CLOSING THE LOOP: OFFICE TOWER SIMULATION ASSUMPTIONS VS REALITY

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ABSTRACT

This document is a case study of the design and construction of a 30,000 sq m office tower that has achieved an excellent energy efficiency outcome close to the simulated potential when modelled with actual weather data. The design features and processes contributing to the result have been considered. Some of the lessons learnt throughout the simulation and results reconciliation work have been articulated to promote interchange of ideas and experiences among simulation practitioners. Differences between the simulated and actual results are also considered, and possible reasons have been identified.

INTRODUCTION

This paper is presented as a "retrospective" on the design, construction, commissioning, fit-out and operational experiences of a 30,000 sq m office tower from the perspective of the simulation consultant. The building is located in the CBD of Perth, Western Australia (32S latitude), has 17 typical floors of approximately 1700 sq m per floor (centre core) and generally has 1.8m high low-e double glazing of 0.26 SHGF. External horizontal shading is provided on the north, east and exposed west facades.

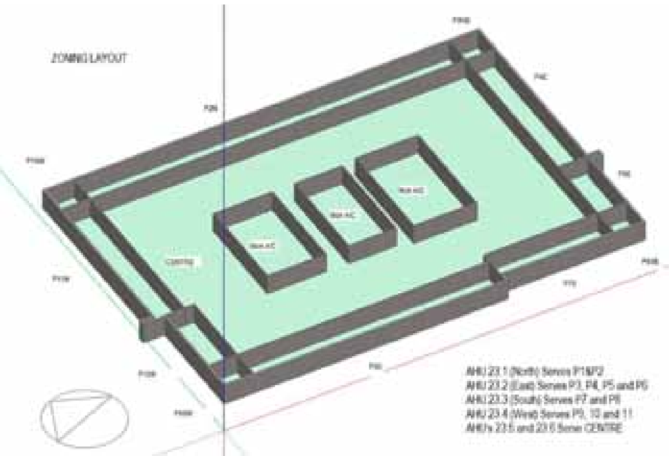


Figure 1: Typical Floor Zoning

Installed lighting density is approximately 6 W/sq m with normal office occupancy averaging around 12sq m/person. The HVAC system is central air handling variable air volume with parallel fan terminals in the perimeter zones, electric reheat and gas-fired hot water warm-up coils. Cooling set-point is 23.5°C and heating setpoint is 21.5°C

The conceptual design commenced in 2005 and the project completed 12 months of operation in December 2010.

Thermal modelling complemented the development process throughout this period to provide the team with feedback, risk identification and suggestions aimed at securing a minimum 4.5 Star NABERS Office Base Building energy rating outcome. The project has produced a certified result of 5.5 Stars, which was well above the minimum standard required and very close to the design potential as established by thermal modelling.

The paper is presented in two broad sections. The first describes the various roles of the simulation consultant throughout the project. Each stage of the development cycle has been reviewed to identify the key processes that may have contributed to achieving and preserving the design potential. The second section presents and reviews the actual results achieved compared to the simulation, lists some of the key architectural and HVAC design features contributing to the results and discusses some reasons for observed differences.

SIMULATION CONSULTANT ROLE

The role of the simulation consultant for this project commenced after the local authority development approval had been granted, and the building size, form, function and general appearance had been established. The developers, ISPT, had a corporate philosophy of sustainable buildings and corporate social responsibility, and agreed to a specialist consultant role to assist the design team in achieving a specific energy-rating outcome.

The ABGR star rating scheme for existing buildings (now NABERS) was used to set a performance target, noting that 4.5 stars was a commonly requested and well respected (by prospective tenants) target in the market. The ABGR rating scheme administrators would only permit a new development to promote a rating target if a simulation consultant was engaged and other strict procedures were followed to validate the design prediction, ensure follow-through to delivery and define corrective action where necessary. A 4.5 Star "Base Building" rating Commitment Agreement was signed with the local administrator. This committed the developer to a normalised 80kgCO_2/sq.m or lower result.

The developers accepted an "end to end" commitment to the role, leading through to the end of defects liability and delivery of the required result – a five to six-year role. Key elements of the role were as follows:

a) Team education and role integration

The developers and design team were fully briefed on the various rating schemes available, associated obligations, simulation methodology and procedures for delivery of a high performing building.

b) Concept design

While the development approval had been granted, there was opportunity for the simulation consultant to offer suggestions to the designers that they then carefully considered in relation to practical, technical and economic feasibility. These suggestions were based on features typically expected in high – performing buildings and on general energy – efficiency principles. The role during this phase included drafting and incorporation of energy – efficiency objectives, processes and philosophies into the design brief that underpinned the consultants' agreements.

A review was undertaken of the best performing buildings in the local market and how they compared to the 4.5 star target. It was apparent that an improvement in performance over these buildings of approximately 20–25% would be required to provide a reasonable level of certainty that the rating could be achieved, even in potentially adverse situations such as partial occupancy or a small tenant requiring 24x7 central plant operation.

