

HVAC system size: Getting it right

Right-sizing HVAC systems in commercial buildings



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HVAC system size — getting it right

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For more information on the project and the final research report refer to <http://www.construction-innovation.info/index.php?id=395>.

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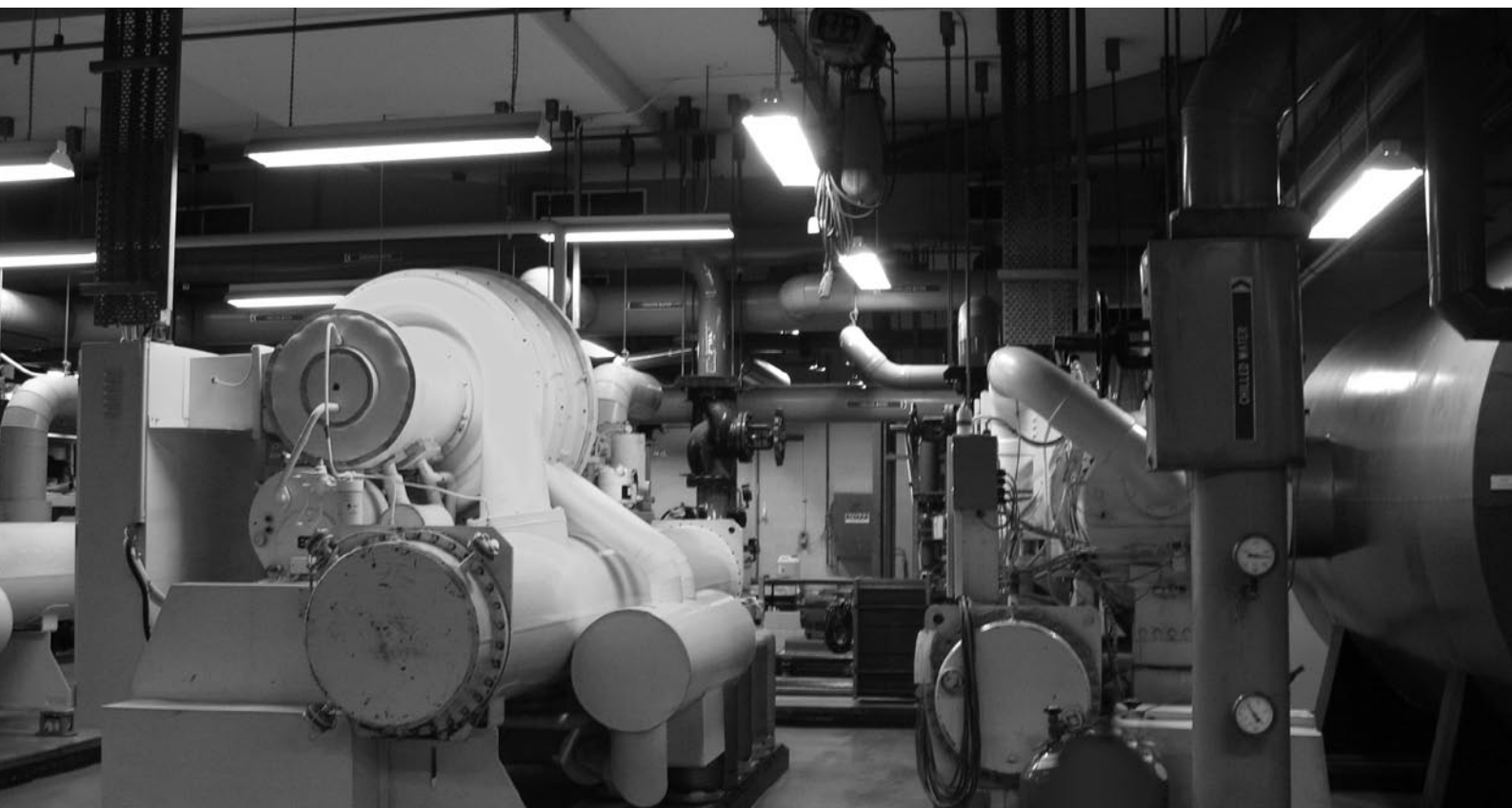
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Contents

