FORUM

Energy simulation of existing buildings and refurbishments

Ania Hampton, B.Eng, M.AIRAH

Hampton Sustainability

1. ABSTRACT

Energy and thermal simulation is a valuable tool in the refurbishment of buildings. It can identify the most effective upgrades, from building fabric to mechanical and electrical systems, and provide energy-saving information to inform feasibility, cost and payback analyses.

However, simulating an existing building is a difficult task, as older buildings are often poorly documented and the condition and efficiency of the plant may be unknown. Metering is usually scarce and a breakdown of significant energy users can be impossible to attain. Attempting to accurately model such a building can be an expensive and often futile exercise. However, the act of modelling can identify many areas within the building's operation where improvements can be made. The fully refurbished building can be modelled to predict the final expected energy performance; however, this is most useful where a replacement of significant mechanical and electrical systems is planned.

This paper describes what can and cannot be achieved through computer simulation. Those areas where modelling is the most effective (such as mechanical plant upgrades) are examined. Key information required by the modeller is identified. Correlating modelling results to actual energy performance is discussed.

Case studies are presented where computer simulation has been used to identify effective upgrades to buildings.

2. INTRODUCTION

Many buildings undergoing refurbishment today do so with a certain environmental performance in mind; indeed, often this performance is a fundamental requirement of and reason for the refurbishment. Computer simulation is an important tool in assessing the performance of the proposed upgrades and in determining if the building is likely to achieve its desired energy rating.

Computer simulation can assist in a number of areas, from selecting individual pieces of equipment to refining control strategies and calculating payback periods for upgrade works. However, modelling by its nature can be inaccurate, and a successful outcome depends as much on the information available about the building as it does on the skill and experience of the modeller.

This paper considers some of the difficulties in modelling existing buildings and how they can be overcome. It also provides information for those engaging a modeller as part of their design team. It draws on the author's seven years of experience modelling both new and refurbished buildings both within Australia and internationally using a variety of modelling softwares and methods.

It should be noted that this paper discusses the energy simulation of buildings only and does not consider daylight, water, comfort and other simulations, which are all also worthwhile. Where ratings or outcomes are referred to, these are typically NABERS Energy star ratings.

3. AN OVERVIEW OF BUILDING SIMULATION

Building simulation is a valuable part of the design process. Done well, it can drive and improve the efficiency of a building. Done poorly, it is not only a waste of time and money but can also lead to poor design decisions and a substandard solution. Good building simulation requires an understanding of the tools involved, the process and the limitations of such modelling.

3.1. Tools

A good building simulation requires four things:

1. Accurate, detailed information regarding the building, its systems and controls. If the fundamental parameters that the model is based on (e.g. building fabric, plant specifics or control logic) are unknown or uncertain, the integrity of the model is undermined.
2. A good thermal modelling software package. Most HVAC design packages will have an add-on energy simulator but these can be very simplistic: for example, some simulate the design day for each month and use this figure for the entire month's energy consumption.
3. A sophisticated, well-developed and proven modelling methodology. Many modelling packages are a "black box": select the type of HVAC system, input a few basic parameters and viola, an answer. It is often impossible in these systems to accurately model, for example, a complicated chiller staging

strategy. For this reason good modellers will only use the thermal modelling software as part of their arsenal of energy simulation methods, not as the end-all.

4. A competent operator with an in-depth understanding of the need for and how to integrate the other three aspects.

3.2. The Process

Modelling is a multi-stage process requiring the input of the entire design team. The key stages of the modelling process are:

1. Data gathering – building geometry and fabric, HVAC and electrical systems, control strategies, equipment data, etc. The information required by the modeller is covered in more detail later in this paper.
2. Construction of the 3D building model – the geometry, glazing, shading features etc. (Figure A)

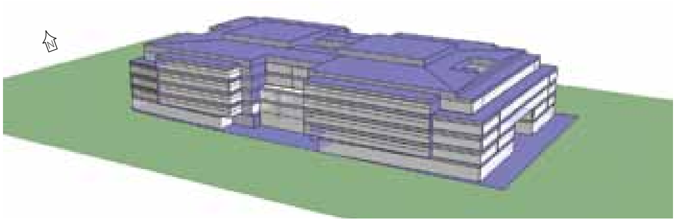

Figure A: Example of a 3D building model.