The implications of the proposed rating target were communicated to the team by comparison of the proposed design against features of existing high-performing buildings in the local market. This approach did not rely on a theoretical simulated prediction in absolute terms, but relied on a relative approach to compare incremental changes. Many typical floor simulations were conducted to give comparisons between the proposed building and the existing benchmark building.

The simulation focus at this stage was to provide feedback to allow the building façade options and mechanical services concepts, capacities and space provisions to be resolved in general terms. Broad performance parameters and targets were agreed with consultants, including insulation levels and extent, overall pressure drop limits for fans and pumping, component efficiencies, lighting level limits and energy sources.

c) Design development

The role of the simulation consultant during this stage was primarily to:

- Develop a complete and detailed thermal model of the proposed building and its systems and test the model under a series of adverse conditions to determine sensitivity and resilience to key risk factors. Refinement and tuning of control systems strategies and settings within the model was undertaken. The high level of detail in the tender functional description was a significant factor in the final result. Cross checks were undertaken between EnergyPlus capacity assessments and the mechanical consultants' capacity assessments.
- Develop a detailed total energy budget (encompassing simulated and non-simulated loads) and ensure all assumptions (including control strategies) were provided to or endorsed by the design consultants and incorporated as requirements in the design documentation.
- Develop a detailed risk assessment and workshop process alerting each entity (with influence over the outcome) to potential problems that could derail the result.
- Develop "energy efficiency" requirements for contract "preliminaries" including shop drawing approvals, commissioning processes, tuning and defects liability. These would be required to ensure that each of the specified duty points, efficiency targets and features were achieved during the contractors' equipment selection, confirmed by tests during commissioning and were not compromised during defects liability. This included defining the scope of work and negotiating the role for the independent commissioning agent (ICA).
- Ensure the metering plan was integrated into the electrical and mechanical documents to allow:
    - monitoring and reporting of all components of the energy budget,
    - proper base building, tenant and retail discrimination for the future rating and
    - self-checking of the metering system integrity.

d) Construction

The main roles undertaken during construction were as follows:

- Check as constructed drawings, duty point calculations and equipment selections/efficiency against simulation assumptions.
- Evaluate variations. There were a number of changes to the design, and each was checked to identify and quantify any potential impact on the rating result. The energy budget was constantly updated with the effect of these changes.
- Review and provide feedback on functional descriptions and assist in the design of the BMS user interfaces.

e) Leasing

Draft leases were reviewed in relation to clauses that may impact energy usage or rating. These included hours of operation clauses, after – hours air conditioning clauses, a/c operation clauses, internal loading limitations clauses, tenant obligations for energy efficiency, green lease clauses and clauses relating to alterations and fit-out.

f) Commissioning

The role of the simulation consultant included:

- Review and comment on proposed energy efficiency tests and plans and the commissioning program.
- Checking that efficiency commissioning principles in the specifications were translated to detailed plans.
- Witnessing the energy-efficiency tests on site.
- Confirming duty point delivery, part-load and low-load motor power draw for pumping and air handling systems.
- Testing control functionality for static pressure and supply temperature control.

- Reviewing commissioning results to check whether the correct airflows were being achieved in each zone, as this was critical to the efficiency equation.

g) Tenancy fit-out

Tenancy fit-out modifications are commonly responsible for creating many energy efficiency problems. These include over or undersizing VAV boxes for actual loads, poor airflow, incorrect temperature sensor location, overloading of spaces, and poor air diffusion. In many buildings these problems, even in a single zone, will cause the central plant to supply colder, higher pressure air to all the VAV boxes, negatively impacting on chiller, fan and heating (reheat) energy, so correct fit-out redesign is critical. Normally there is very substantial headroom between the design capacities for each zone and those actually encountered. VAV boxes can therefore operate at minimum volume for much of the time. This is a common source of energy inefficiency (unnecessary cooling, fan and reheat energy) so careful matching of VAV box capacity to actual fit-out loads is a critical factor.

The simulation consultant was therefore engaged to:

- Write sections of the fit-out guide to assist in reducing these problems.
- Check the actual internal loadings against design limits and simulation assumptions.
- Cross-check some aspects of the work of the fit-out designers including air delivery after duct modification, sensor locations, supplementary A/C system provision, type, capacity and control.
- Check the predicted energy efficiency and NABERS star ratings for the tenancy.
- Review the performance testing of the completed systems.

This process allowed many instances of potential problems to be identified and averted. In particular, careful specification and tenant fit-out guide wording assisted in ensuring that supplementary a/c systems were installed where zone internal loadings exceed design criteria.

h) Defects liability

The simulation consultant's role initially included:

- Analysing metering data and identifying anomalies.
- Observing plant operation to cross-check the controls operation and settings.
- Checking instantaneous and accumulated performance data against simulated results.

It took several months after practical completion to debug the metering system including faulty meters, incorrect wiring, incorrect CTs installed, incorrect CT ratio's, and incorrect labelling of meters. Energy usage data was carefully analysed on a weekly basis and compared against the energy budget for each component. Regular meetings were held to discuss differences between the budgeted energy usage and actual and identify, diagnose and rectify controls that were not functioning as intended.

