure 11 and Figure 12 illustrate the other energy and mass flows within a commercial building, and the other factors that are associated with and affect these systems.

Figure 10: Energy and mass flows associated with the operation of cooking appliances



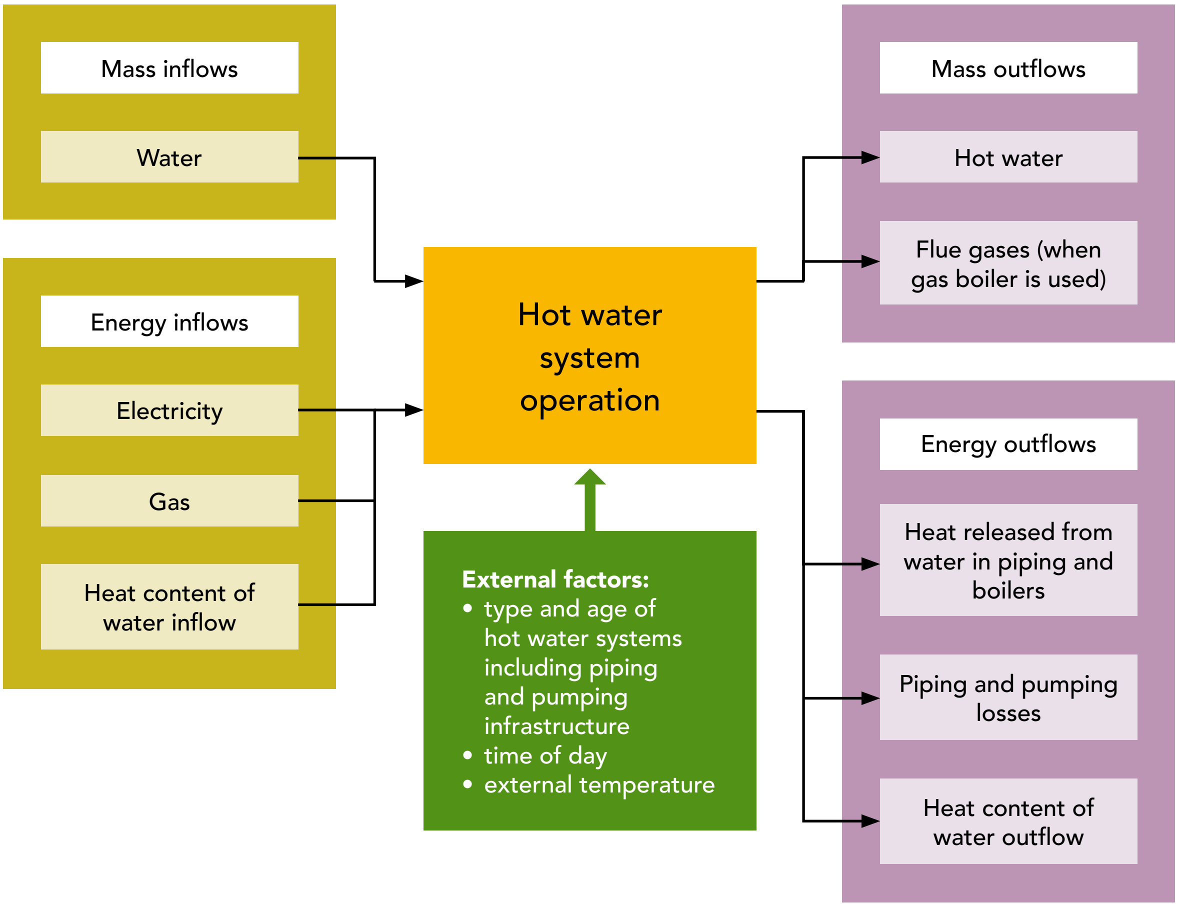
Energy and mass flows associated with cooking appliances can be determined from billing and metering data using the analysis methods outlined in previous sections. Digital power meters may also be used to gain a more detailed picture of electrical equipment energy use. Air temperature variations within the kitchen can be analysed to identify potential HVAC system changes to moderate temperature, such as improved ventilation.