3. Input of parameters – building fabric and internal heat loads such as equipment, lighting, people and infiltration
4. Construction of the HVAC system model – the equipment, air supply volumes and temperatures, plant and control logic etc. (Figure B).
5. Heat load and then energy calculations for the HVAC system – chillers, boilers, pumps, fans, cooling towers etc.
6. Energy calculations for other building systems such as lighting, DHW, ventilation systems, lifts, building control systems, hydraulics, etc.

When modelling a refurbishment, often the simulator will first attempt to model the existing building with its services and correlate this model with current energy consumption before modelling the building with the proposed upgrades. However, it is argued that this can sometimes be a largely pointless exercise, as modellers can simply change the plant equipment efficiency or use a "safety factor" to achieve the correct consumption. It is also usually impossible to correlate the energy use of individual equipment; just because the overall energy consumption is correct does not mean that the breakdown of energy use is (Figure C).

When major upgrades to the building are planned, it is usually sufficient to just model the refurbished building.

3.3. Limitations

Many office buildings, both new and old, fail to perform at the level suggested by their computer model. This is largely because models often represent an ideal scenario. A computer simulation, by its very nature, must make many assumptions about the building, its systems, its controls and the people who operate it. Many modellers have very little experience in the actual operation of buildings – some have never even seen a plant room. Models are usually based on an idealised set of operating conditions; rather than attempting to model the hysteresis in a