ARCHITECTURE

Energy efficiency principles

Energy-efficiency suggestions offered for this project relating to building architecture were as follows:

- Design to allow people to be comfortable at higher temperatures in summer or lower in winter by control of MRT.
- Reduce direct solar ingress via external shading.
- Reduce peak façade thermal loads to increase the ratio of average load to peak load.
- Reclaim heat generated by lights
- Collect heat rising from internal glass surfaces to return air before it adds to the room cooling load.
- Use north overhangs to offset winter heating requirements and reject solar loads during summer.
- Reduce infiltration loads and stack effects.

Simulation methods

The selection of extent and type of glazing and external shading is a critical stage in the design concept development, which presents many options to designers. The problem is how to provide rapid, useful feedback to guide decisions at the concept stage when the rest of the building and system design is not completed.

The preliminary simulation work was on a typical floor only, as it could be changed quickly and results obtained in minutes rather than the many hours for a simulation run with a complete building model. The cooling coil loads and heating loads for the proposed façade options (peak and annual) were compared to the "benchmark" building façade loads by assuming they both had the same type of high efficiency a/c system and internal loads.

Initial external shading and glass selection parameters were provided by the mechanical engineer as a starting point based on experience and preferred sun angles affecting occupants.

Feedback was given to the architects concerning whether the target level of improvement was being achieved with each option. The façade improvements reduced mechanical plant capacities, allowing reduced duct pressure losses.

The architect requested a number of external shading options and glass types be assessed to reduce cost, achieve aesthetic objectives and to improve the extent of glazing where views were a priority.

The typical floor was modelled with a ceiling plenum for return air. The correct modelling of a return air ceiling plenum is considered critical due to the substantial difference in room heat loads from lighting with and without a plenum.

Actual energy results for simulated loads are presented in the following section. Anecdotal feedback on the general comfort standards of the building have been very positive.

HVAC SYSTEMS

Energy efficiency principles

- Maintain complete separation of office and non-office (retail) systems.

- Maximise the economy-cycle benefit through high cooling design supply air temperatures. This provides air-quality benefits, maintains good air movement, reduces chilling, and reduces reheat. Increased fan energy is offset by very low pressure air distribution systems allowing the building to "breathe" easily. The central plant fan static pressure rise (supply and return fans combined) at full volume is typically 580Pa rivalling floor-by-floor air handler designs.
- Ensure good dehumidification at low loads. Shortage of dehumidification capacity and consequent humidity increases at part-load is a problem with most cooling coils where humidity is not controlled. This has been addressed with a coil-bypass arrangement on the air side, and a 33%/66% split-coil and control-valve arrangement.
- Maintain high air-change rates, as this improves thermal comfort at higher temperatures and reduces temperature fluctuations and gradients in the space.
- Eliminate reheat by reducing minimum primary air volumes on VAV boxes, reclaiming heat from lighting and increasing supply air temperatures.
- Design for low water-side pressure loss (large pipes, smooth bends, no unnecessary resistance). The main chilled-water-pump design pressure rise is 240kPa, and the condenser water-pump pressure rise is 140kPa. Water flow is controlled entirely by VSDs (no control valves).
- Select chillers for minimum water-side differential pressure, (large heat exchangers), maximum low-load efficiency, maximum turndown ratio and ability to operate with the coldest condenser water temperatures.
- Separate façade-based air handling.
- Maximise turndown efficiency for pumping and air handling systems with variable flow.
- Design for efficient and stable central plant air handler operation at loads down to 5%. A dual fan design was originally proposed to achieve this as a precaution against excessive poor efficiency cause by after-hours operation. This can be a significant disadvantage for central air-handling systems.
- Chiller plant completely off below 16°C. This principle ensured that there were no chilled-water fan coil units connected to the plant without an economy cycle, no matter how small. Control room, building management server room, and lift motor room systems were all independent from the main system.
- Accurate, closed-loop control of outdoor air volumes.

The services concepts were established very early on in the schematic design phase. Decisions about plant configuration (central plant or floor-by-floor), shaft sizes, plant-room locations and sizes were made based on the mechanical engineer's experience and the simple typical floor-simulation approach, without the benefit of a full simulation of all options.

Detailed modelling was conducted on the final design to prepare the energy budget and predict rating outcomes. The overall results are shown in fig 2.

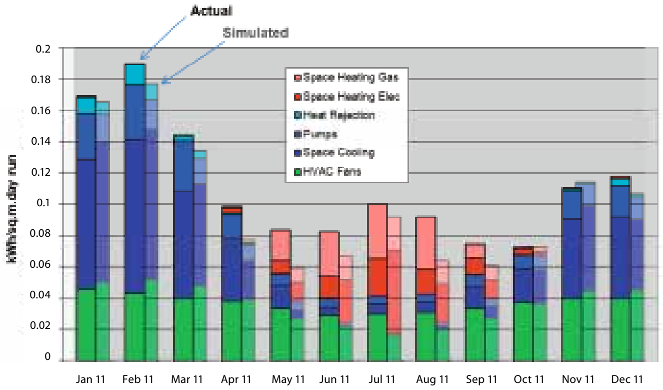


Figure 2: Actual vs. simulated central HVAC energy

The simulated results (appearing in the background) have been adjusted from the original simulation results by modelling with actual weather data over the measurement period and to account for increased operating hours (63 hours weighted average per week compared to 50 in the original modelling).