Figure 11: Energy and mass flows associated with the operation of lifts and escalators



The electricity consumed by lifts and escalators will be captured by the metered electricity data for the entire building. Sub-metering of lifts and escalators could be installed to give a more accurate picture of energy use. Lift and escalator simulation software may also be used to model the energy use of these systems and quantify potential energy savings. People and product mass flows can be quantified using optical people counters and billing data.

Figure 12: Energy and mass flows associated with the operation of hot water systems



Hot water system energy and mass flows will require more detailed analysis using engineering calculations, measurement devices and simulation software if available. Electricity and gas consumption associated with the heating and pumping of water around the building can be determined from direct metering. Water flows will also be determined from metering data and may also be analysed more precisely using flow meters.

Heat released from boilers or from hot water as it travels through piping can be modelled using simulation and modelling software, or calculated using the stated efficiency of boilers or engineering heat transfer calculations.[39] The content and flow rate of flue gases emitted from boiler systems and hot water systems can be analysed using flue gas meters and flow meters. As discussed in Section 3.7, piping and pumping losses can be determined from pump specifications and engineering calculations.

Energy used by refrigeration systems is strongly affected by the age and condition of equipment. Heat transfer surfaces such as radiator grilles should be maintained so as to optimise their performance. While the walls of refrigerators are insulated, over time condensation can seep into the insulation, raising its conductivity and greatly increasing energy use due to heat transfers. Temperature measurements inside and outside the fridge combined with heat transfer calculations can determine whether insulation has failed. Refrigeration systems, particularly freezers, should be enclosed where possible to reduce the HVAC system energy use associated with condensation and evaporation.

The other factors detailed in Figure 10 to Figure 12 will have varying impacts on energy use and productivity. Examining and adjusting for the impact of these factors may raise efficiency and yield energy and cost savings. Considering the impact of external weather conditions and ageing and poorly maintained equipment is especially important.

39 See F Kreith (ed), *CRC handbook of thermal engineering*, CRC Press, LLC, Boca Raton, Florida, 2000.

6.3 POTENTIAL ENERGY EFFICIENCY OPPORTUNITIES

The energy efficiency of kitchen appliances will vary depending on the way food is cooked and prepared. If comparisons between engineering calculations and measured energy use indicate that older equipment is performing inefficiently, maintenance or replacement of that kitchen appliance may produce energy savings. There may be opportunities to reduce heat losses from ovens, for example, by installing double-glazed doors.

The relative efficiency of new appliances is indicated by the electricity or gas energy star rating. Hence, if new electrical appliances are being purchased, these star ratings can be used to compare to energy efficiency of similar models.[40] Assumptions used in these ratings tests should be taken into account when making major equipment purchases.

Lifts and elevators are systems that may require simulation and modelling, or in-service trials, to determine potential energy savings. Energy savings could potentially be obtained by reducing the number of lifts in operation during periods of low activity. While modelling and simulation software could be used to quantify the potential benefits, in-service trials could also be used to estimate energy savings, costs and benefits. Effective lift and elevator maintenance practices will ensure that equipment is operating efficiently, potentially minimising downtime whilst saving energy. Modern lifts and elevator systems come with sophisticated control systems, which can maximise operational efficiency and enhance the speed with which errors and maintenance problems are identified. Installing such systems in new buildings can incorporate energy efficiency over the entire life cycle of the building.

Energy efficiency measures for hot water systems are similar to those for HVAC systems. The retrofitting of additional insulation around water heaters and pipes will minimise heat losses, potentially reducing the initial temperature set point. Replacement of older boilers and water heaters with new efficient models will also yield savings, especially if the existing system has insufficient or degraded insulation. As with refrigeration systems, the condition of insulation can be gauged using temperature measurements and heat transfer calculations to estimate conductivity. Water seepage into the insulation dramatically increases heat losses. Pump maintenance and replacement of inefficient pumps may also reduce energy losses, as outlined in Section 3.8.

40 For more information on energy star ratings, see http://www.energyrating.gov.au/index.html.

7 PUTTING THE EMB TOGETHER

Once the energy and mass flows for the individual systems within the commercial building have been determined, it will be possible to bring together the EMB for the entire building. Documenting the outcomes of the EMB may involve the tabulation of data, or a report combining the outcomes of the analysis conducted on the various systems within the building.