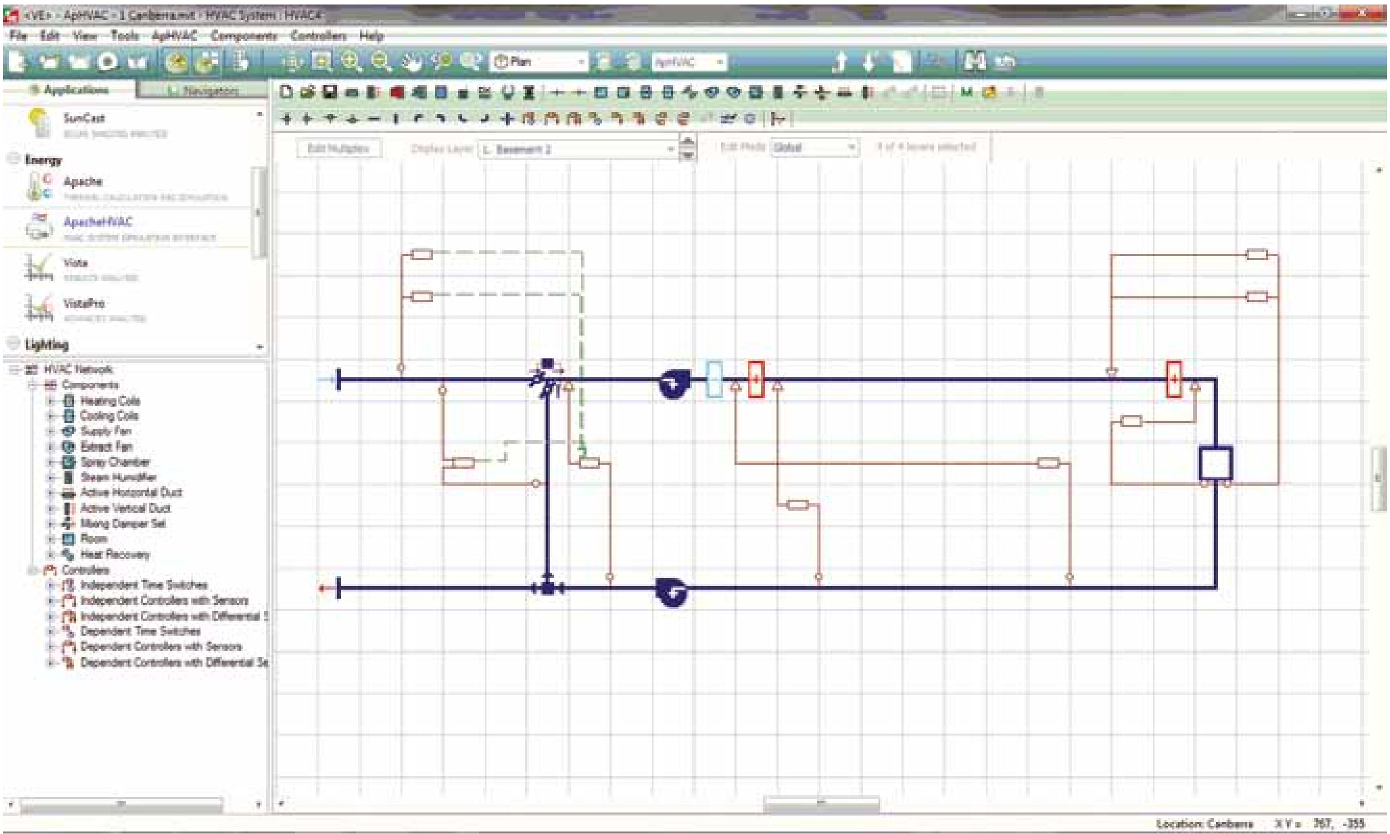

Figure B: Example of HVAC Schematic.

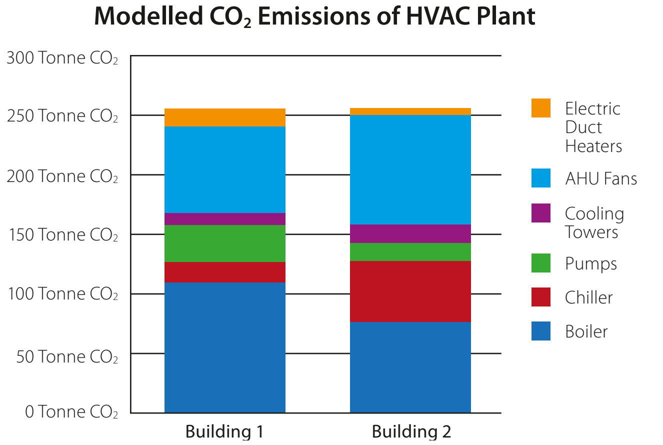

Figure C: Example of two HVAC plants with identical overall energy end use but different breakdowns.

control system, a blanket safety factor is applied to the energy consumption of the entire mechanical plant.

Engaging a modeller who has proven experience and a strong understanding of fundamental engineering principles is key to minimising these limitations, as is providing them with the information and time to complete the model accurately.

4. SIMULATION VERSUS OPERATION

Imagine you are purchasing a new car that promises to handle like a Ferrari. Only when you get it home do you read the fine print: "will handle like a Ferrari as long as you drive like Michael Schumacher". This is exactly what is often behind a building simulation. If the building has been simulated to achieve a certain performance, there will be an extensive list of events that must occur and parameters that must be maintained in order for this performance to be realised. These almost always include building operation, management and maintenance but can also include the installation of specific equipment. Examples include plant start times, specifying equipment with a certain efficiency, or maintaining certain duct pressures.