1.0	Project overview	1
2.0	Symptoms of over-sizing	1
3.0	Impacts of over-sizing	2
3.1	Component over-sizing	2
3.2	Inefficient operation	3
3.3	Cost impact	4
3.4	Thermal comfort	7
4.0	Barriers to right-sizing	8
4.1	Occupancy loads	8
4.2	Internal loads	8
4.3	Temperature setpoints	9
4.4	Discrete design process	9
4.5	Overshadowing	9
4.6	Unknown tenants	9
4.7	Contractual obligations	9
5.0	Over-sizing recommendations	10
5.1	Challenge “rules of thumb”	10
5.2	Accurate load estimation	10
5.3	Dynamic calculation methods	10
5.4	Systems approach	10
5.5	Design for flexibility	11
5.6	Separate high load areas	11
5.7	Integrated design process	11
5.8	Recognise the value of design	11
5.9	Commissioning and maintenance	12
5.10	Life Cycle Cost Analysis	12
5.11	Mandatory disclosure	12
6.0	Future work	12
7.0	References	13



1.0 Project overview

Many heating, ventilating and air-conditioning (HVAC) systems installed in commercial buildings, have more capacity than is ever required to keep the occupants comfortable. Such “oversized” HVAC systems can have negative effects on the environment, on occupant comfort, as well as on the economic outcomes for the building.

Studies of two large office buildings — Case study 1 in Sydney and Case study 2 in Melbourne — were the focus of this project. The project team’s approach was to:

- study as-built drawings and specifications
- undertake site visits
- perform technical and economic analyses
- hold interviews with members of the buildings’ design team, building managers and occupants in order to obtain a wide range of perspectives
- organise and hold an industry workshop with input from consultants, contractors and developers to get insights on the issue of HVAC over-sizing from a range of viewpoints
- hold focus groups to get a user’s perception of comfort in the office spaces.

Drawing on all of this material, this project collated and documented the following:

- the symptoms of over-sizing
- the impacts of over-sizing
- the barriers to right-sizing
- suggestions and solutions to reduce over-sizing.

2.0 Symptoms of over-sizing

For comfort cooling applications, standard design practice uses the concept of a “design day” — conditions that are exceeded, on average, on 10 days per year. Thus the HVAC system in a building will be fully loaded, that is, will run at full cooling capacity, on these 10 days. Cooling systems can also operate fully loaded when removing heat built up after a hot weekend. The loading on the HVAC system will be reduced due to load diversity in these instances. Load diversity may be due to such elements as occupancy being less than design load, staff being on leave or otherwise out of the office, the installed and the operating equipment load being less than the design load in many areas.

If an HVAC system is undersized, there will be more hours per year when the plant is running fully loaded, and the system will not be able to hold indoor design conditions even on a design day, let alone any hotter days; that is, temperatures in these air-conditioned spaces will rise.

If an HVAC system is over-sized, it will never run fully loaded — a log of chiller loading will reveal that utilised capacity will almost always be less than 80 or 90 percent of installed capacity.

Other symptoms that over-sized HVAC systems may exhibit are:

- frequent short cycling of individual chiller machines
- difficulty in maintaining design conditions during periods of high humidity
- excessive re-heat energy consumption.

Some of the conditions that must be fulfilled for the definition of “over-sized HVAC” system to be warranted are as follow.

- System components and controls must have been correctly designed and commissioned. If chilled water system flow rates are lower than designed, the chiller set will never be fully loaded. Cooling loads can also be reduced if outside air rates are low or if space temperatures are not controlled within designed limits.
- The building must be fully occupied.
- False loading of heating and cooling systems must not be occurring; that is, if heating is fighting cooling, due to dampers or valves leaking, the chiller plant may be artificially loaded, giving the impression of correct sizing.
- Spare capacity, intentionally included in the design, must be excluded from the analysis. This spare capacity provides redundancy to cover breakdowns or an allowance for future increased tenant loads.