Chilled water systems

EnergyPlus has a very comprehensive chiller modelling and staging capability, and determines the unique COP for each timestep based on:

- Associated chilled-water flow and temperature (from detailed coil modelling assessing water flow required to deliver the supply air temperature setpoint).
- Condenser water temperature from the cooling tower based on ambient conditions.
- Detailed cooling tower performance calculations.

A mathematical "model" was created for each chiller based on extensive part-load data sets provided by the chiller manufacturers. EnergyPlus uses several variables to predict the chiller power input at any point in time, including chilled water entering temperature, condenser water entering temperature and chiller part-load ratio based on a maximum capacity curve. The maximum capacity curve adjusts for the fact that maximum chiller capacity varies with condenser and chilled water temperatures.

The model was based on three chillers and a four – step staging strategy of small, large, small+large and two large chillers. Staging was based on total cooling demand.

Water flows were assumed constant through each chiller that was required to be running. The plant-side modelling in EnergyPlus (water loops) was a very demanding component to the simulation work but provided very good results and comprehensive performance analysis data.

The chilled water temperature was set to a constant value, and no attempt was made to model the improvement that could be achieved with chilled water temperature rescheduling. Condenser water entering temperature was calculated by EnergyPlus and varied as described in the "heat rejection" section below. The results for the chiller energy usage are shown in fig 3.

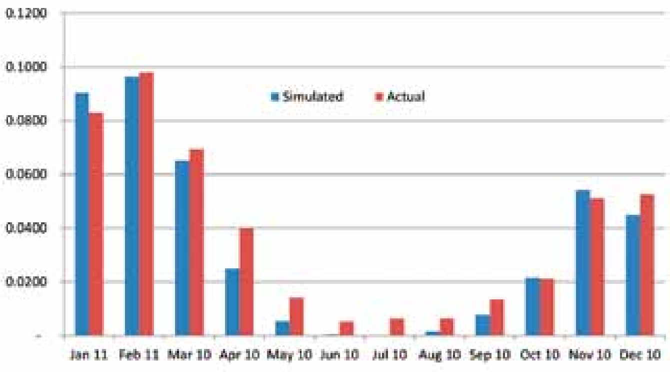


Figure 3: Chiller Energy kWh/s m day

The increases in chiller energy usage (operation in winter) are due to the fact that supply temperatures are generally being controlled lower than the simulation suggested would be necessary. The reason for this is that some zones are being loaded beyond expected levels by tenants and/or fan pressure control variances that result in VAV boxes not delivering full capacity when required. This drives the central plant supply temperatures down, requiring some chilling rather than using full free cooling from the outdoor air economy cycle. The practice of allowing the model to select "ideal" supply temperatures to meet the worst-case simulated zone demand has underestimated the real chiller energy required, especially in mid and cold seasons.

Pumping systems

The system was modelled by creating a single variable-flow chilled water pump that had the same part-load curve efficiencies (derived by curve fitting) as the three actual pumps operating in sequence. The pump delivers constant flow-through appropriate to the operating chillers, with a bypass picking up the difference between chilled water demand and the fixed chiller flows. This model closely reflected the actual design of the system.

Some additional benefit could be obtained by implementing variable flow on the chiller vessels; however, this was not modelled.

The results for the main pumping systems are shown in fig 4 and 5. The increase in chilled water pumping power is due to the operating choice to run the two large chillers when a large chiller and the smaller chiller would suffice. This choice was made during commissioning to simplify the staging controls and avoid operational instability at the staging points.