Increasingly, refurbishments are being delivered under the energy performance contract method. This author has seen several such contracts, which promise an energy performance outcome but with very little detail of how this is to be achieved. They also carry the disclaimer that any assumptions made are true and accurate and that the building will be operated correctly. It is imperative that the building owner, operator and any other parties involved understand exactly what is assumed and required from them in terms of ongoing building operation. The contractor should be required to produce a detailed modelling report in accordance with the NABERS guidelines for commitment agreements. It may also be wise to seek the advice of an independent assessor to verify that the assumptions made are realistic and achievable.

5. CHALLENGES OF SIMULATING EXISTING BUILDINGS

5.1. Available information

Modelling a brand new building, with a complete set of plans, specifications and equipment data sheets, is difficult enough. Now consider the information available for most existing buildings and the challenges can be seemingly endless.

Most of Australia's building stock is over 20 years old; many are over 50. Most have had multiple refurbishments, HVAC and lighting revisions and changes in management, many of which have only been partly, if at all, documented. It is not unusual to find a building with floor plans for only some floors, only basic elevations, no sections and no fabric details. Mechanical and electrical plans, if any, can contain little information and what is there is often outdated. It can also be impossible to obtain performance information of ageing equipment such as chillers, boilers and cooling towers.

To gather suitable information, a site visit by the modeller is imperative. The building may need to be physically measured. Measurements can also be taken for HVAC plant items – air-flow rates in ducts, supply air temperatures, pump and fan operating current etc. Light fittings need to be inspected and counted if necessary. The facilities manager must be present to describe building control strategies and provide any other information that they may have.

Where information cannot be obtained, one avenue is to use the industry standards at the time of the building's construction or worst-case assumptions. For example, where a building is over 20 years old, it can be reasonable to assume that much of the insulation has deteriorated to the point where it is no longer effective.

5.2. Metering

Existing buildings are often poorly metered – many do not even separate base building from tenancy energy. Correlating the performance of such a building to a model can be difficult, if not impossible. If sub-meters are installed, these must be read. If you have a building with sub-meters, ensure the regular readings are taken for future use. If you are considering modelling upgrades in the future, install sub-meters now – the more data the better.

5.3. Actual Operating Parameters

Every building owner and manager knows that good facilities managers (FM) are worth their weight in gold. Good FMs know exactly how their buildings are run. They can tell you about the quirky damper on Level 6 and that the lighting controls in the second floor foyer sometimes don't work. They know exactly how the chillers are staged, what time the boiler comes on in the morning and what kind of light fittings are used throughout the building.

Unfortunately, not every building has this kind of FM, and it is often surprising just how little is known about the operation of the building. When the answer is "we don't know", the next question must always be "well then, let's find out". If you are going to the effort and cost of having your building modelled, not taking the time to find out how it is currently operating is counter-productive. Often the very act of investigation unearths a number of areas where energy savings can immediately be made.

5.4. Applying the NABERS Modelling Protocol

The National Australian Built Environment Rating System (NABERS) not only provides the framework for rating the energy performance of buildings; it also has a set of guidelines for computer simulations of buildings . When applying for a commitment agreement to market the future energy performance of a building, this protocol must be followed. It is also an excellent basis for modelling existing buildings.

The protocol contains a set of default figures and profiles for internal equipment, lighting and occupancy heat loads. It is often presumed that these default values must be used in all models; however, they are only to be used when the actual loads are not known (i.e. new buildings or a new tenant). If the existing tenants are unlikely to change for at least a year following the refurbishment, their occupancy, lighting and equipment loads and profiles should be used in the simulation rather than the default values. This is particularly important in the case of tenants with exceptionally high or low office densities (e.g. call centres). When known, actual loads or consumption for items such as lifts, domestic hot water, supplementary tenancy cooling, etc. should always be used in preference to the default NABERS figures.

Where NABERS protocol figures are not deemed appropriate, other protocols such as the Green Star or BCA Section J protocols can also be used. Essentially, they all provide a set of assumptions to make comparisons between different building stocks.