This report studies over-sizing of HVAC systems; that is, when significantly more capacity than is required to meet the design brief is installed on a large commercial building project. There is evidence in research literature of such over-sizing overseas. Surveys of 30 systems in Wales (Knight and Dunn, 2004) and 50 systems in the UK (Crozier, 2000) concluded that virtually all systems were over-sized.

3.0 Impacts of over-sizing

3.1 Component over-sizing

Over-sizing of cooling plant can mean that at least some of the following items are over specified due to the flow-on effect across the whole HVAC system:

- chillers and cooling towers
- pumps, pipes and valves
- plant rooms, risers, and ductwork
- fans, motors, cables, switchboards, and sub-station
- variable air volume (VAV) boxes, grilles and registers.

Analysis of the two case-study buildings in Sydney and Melbourne was undertaken to determine whether over-sizing had occurred. A load estimate was made using design briefs and building simulation software. This was compared to the installed equipment in the buildings. Chiller capacity was estimated to be over-sized by 34 percent in Case study 1 and 10 percent in Case study 2.

Significant flow-on changes in pump, fan and associated motor sizes were predicted by performing a re-sizing exercise on the case-study buildings.

Piping and ductwork can accommodate a range of flow rates for each discrete size of diameter (pipe) or cross-section (duct). Reviewing the case-study designs indicated that there was less potential to replace the smaller on-floor branches of piping or ductwork. In most cases, the existing pipe or ductwork was still the correct dimension to cater for the reduced flow.

However, estimating changes in the size of main pipe and duct runs provided important insights. There can be large savings for both these components if the particular design is at the limit of a pipe/duct size, and right-sizing of the HVAC system resulted in a step down in size for the main branches. However, there are significant advantages in ensuring that main branch pipes and ductwork are generously sized, as explained below.

Reduction in the size of the main ducts could potentially reduce riser size requirements, with a possible increase in net lettable area (NLA). However, in the authors' experience, many buildings have insufficient riser areas, forcing the mechanical engineer to design with high air velocities (and high static pressure) in associated ductwork. The result is significantly increased fan motor sizing and energy use for every single hour of fan operation. Reducing riser sizing is false economy!

The impacts on cable sizes and switchboards were not studied in detail for these case studies. However, it is anticipated that cable sizes would be affected in a similar way to pipes and ductwork. The potential for a commercially viable reduction in cable diameter specification for larger components is more likely, as compared to cable size reductions for on-floor electrical circuits.

3.2 Inefficient operation

Over-sized plant will operate inefficiently on a number of levels, as described in this section.

Since the entire system is over-sized to handle even the peak design day conditions, almost all installed equipment and machinery will operate at low part load factors for large percentages of their total operational time.

One of the symptoms of over-sizing has already been mentioned, that of chiller logs providing proof that a significant fraction (20% or more) of installed chiller capacity is never used. Figure 1 plots the predicted outputs from a building energy simulation model that show estimated run time at various part load capacities for a single chiller plant room. The graphs display a right-sized chiller (Chiller 1) and an over-sized chiller (Chiller 2). It is clearly seen that the over-sized chiller runs most of the time at below 30 percent of rated capacity.