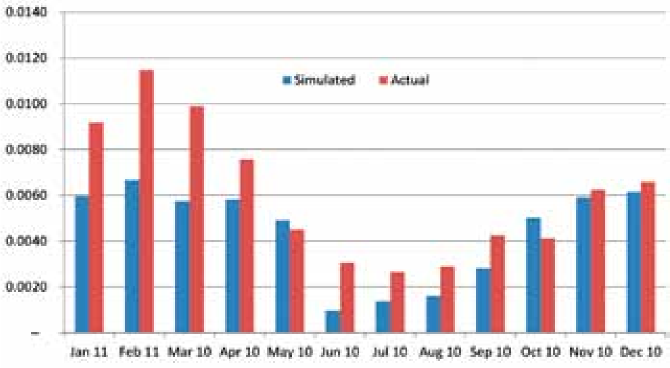


Figure 4: Chilled Water Pumps kWh/sq m day

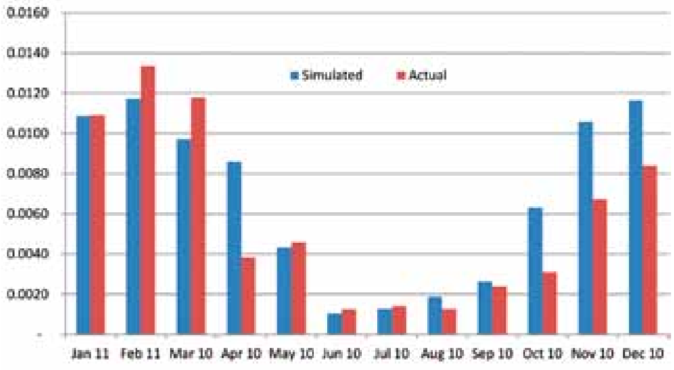


Figure 5: Condenser water pumps kWh/sq m day

Some pumping power increases were therefore accepted to improve stability. This again highlights the difference between real-world controls operational constraints and the "ideal" controls in the model. The modelling of increasingly sophisticated or complex control strategies to achieve ever-diminishing returns on efficiency is likely to produce misleading results when simplicity is the priority for installers and operators.

Heat rejection systems

The specific cooling towers selected by the mechanical engineer were evaluated to determine their natural convection cooling capacity and other parameters that were required as inputs for the cooling tower model. This level of detail was critical to the accurate assessment of chiller COP under varying conditions. The detailed model allowed the condenser water temperature control strategy to be "As the leaving condenser water temperature rises, switch the condenser fans on at 21°C and maintain this where possible".

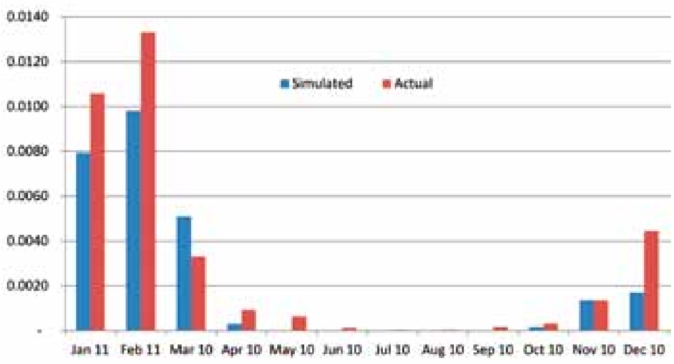


Figure 6: Cooling Tower Fans kWh/sq.m.day

If colder water than 21°C came off the tower due to natural convection, this would correctly be reflected in COPs. If the temperature rose above 21°C (with the fans running at full speed), this would also be fed through to the chiller COP calculation. The results for the cooling towers are shown in fig. 6: The actual cooling tower fan energy is higher than the model; however, reasons for this have not yet been investigated.

Airside systems

The zone airside system consisted of parallel, intermittently operated fan-assisted VAV boxes on the perimeter zones, with primary air shut-off and conventional cooling-only VAV boxes in the centre zones. Problems were encountered modelling the perimeter boxes, and the decision was made to model them as conventional VAV boxes with electric heaters and volume turndown to 10%, then overlaying manual calculations for the terminal fans' energy based on hours of operation.

One objective in the design of this building was to reduce central chiller plant operating hours with the economy cycle. This meant providing additional air capacity on the north and east zones so that the cool outdoor air that often prevailed when these zones peaked would fully satisfy the peak load without activating the central chiller plant and pumps.

Supply air temperature controls were based on satisfying the zone with the greatest demand for cooling, within fixed upper and lower limits. An "off axis" model was analysed using a constant supply air temperature all year round at the lowest set-point to assess potential impact as the "ideal" rescheduling is never likely to be achieved in practice.