6. MODELLING AN EXISTING BUILDING

6.1. When is modelling most effective?

Put simply, the more things being upgraded, the more accurate and effective computer modelling is likely to be. Accurately modelling an existing building in its current form is time consuming and difficult. Doing so simply to then calculate the energy savings from a small plant upgrade (e.g. new fans or pumps) is usually not worth it – the money could be better invested in a more efficient piece of equipment.

Modelling is vital if a certain energy performance outcome is required (e.g. 4.5 stars). It is also highly useful when the services have reached the end of their life and a full replacement is possible. Modelling can be used to choose between entire systems and compare individual pieces of equipment. It is also very useful in optimising plant control strategies.

Modelling is in itself an inexact science. Even with totally accurate inputs, a model will never exactly predict how a building will perform. This point must be appreciated if the results of the model are to be useful. Allowances for a safety margin within the final result must be made.

6.2. Information required for effective modelling

The results of a building simulation are only ever as good as the information used to create it. The more detailed and accurate the inputs, the higher the integrity of the model. When modelling an existing building, much of this information can be difficult to obtain; however, every effort needs to be made. This may require a physical investigation of the building or its services.

Information required by the modeller includes:

1. Architectural documentation such as plans, elevations, sections and fabric details
2. Tenancy layouts and loads (where a tenant is staying or a new fit-out is being installed)
3. Electrical details – lighting layouts and fittings, metering arrangements, onsite generation
4. HVAC details – system parameters, zoning layouts, air supply temperatures and flow rates, equipment specifics on chillers, boilers, pumps, fans, cooling towers, heat exchangers, etc.
5. Hydraulic details – domestic hot water services, pumps, etc.
6. Control strategies for all services
7. Equipment data sheets for chillers, boilers, fans, pump, cooling towers, heat exchanger, onsite power generation, heaters, etc. Motor powers and equipment efficiency part-load curves are essential.

6.3. Correlation of results

Effective correlation of a building model to measured energy consumption relies entirely on the energy metering available. A model can easily be adjusted to correlate with actual measured energy consumption by manipulating equipment efficiencies and adding "safety factors". But without knowing the actual breakdown of energy end-users, it is possible that some items have overestimated their energy use while others are underestimated. This can have significant consequences if this same model is then used to calculate energy savings from upgrading a particular piece of equipment (e.g. chiller or boiler) – if the original energy consumption from that equipment is overestimated, then energy savings may also be overestimated.

7. CASE STUDIES

Two case studies are presented to illustrate the process and benefits of modelling an existing building. The first case study shows how modelling can identify effective upgrade solutions, while the second highlights some of the challenges associated with simulating an existing building with poor documentation. The case studies refer to greenhouse gas emissions (GHG) rather than pure energy, as both were targeting specific NABERS ratings, which assess greenhouse gas emissions.

7.1. Building A

The owner of a 15-year-old office development in Melbourne's eastern suburbs wished to upgrade the building to from 3.5 Stars to 5 Stars NABERS Base Building. The owner requested a "shopping list" of potential upgrades with individual energy saving potential and also an overall "5 Star package" recommendation.

A great deal of information was available about the existing building and its systems, both written and from the FM. A model of the existing building was created, which correlated within 10% of actual measured energy consumption (Figure D).

From there, various upgrades were modelled including:

- The addition of economy cycle to air handling units
- Replacement of boiler
- Replacement of chiller
- Replacement of existing T8 lighting fittings with T5 and all halogen downlights with CFL downlights plus a sophisticated lighting control system (modelled separately)
- Replacement of the single chilled water pump with a primary/secondary system with VSD