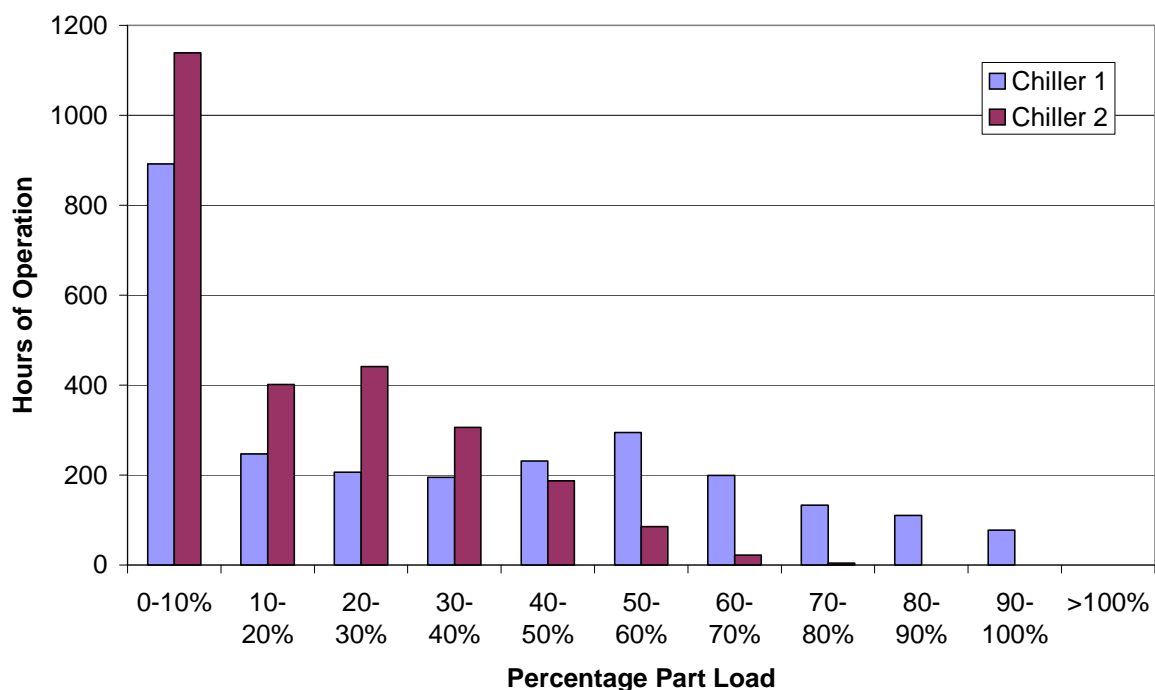


Figure 1 Estimated run time at various part load capacities for a single chiller plant room design — Chiller 1 (right-sized chiller) and Chiller 2 (over-sized chiller)

Another symptom of over-sizing is intermittent plant operation. This occurs when the diversified loads, during off-peak conditions, are so small that the cooling plant is unable to turn down to low load levels that allow the plant components to operate in a stable manner. This results in frequent stop-and-start operation, which could lead to shorter mean time between failures, and higher maintenance costs.

Over-sized fans on variable-speed drives (VSD) will turn down to the lowest speed possible and work as a virtual constant speed system. There is no control of flow in such a situation. This is illustrated by Figure 2 which plots simulated annual results for the operation of an over-sized fan system.