Because many of the outflows from one system within a building also represent inflows for other systems (e.g. heat outflow from hot water piping representing a heat energy inflow for the HVAC system), separating the documentation or tabulation of energy and mass flows by energy-using systems will simplify the analysis and ensure that values are not double-counted.

It is also important to remember that some energy flows, such as heat transfers through the building envelope, will be either an inflow or outflow depending on the season and external temperature conditions. Therefore, it is important that such variations be accounted for when collating EMB data.

An unquantified example snapshot of the tabulated results from an EMB process for a commercial building is provided in Table 6. It is important to note that this table is intended to only be partial example of potential data that could be included when collating the results of the EMB process. Further examples of tabulated EMB results are provided in the *Energy Savings Measurement Guide*.

As outlined in Section 1.1, the assumptions, calculations, equations used and decision processes should all be documented and kept for at least seven years. This is not only important for verification purposes; it will also ensure that the EMB process conducted for the commercial building can be replicated and updated in later EEO assessment cycles.

Table 6. Possible data to be tabulated when consolidating an EMB

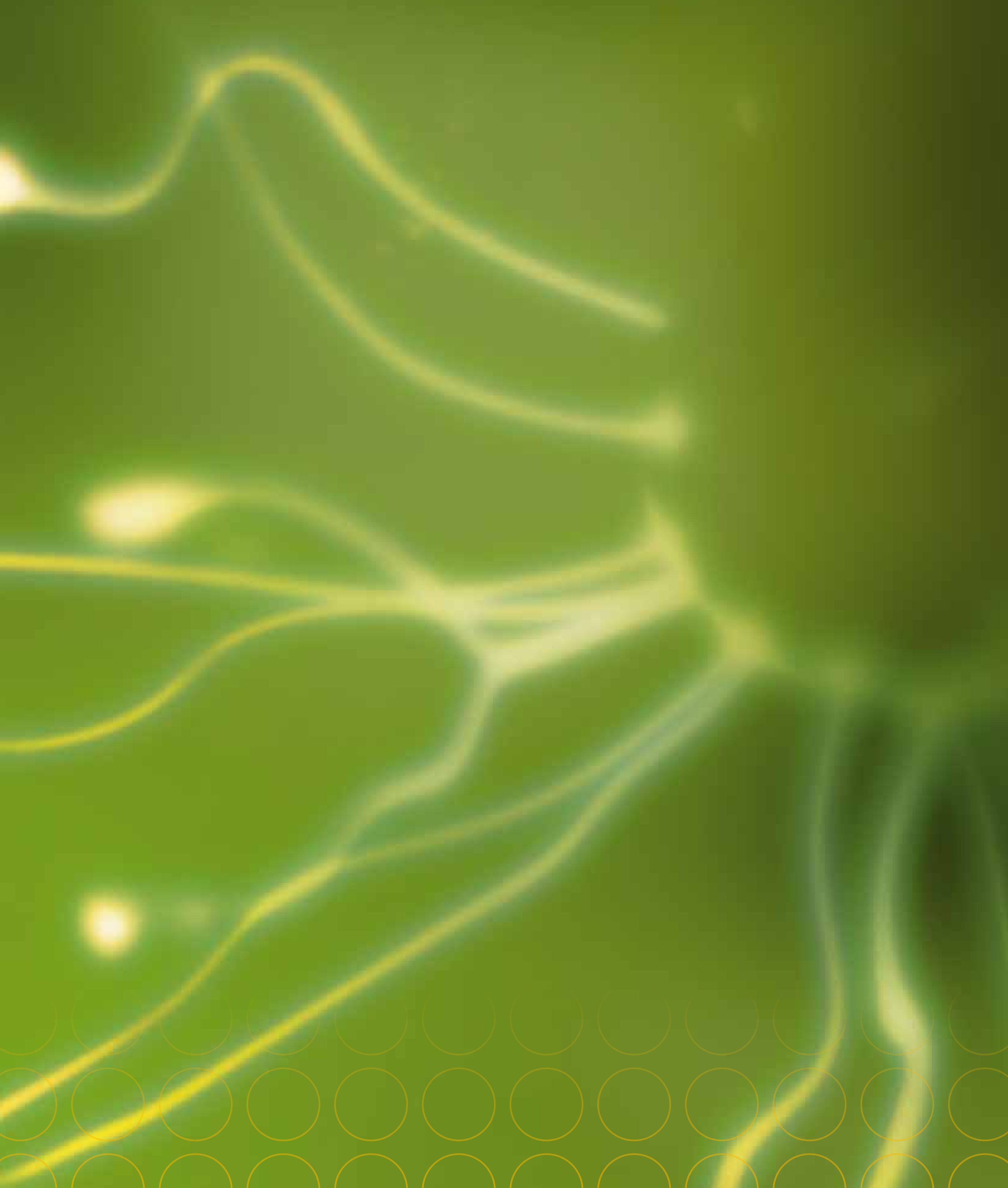
HVAC System	
Energy and mass inflows	**Possible units**
Electricity for HVAC	GJ/year
Gas for HVAC system	GJ/year
Heat from HVAC hot water piping	GJ/year
Inward ambient heat transfers through the building envelope	GJ/year
Heat released from electrical appliances	GJ/year
Heat released by building occupants	GJ/year
Heat from other hot water piping	GJ/year
Heat released from hot air ducting	GJ/year
Heat from solar gain	GJ/year
Heat content of air inflow	GJ/year
People	People/year
Products	tonnes/year
External air inflow to HVAC system	m^3/year
Re-circulated air inflow to HVAC system	m^3/year
Other air inflows/infiltration (from entrances, windows etc)	m^3/year
Total air inflow	m^3/year
Humidity processed by HVAC system	L/year
Refrigerant	kg/year
Water for HVAC system	L/year
Energy and mass outflows	**Possible units**
Heat released from water piping	GJ/year
Heat introduced to building as part of HVAC system operation	GJ/year
Outward heat transfers to external environment through the building envelope	GJ/year
Heat removed from building and expelled to atmosphere as part of HVAC system	GJ/year
Waste heat emitted from gas boiler (through boiler walls or emitted as part of flue gases)	GJ/year
Heat content of air outflow	GJ/year
Heat released from air ducting	GJ/year
Heat released from water piping	GJ/year
Temperature and humidity modified air from HVAC system	m^3/year
Air expelled to atmosphere by the HVAC system	m^3/year
Other air outflows (from entrances, exits, windows, exhaust outlets, roof openings, cracks in a building etc.)	m^3/year
Condensation	L/year
Flue gases	m^3/year
Refrigerant	kg/year