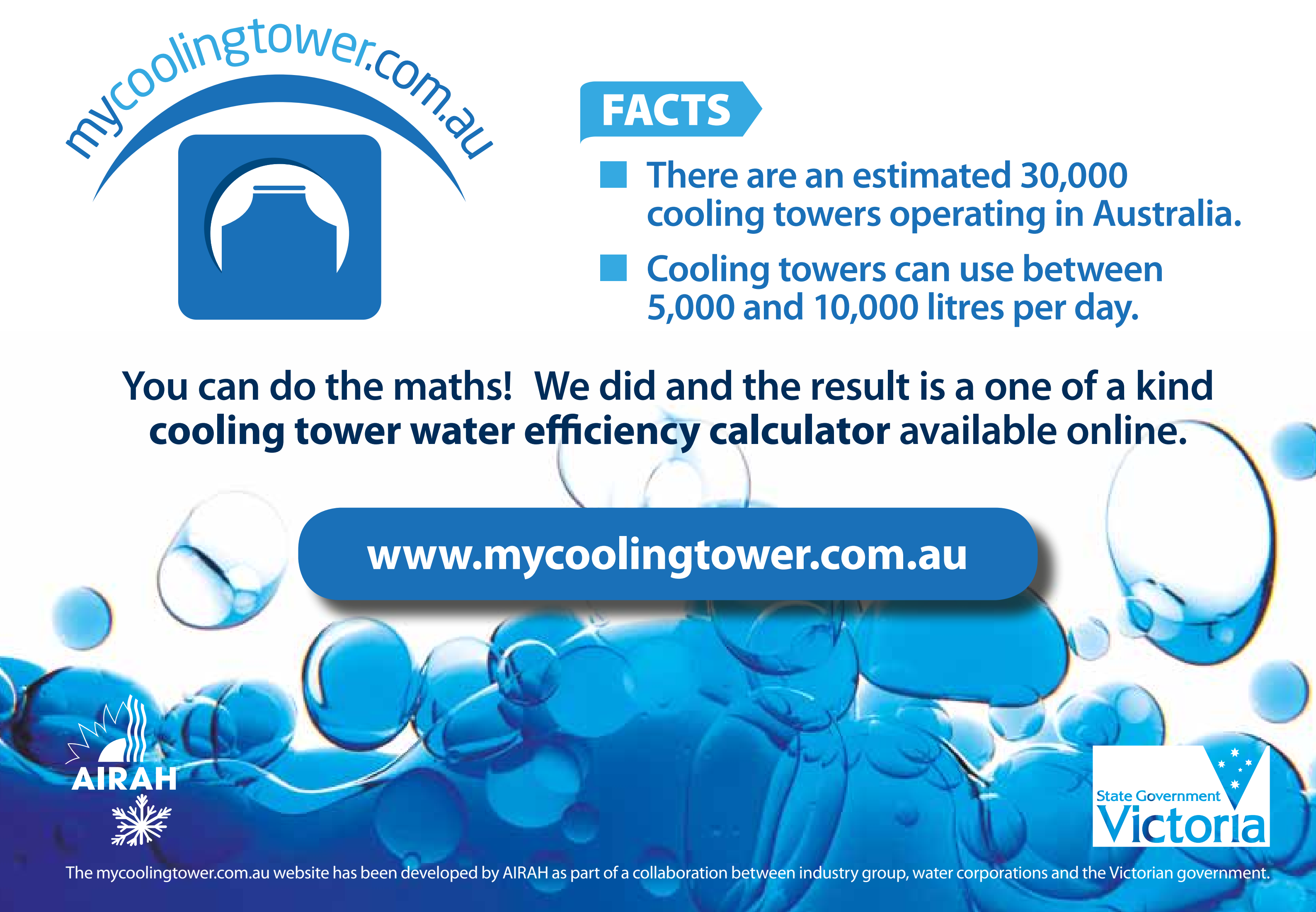
Outdoor air-flow rate modelling options for VAV systems include either a proportional outdoor air-flow model or a fixed-flow model. The fixed-flow model was used because this building is equipped with volume sensors and a closed-loop damper control system for outdoor air flow. It was found in practice that the installed control system introduced unexpected additional resistance in the return-air dampers so that adequate outdoor air volumes would be induced. This added to the overall system resistance and may contribute to fan energy exceeding simulation allowances in some months.

The built-in economy cycle controller was used for modelling based on enthalpy control, upper enthalpy and dry bulb limit, and lower dry bulb limit. This reasonably reflected the actual controls.

The central plant fan efficiency part-load curves were derived from specific fan data provided by suppliers, giving shaft power at nominated airflow and pressure points throughout the load range. The pressure at each volume point was individually assessed by the mechanical engineer based on the minimum VAV box pressure requirements and calculated losses. The default curves within EnergyPlus were not suitable due to VFD and motor inefficiencies at low load. A specific assessment of motor and VFD efficiencies at part-load was undertaken and overlaid on the fan efficiencies provided by the engineer (based on shaft power at the fan). This assessment indicated that substantial losses were incurred at low load. Bernier and Bourret, 1999, predict a 35% power input at 50% flow compared to 13.9% for the pump law curve if a pump motor is 100% oversized (not uncommon). At 30% flow, the prediction is 32% of full-load input power compared to approximately 4% for the ideal curve.

These motor and VFD inefficiencies were then overlaid on the fan efficiency curve to produce a custom curve that was "curve fitted" for this project and incorporated into the model.

In relation to actual VFD efficiency, the metering system allowed comparison of the actual power fed into a group of VFDs to the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power delivered by the VFD to the motor (as recorded by the VFD). The results of this comparison over 12 months are as follows:

- Supply Fans VFD Apparent Efficiency 86%
- Return Fans VFD Apparent Efficiency 76%
- Pumps/Tower Fans VFD Apparent Efficiency 84%

These overall inefficiencies are not immediately apparent and should be considered when determining part-load efficiency curves for modelling purposes.