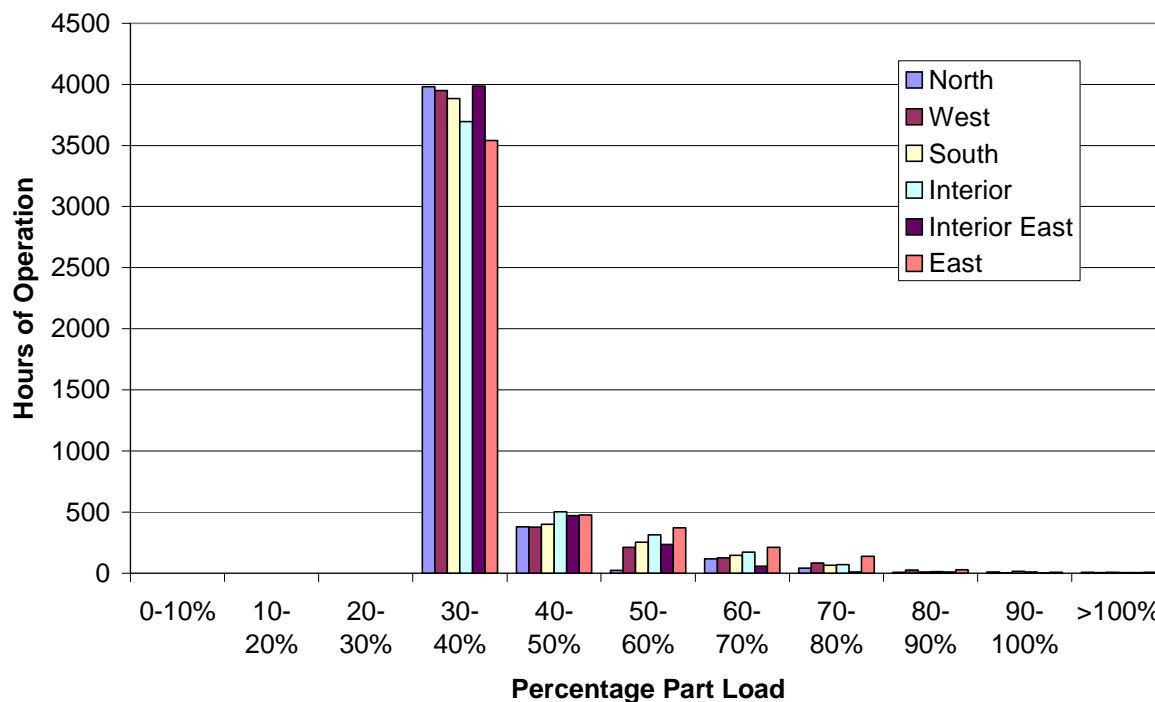


Figure 2 Simulated results depicting annual operation of a VSD controlled, oversized AHU (air-handling unit) fans. The fans turns down to the lowest allowed part load (30% in this case) for approximately 60 percent of operational hours.

Air volume at this lowest speed setting may still be too high, and excessive re-heat energy use can be another symptom of over-sizing.

3.3 Cost impact

Components with the largest capital cost penalties in an over-sized HVAC system design are the major items of cooling plant; namely chillers, pumps and cooling towers.

Other components like air-handlers (fans, motors and coils), pipework and ductwork can also have significant cost penalties, because of the large quantities involved.

Right-sizing would lead to energy-efficient operation, resulting in annual energy and energy cost saving. Additionally, savings in maintenance from lower equipment breakdown rates would result as the systems would operate for a greater number of hours nearer their design point.

Table 1 provides the results of a costing exercise for Case-study 1 — the higher level of over-sizing (chillers estimated to be oversized at 34%). A typical floor plate was modelled, using a whole building energy simulation program. Estimates of peak demands with detailed glazing and geometry were entered into the model and the results used to recalculate plant capacities. On-floor loads were also calculated and AHU sizes were recalculated. These differences were costed and listed in Table 1. In this instance, the estimated savings on main plant are seen to be substantial, almost 29 percent for cooling towers and 21 percent for chillers. Savings on air-handlers are estimated at 24 percent. In this project, the predicted absolute savings are well in excess of \$0.5 million.

The degree of over-sizing was reviewed for major ducting, and was estimated at about 25 percent of cross-sectional area. On-floor ducting was estimated to be over-sized between 19 percent (west zone) and 26 percent (centre zone). However, the costing exercise was not extended to this level.

A full simulation analysis using the building model for this building was not performed as management did not collect or record the multiple-tenant energy consumption data. This made it impossible to correlate the whole building energy use with real data. However, the annual energy use for the base building was estimated based on the authors' experience gleaned from numerous parametric simulation runs on a number of office building models. The cost savings for the estimated energy savings is smaller than the fraction of energy savings itself because most of the saving would occur at shoulder and off-peak energy rates.

Table 1 Estimated cost savings for Case study 1 — the building estimated to have significant chiller over-sizing

system component	as-installed	right sized	saving \$	saving within component, %
Cooling Towers	\$ 401,600	\$ 285,600	\$ 116,000	28.9%
Chillers	\$ 1,112,000	\$ 879,000	\$ 233,000	21.0%
Condenser Water Pumps	\$ 49,500	\$ 41,900	\$ 7,600	15.4%
Chilled Water Pumps	\$ 41,000	\$ 33,400	\$ 7,600	18.5%
Air Handling Units	\$ 1,164,900	\$ 885,600	\$ 279,300	24.0%
total equipment	\$ 2,769,000	\$ 2,125,500	\$ 643,500	23.2%
energy-elec	\$ 1,889,546	\$ 1,811,405	\$ 78,141	4.1%
energy-gas	\$ 50,647	\$ 45,583	\$ 5,065	10.0%
total energy	\$ 1,940,193	\$ 1,856,988	\$ 83,206	4.3%

The above costs were factored into a 15-year life cycle cost analysis, with zero escalation, and the results indicate significant savings as shown in Table 2. The order of savings due to system components is more than double the capital cost saving estimate at more than \$1.3 million; however, this saving is the same order of magnitude as the energy saving. The total saving over 15 years is approximately \$2.5 million for this case-study example.