Lighting Systems	
Energy and mass inflows	**Possible units**
Electricity for lighting	GJ/year
Energy and mass outflows	Possible units
Heat	GJ/year
ICT	
Energy and mass inflows	**Possible units**
Electricity for ICT	GJ/year
Energy and mass outflows	**Possible units**
Heat	GJ/year
Hot Water System	
Energy and mass inflows	**Possible units**
Electricity for hot water heaters	GJ/year
Gas for hot water system	GJ/year
Heat content of hot water inflow	GJ/year
Water for utilities (i.e. used in hot water system)	L/year
Energy and mass outflows	**Possible units**
Heat released from water piping	GJ/year
Waste heat emitted from gas boiler (through boiler walls or emitted as part of flue gases)	GJ/year
Heat content of hot water outflow	GJ/year
Hot water	L/year
Flue gases	m^3/year
Other energy and mass inflows	**Possible units**
Electricity for other electrical appliances (e.g. cooking appliances, lifts)	GJ/year
Other gas appliances	GJ/year
Other energy and mass outflows	**Possible units**
Heat released from electrical appliances	GJ/year
People	people/year
Products	tonnes/year
Effluent	L/year

8 CONCLUSION

The development of an EMB is an iterative process that provides a deeper understanding of the energy and mass flows through a site or process. The initial version of an EMB will assist in identifying areas for improvement in data collection and analysis. Initial EMBs will also identify some low cost, easily implemented opportunities, with subsequent improvements to data and analysis refining the understanding of energy usage. Further iterations of the process will produce a final, comprehensive EMB, providing for a more thorough analysis of components within the system, and the identification, detailed investigation and evaluation of specific opportunities. If prepared as part of an approved representative assessment approach, EMBs for a sample of buildings may be applied across the entire portfolio.

This document was developed to provide guidance on the key considerations involved in conducting an EMB on a commercial building. In particular, it identified the key energy-using systems within a building and associated mass flows that the analysis should focus on and discussed typical energy efficiency opportunities for these key systems.



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