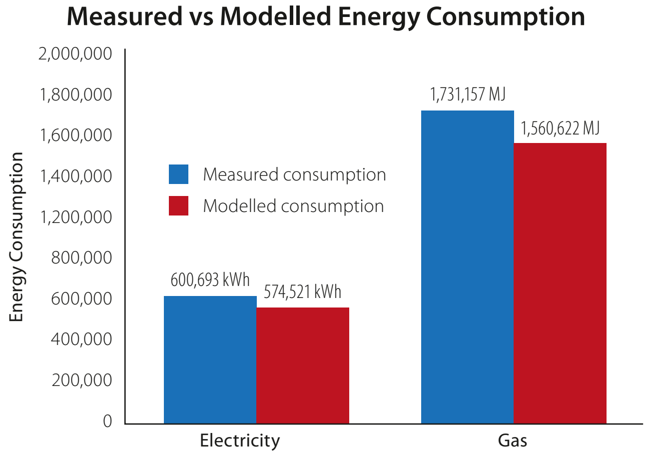

Figure D: Measured vs Modelled Energy Consumption.

- Installation of insulation in the roof
- Replacement of heavily tinted glass with clear glass and horizontal overhanging shading on north and east facades (modelled as a stand-alone upgrade and also with the daylight dimming option).

Each upgrade was modelled individually, with the potential CO_2 saving calculated as shown in Figure E:

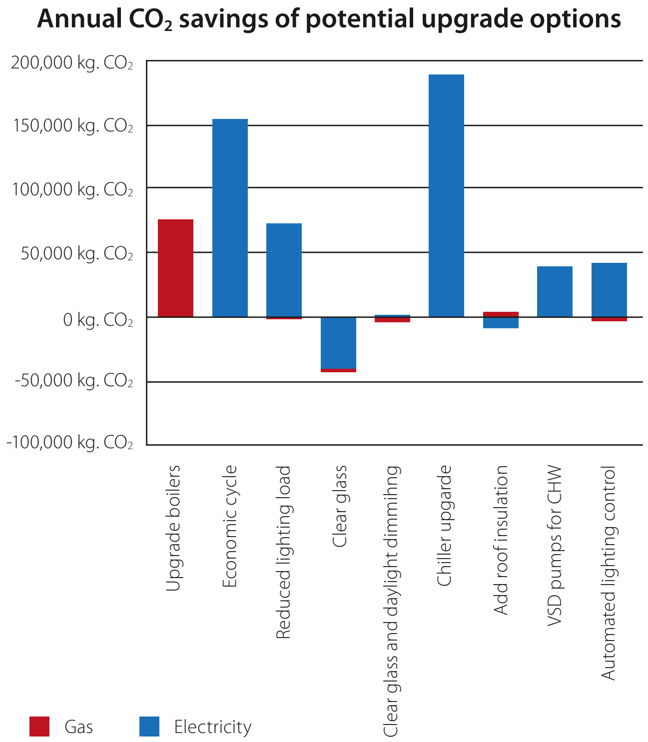

Figure E: Predicted annual CO_2 saving of each upgrade option.

The following points were also considered when assessing options:

1. While upgrading the chiller made the single largest saving, the chilled water plant was assessed to still have 10 years' life left, and due to the embodied energy and cost of replacement, it was decided to leave the existing chiller and focus on other improvements.
2. When operating, economy cycle would increase outside air rates and thus improve environmental conditions for occupants.
3. Reducing the light load and upgrading controls, while only having a moderate impact on base building emissions, would have significant environmental and cost benefits for tenants, which the building owner recognised as a selling feature.
4. Improving the building fabric increases cooling energy for the following reasons:
   - For the majority of the year (whenever outside temperature is below approximately 26–28°C and the HVAC is in cooling mode), heat gains from internal loads outweigh those from the external building fabric. Some of this heat is lost through the building fabric: increasing the roof insulation means less heat can escape.
   - The current glazing is so heavily tinted that it is more effective in removing solar loads than the proposed possible external shading. Proposed external shading provisions can be increased to combat this, but this would reduce available daylight.

Although there would be a very slight energy penalty for upgrading the building fabric, the improvements in comfort and reductions in peak load would outweigh this. Therefore these improvements were also recommended to the client. However, these works could not be completed with the allowed budget so were omitted.