Table 2 Estimated life cycle cost savings for Case study 1 — the building estimated to have significant chiller over-sizing

system component	saving \$
Cooling Towers	\$ 272,020
Chillers	\$ 535,900
Condenser Water Pumps	\$ 17,480
Chilled Water Pumps	\$ 17,480
Air Handling Units	\$ 505,334
total equipment	\$ 1,348,214
energy-elec	\$ 1,172,114
energy-gas	\$ 75,971
total energy	\$ 1,248,085
total savings	\$ 2,596,299

A similar analysis was carried out for Case-study 2 where over-sizing was estimated to be much smaller, at about 10 percent of total chiller capacity. As expected the numbers are smaller, with an average capital cost saving of approximately 5 percent. However, the picture is not quite as clear for this case-study building, where the HVAC system configuration was set up in a manner that made it difficult to estimate the true level of over-sizing. There were other, technical design features, which made this otherwise extremely well-managed and maintained building quite inefficient, in greenhouse emission terms, for base building operation.

Table 3 Estimated cost savings for Case study 2 — the building estimated to have limited chiller over-sizing

system component	saving within component, %			
	as-installed	right sized	saving \$	%
Cooling Towers	\$ 359,200	\$ 341,200	\$ 18,000	5.0%
Chillers	\$ 769,000	\$ 725,000	\$ 44,000	5.7%
Condenser Water Pumps	\$ 36,500	\$ 31,700	\$ 4,800	13.2%
Chilled Water Pumps	\$ 33,000	\$ 33,000	\$ -	0.0%
Air Handling Units	\$ 754,200	\$ 717,300	\$ 36,900	4.9%
total equipment	\$ 1,951,900	\$ 1,848,200	\$ 103,700	5.3%
energy-elec	\$ 1,915,482	\$ 1,867,595	\$ 47,887	2.5%
energy-gas	\$ 178,464	\$ 169,541	\$ 8,923	5.0%
total energy	\$ 2,093,945	\$ 2,037,135	\$ 56,810	2.7%

A similar 15-year life cycle cost analysis provided the results shown in Table 4.

Table 4 Estimated life cycle cost savings for Case-study 2— the building estimated to have limited chiller over-sizing

system component	saving \$
Cooling Towers	\$ 42,210
Chillers	\$ 101,200
Condenser Water Pumps	\$ 11,040
Chilled Water Pumps	\$ -
Air Handling Units	\$ 67,527
total equipment	\$ 221,977
energy-elec	\$ 718,306
energy-gas	\$ 133,848
total energy	\$ 852,153
total savings	\$ 1,074,130

In this case, the small energy savings when considered over the 15-year life cycle, far outweighed the life cycle cost saving from HVAC system components. The total saving figure was around \$1 million.

3.4 *Thermal comfort*

Over-sized plant can result in increased discomfort in the air-conditioned space. Space temperatures would be difficult to control when minimum flow rates result in significantly more cooling than is required. This would result in the space temperatures being rapidly driven below the thermostat setting. When the spaces become too cold, electric or gas energy would be used to re-heat the air in an effort to maintain comfort conditions. The result is a very significant impost on energy use, quite easily doubling the energy use in such spaces.

Since flow rates will be at minimum flow as explained above, over-sizing of diffusers will lead to poor air distribution in the space for most operational hours. This could result in cold air dumping just below the diffusers, and stagnant areas within the air-conditioned spaces.