The air handler cooling coil capacities, chilled – water temperatures and flows, and air-flow and required air-off conditions were nominated by the engineer and entered to the model. EnergyPlus used internal algorithms to determine the number of rows, fins per inch and coil sizes required for modelling purposes. Specific modelling of coil performance is important to accurately determine available dehumidification at part load, and therefore zone humidity at any time. Modelling indicated the potential for high internal humidity in some circumstances, so a separate control strategy and design was developed for coils to maximise dehumidification at part load. The results for the fan systems are shown in fig 7. The reasons for the differences in summer relate to changes to the design during construction. The simulation and design was for a dual fan arrangement with high efficiency at very low load. A single-fan design was ultimately adopted to simplify the design and controls. This produced higher peak-flow efficiencies at the expense of reduced low-flow efficiencies. The effect of this change was evaluated outside the model, and the increase in fan energy was accepted due to the reduced risk of potential control problems. The actual results from May-September clearly show the reduced actual efficiency at part load, which is compounded by higher-than-expected system pressures being required by the control system at low load. Large fan systems require minimum pressures and fan speeds for stable operation at low load. The default part-load efficiency curves offered in the modelling software do not take this into account. The overestimation of fan energy during the peak load months is due the reduced supply air temperatures (and lower airflow) discussed earlier.

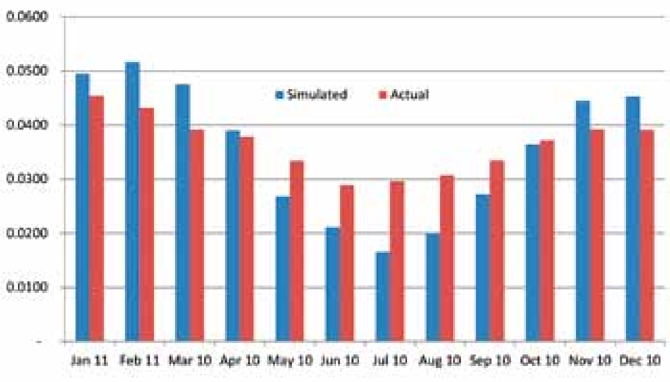

Figure 7: Main Fans kWh/sq.m.day

Heating systems

The heating system was modelled as an electric heating element in each perimeter VAV box. Modelling indicated that this heating requirement was very small with a fully occupied building. However, the requirement would be more significant for partly occupied scenarios or if perimeter zones had unusually low internal loads.

A generic central gas-fired boiler serving outside air preheat coils was modelled only for the centre zone air handlers, as the simulation work indicated that centre zone heating would only be required during the first occupied hours on very cold mornings. Assessment of space conditions from the model indicated overcooling would occur without these coils. This is when the minimum centre-zone fresh air requirements were a substantial proportion of total centre-zone supply air, and caused unusually low supply-air temperatures. The simulated warm-up strategy for the building was to operate only the perimeter fan terminal fans (no central fans) and associated electric heaters when required.

The heat reclaim benefit of the perimeter fan – assisted boxes could not be modelled easily, and was ignored for the purpose of the energy budget. The results for the heating systems are shown in figs. 8 and 9.

The differences in electric heating reflect the unquantified benefit of the heat reclaim from lighting. The value of the heat reclaimed by the induction fans on each VAV box was not able to be modelled due to software limitations. The increase in gas is attributable to the late decision to condition the main lobby 24x7 for security staff, as the boilers and pumps run 24x7 during the winter periods.

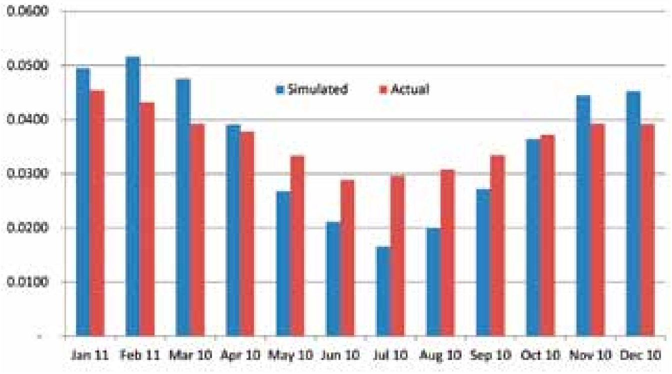

Figure 8: Electric Heating kWh/sq m day

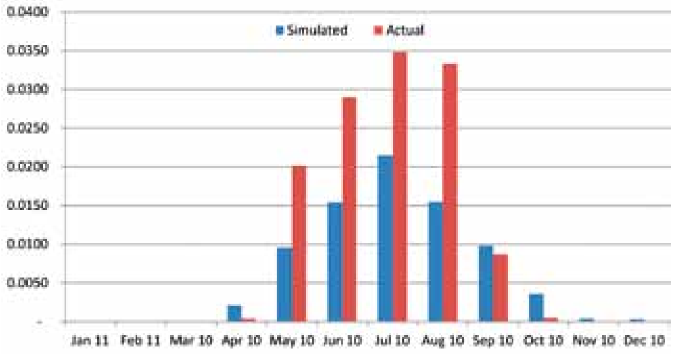

Figure 9: Gas Heating kWh/sq.m.day

NON-SIMULATED LOADS

For this project, the non-simulated loads energy usage was a very significant factor in the energy budget development representing approximately 66% of total base building (non-tenant) energy. Detailed assessment of the actual loads for these is beyond the scope of this paper. However, there were a number of surprises in the energy budgeting process that highlight the need for a detailed analysis and tracking of these non-simulated loads.