The preferred upgrade options (boiler upgrade, economy cycle, pumps upgrade and lighting improvements) were then modelled together to calculate their overall energy-saving potential. This saving was then subtracted from the measured energy consumption to determine the building's potential base building energy rating of 5 stars.

The energy upgrades are currently being undertaken.

7.2. Building B

A 5,000m² office building was to be upgraded to 4.5 stars.

As-built information about this building was difficult to obtain, with only part plans and elevations being supplied. Mechanical and electrical information was patchy and the (external contractor) FM admitted to knowing little about the actual operating parameters of the building.

The client requested the refurbished building be modelled to determine if the desired 4.5 star rating could be achieved. However, the lack of information meant that the predicted improved energy consumption was only marginally better than the actual measured current energy consumption (columns 1 and 2, Figure F). The design team then measured the building's operating parameters. Measurements taken included:

- Supply air flow rates and temperatures
- Duct pressure drops
- Fan and pump operating currents
- Chiller starting hours were recorded
- Supplementary tenancy cooling unit loads

With this information, the building's energy consumption was modelled to within 3% of actual, but the upgrades failed to achieve the desired energy performance (columns 3 and 4, Figure E). While taking the measurements the FM identified several areas where equipment was not operating as intended and immediately made improvements. The design team is currently considering other upgrade options to achieve the desired 4.5 Star rating.

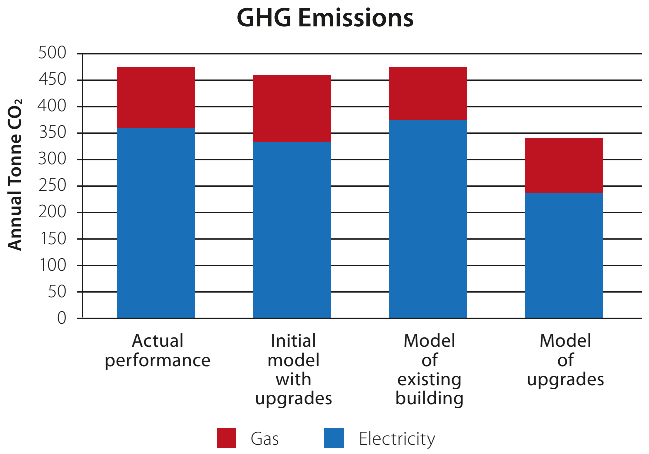

Figure F: Results of modelling process.

8. CONCLUSION

Computer simulation of existing buildings can assist the refurbishment to achieve a desired energy performance. It can be useful in assessing the merit of various pieces of equipment and can identify the most effective upgrades. However, adequate information regarding the building, its services and its operation is vital in achieving a robust and useful model.

ABOUT THE AUTHOR

Ania Hampton B.Eng(Mech)(Hons), M.AIRAH, is an ESD consultant experienced in a wide range of projects, including healthcare, community, residential and commercial. Ania founded Hampton Sustainability in 2009 with the aim of designing practical, cost-effective sustainable buildings. She believes environmental efficiency is easily accessible on projects of all sizes and shapes and strives to embed sustainable practices in the fundamental design of a building.

Ania is an Accredited Green Star Professional, NABERS Assessor and Thermal Performance Assessor. She regularly lectures at postgraduate sustainable building courses for the University of Melbourne and Swinburne University, and writes papers for the Royal Australian Institute of Architects' Environmental Design Guide. Email: ania@hamptonsustainability.com.au

mycoolingtower.com.au

FACTS

- There are an estimated 30,000 cooling towers operating in Australia.
- Cooling towers can use between 5,000 and 10,000 litres per day.

You can do the maths! We did and the result is a one of a kind cooling tower water efficiency calculator available online.

www.mycoolingtower.com.au

AIRAH

State Government Victoria

The mycoolingtower.com.au website has been developed by AIRAH as part of a collaboration between industry group, water corporations and the Victorian government.