Air-conditioning systems for office building applications are generally designed for “comfort cooling” and are not required to maintain “critical” processes. No explicit humidity control component (dehumidifier, humidifier) is generally specified in these types of applications. In some system configurations, space temperature at low load is controlled by allowing the chilled water temperature at the cooling coil to increase. In over-sized systems, this would happen most of the time, since the system will always be over cooling. Higher chilled water temperature severely reduces the dehumidification potential of the cooling coil, and the relative humidity in the space increases when ambient humidity is high. Spaces served by such systems will feel “clammy” or “muggy” when climate conditions are warm (not hot) and humid.

Worker satisfaction, thermal comfort, air movement, Indoor Air Quality (IAQ), visual and acoustic comfort were explored in volunteer focus groups for the two case-study buildings. Common experiences though with different causes included:

- poor temperature control within different areas of each tenancy
- down drafts from ventilation supply diffusers
- various IAQ problems in the toilets
- a range of awareness of (and capacity to respond to) changing light levels, glare and noise.

Some of these issues may have been exacerbated due to HVAC system over-sizing; however, there were many other factors that also played a part in generating these responses.

4.0 Barriers to right-sizing

A number of design assumptions can be approached from a conservative point-of-view. The collective impact of these individual, conservative, design assumptions will almost always result in a system that is significantly oversized.

4.1 Occupancy loads

Knight and Dunn (2004) conclude that high design guide values for estimating internal heat gains (occupancy, lighting and equipment) are one important reason why commercial HVAC systems are being over-sized. These values are based on high occupancy levels (persons/m²) which are rarely reached.

Traditionally, design loads for occupancy in office buildings are set at 10m²/person. A report by the various state governments in Australia (GREG 2000) reveals that the internal targets for NLA per “full time equivalent” employee ranged from 15m² to 18m². Actual numbers were even higher, ranging from 17.6m² to 21.2m² (Tasmania had an unrepresentative value of 26m², due to its high percentage of heritage-listed buildings with inefficient space utilisation). From this report it seems that government offices may be designed for occupancies that are 50 to 100 percent higher than required.

There may be some automatic application of the default figure of 10m²/person, required by AS1668 for calculating fresh air requirements when occupancy is unknown, to calculation of heat gain from occupants. There is no reason why the same figure should be used for both.

4.2 Internal loads

The Property Council of Australia (PCA) has developed a grading matrix for office buildings that is the benchmark for space quality in the Australian real estate industry. This matrix quotes internal load capability for a particular grade of building to be *more than* a designated W/m² value. This type of grading encourages “chest beating” exercises within the real-estate industry, with each property manager promoting higher and higher internal load capabilities. Anecdotal reports of property managers advertising internal load capabilities of 40W/m² are known to the authors.

Anecdotal reports seem to suggest that in Australian real estate, activities in the top end of the market are diverging. For open-plan office space in general, there seems to be evidence of the internal load reducing. This is due to uptake of much more efficient LCD monitors that also offer other advantages through glare and contrast performance. Many employers are providing employees with laptops, and requiring them to take them home. Both these actions would tend to reduce internal loads, because the equipment is much more efficient and notebook computers are generally not left on overnight. Komor (1997) reported measured loads from office equipment in 44 buildings in the USA. The simple average was 8.9W/m² and the highest value was 12W/m².

However, there are higher energy density requirements for areas dedicated to IT, which house computer servers and other high power equipment in a confined space, due to security requirements. These areas require 24-hour cooling and are usually conditioned by additional supplementary HVAC systems supplied by a dedicated tenant condenser water system. These specialised internal loads should not be accounted for in calculating the size of the base building chilled water system.

4.3 Temperature setpoints

Close control of internal temperatures (e.g. $22.5^{\circ}\text{C} \pm 1^{\circ}\text{C}$) is difficult to maintain in practice and can lead to excess capacity and higher energy use. The energy efficiency provisions proposed for the new Section-J of the BCA (2005) will require HVAC systems to be designed to maintain a temperature range between 20°C and 24°C for 98 percent of the system operating time. Such wider thermostat settings can improve stability of operation due to a larger “dead-band” provision, and also result in a smaller system capacity requirement.