Some worth mentioning are:

1. Generator sump/jacket heaters and battery chargers. Manufacturers data for selected generators indicated energy use of these systems was very significant.
2. Lifts energy usage, even with state-of-the art destination control systems, was in reality well above the ABGR "default" allowance and well above the levels originally predicted.
3. Water treatment systems with UV treatment and sidestream filtration need careful attention in the energy budget.
4. The BMS servers and various computer system run 24x7 and consume significant energy.
5. The control systems components collectively draw very substantial power 24x7. The VAV box control transformers were changed on this project from the standard units (drawing 22W quiescent) to toroidal transformers using 8W. With over 300 VAV boxes running 24x7, these are significant loads.
6. VFD's are powered 24x7 and with 132 VFDs the annual energy use is not insignificant.
7. The tenant condenser water loop in this building was designed on strict variable flow principles, where each connected a/c unit has a shut-off valve that closes when the unit is off or not in cooling mode. This dramatically reduced condenser water-loop pumping power.

AUTOSIZING

Accurate autosizing is critical for preliminary simulations. Predicted capacities for each option must compare well to the mechanical engineer's capacity assessments on a zone-by – zone basis. A "sizing" run uses very different assumptions to an energy assessment simulation run. For this building, a careful comparison was undertaken of reported peak loads from the simulation (on design days and with design internal loads) compared to the peak loads calculated by the mechanical engineer. There were some zones where the software reported significantly higher peak loads than the design capacities, which triggered further investigations to reconcile the differences and some precautionary adjustments to the design capacities.

The simulation software provides a very rigorous method for thermal load assessment, and there appears to be no intrinsic reason that peak-load analysis for HVAC design capacity assessment cannot be undertaken with a tool such as this. Peak load analysis is only valid in EnergyPlus if a series of design day objects are created representative of the varying design conditions that occur in each month. This ensures that peak cooling loads that occur in mid-season or in winter are correctly identified and accounted for.

Note also that the correct incorporation of carpet, drapes, interior lightweight partitions, ground reflectances, ground temperatures and peak internal loads are critical factors in the correct assessment of peak loads. As autosizing is often used in preliminary comparative assessments for conceptual design, these factors must always be considered.

Care is needed with autosizing in EnergyPlus because the model will often indicate unreasonably large loads on start-up as it seeks to bring all zones to set-point in the first time step. This does reflect reality to an extent but in autosizing mode, there is no upper limit on capacity as would be encountered in reality.

The "time steps in averaging window" input makes a substantial difference to autosized capacity results. This parameter should be well understood and adjusted to give reasonable warm-up or pull-down loads and time periods.

The industry acceptance of peak-load analysis with tools such as EnergyPlus will take significant time because it will compete with the collective confidence and expertise that has been built over many years in the traditional and, in some cases, empirical-capacity calculation tools. The journey is certainly worthwhile, as the traditional tools lack much of the sophistication, flexibility and, in some cases, accuracy of programs such as EnergyPlus.

CONCLUSIONS

The review concludes that building thermal simulation is an important decision support tool during the earliest stages of conceptual design by architects and engineers. While the level of detail is low, a comparative, simplified simulation approach can inform many decisions and establish design principles and guidelines that will lead to a result in line with the developer's targets. Reliance on model defaults and standard performance assumptions are therefore common in early simulations. Though they can be appropriate for comparative simulations with existing buildings, they may be inappropriate or easily compromised during the remaining development stages unless they are recognised, critically assessed, understood and adapted to the project by the simulation consultant.

Key performance requirements must be carefully tracked and preserved throughout all stages until proven results are achieved. Lessons learnt include:

- Ideal supply air temperature reset models should not be relied upon.
- Reliance on complex control strategies in the model or design should be avoided.
- Unexpected tenant behaviour will affect results.
- Real-world fan pressure controls do not match default part-load curves in the model.
- VFD inefficiencies are more significant than expected.
- Physical stability limitations (fans and chiller staging) must be investigated and practical solutions agreed before modelling.
- Modifications during construction for practical purposes will generally reduce efficiency.
- Operational faults and reliability problems are inevitable and will impact on results.

NOMENCLATURE

VAV:	Variable air volume
VRV:	Variable Refrigerant Volume
ABGR:	Australian Building Greenhouse Rating
NABERS:	National Australian Built Environment Rating System
VFD:	Variable frequency drive
CHW:	Chilled water
CCW:	Condenser cooling water
CA:	Commitment agreement
HVAC:	Heating, ventilation and air conditioning
MRT:	Mean radiant temperature
CT:	Current transformer
FD:	Functional description
ICA:	Independent commissioning agent
BCA:	Building Code of Australia
SHGF:	Solar heat gain factor

REFERENCES

Bernier, M.A., Bourret, B. 1999. Pumping Energy and Variable Frequency Drives, *ASHRAE Journal* December 1999.