4.4 Discrete design process

Concept designs can be carried out independently by project team players. For example, an HVAC designer may use overly conservative glazing characteristics very early in the project and develop high cooling load estimates. If these are not later revised, due to paucity of time or budget for example, there is a good chance that the installed HVAC system will be oversized.

4.5 Overshadowing

Not considering the impact of surrounding buildings when doing the cooling load calculations can have a significant impact on peak demand. This path is sometimes taken because the client or engineer takes the view that buildings around the project may be demolished at some later date. Such a situation could lead to a significant increase in design cooling load on the project for considering a scenario that might never eventuate.

4.6 Unknown tenants

Most buildings in Australia are speculative. Tenant requirements are unknown until late in the project when a real-estate agent may be successful in finding an anchor tenant. The PCA grading matrix recommendation provides minimum internal load capability, and encourage larger, rather than smaller, internal loads assumptions for design calculation.

4.7 Contractual obligations

A correctly designed system will not maintain temperatures on the worst hours of the year, when conditions go beyond the design day and other internal loads are at high levels. Engineers are conscious that building use changes frequently, and design their HVAC systems to be able to cope with such changes by over-sizing. Design fees for engineers are based on competitive tender, and do not generally allow for iterative or integrated design solutions. Ultimately, engineers feel their reputations would suffer should a building HVAC system fail to maintain temperatures even on days when ambient temperature increase beyond the design conditions.

There is also the “split-incentive” impact, identified as one of three major reasons for the government to propose a mandatory regulation of energy efficiency via a new section of the Building Code of Australia (BCA). This split incentive exists because the developer does not generally reap the economic benefits of an energy-efficient, lower greenhouse impact design, since the developer does not normally own and operate the building. Given two alternative design solutions, the developer will pick the least-cost solution.

“Design and Construct” contracts generally discourage right-sizing approaches. The contractor tenders on a rough design load that is to be confirmed before detailed design and construction. The competitive tender situation under which these jobs are won means there is little incentive to review and optimise design calculations.

This type of risk-averse, aggressive, commercial environment discourages right-sizing by using a “worst case” approach as a convenient, no-hassle solution to these issues. Unfortunately it is the environment, society and building tenants that are penalised by such wasteful building practice.

5.0 Over-sizing recommendations

Following are suggestions that the building industry could implement to reduce the barriers listed above. Further research is urgently required to establish new evaluation methods, design practices and guidelines that are agreed to and promoted for use by industry societies.

5.1 Challenge “rules of thumb”

Challenge “rule of thumb” load calculations and/or brief requirements which may be out of date, or copied from a previous project specification. For example, obtain current equipment load data that matches the intended use.

5.2 Accurate load estimation

Conduct an accurate load estimate, using established design data (e.g. from AIRAH or ASHRAE) specific to project location, and then resist the temptation to apply “safety factors”. Do not use W/m² loading or other approximate methods for sizing equipment.

5.3 Dynamic calculation methods

Use of computer-based load estimation programs that account for thermal storage and diversification of peak loads for each zone and air-handling system should be encouraged. Static methods cannot properly account for the daily diversity (e.g. between east and west zone cooling loads) and the final block load estimate will be over-sized. The new methods allow for the impact of innovative shading schemes that are difficult to quantify using static methods. The solutions generated by such calculations can be significantly smaller than numbers considered acceptable in “traditional” practice.

5.4 Systems approach

Use a systems approach, rather than a component-based approach to designing the HVAC system. The designer should consider overall system configuration, and explicitly design the low load operation strategy. Select chiller sizes and staged- or variable- speed pumps and fans to ensure good part load performance. Most buildings spend the bulk of their operating hours running at less than 50 percent load. Individual chillers usually become less efficient once the load falls below 50 percent. This problem is exacerbated if the chiller is over-sized. Pumping systems and cooling tower configurations should also be designed to operate efficiently at low loads.

Modern chilled water plants have many configuration and control options that are designed to improve low part load operation. These include the use of chilled water and/or condenser water temperature resets, primary/secondary pumping loops with variable speed control, chillers that can handle variable flow or have in-built variable speed control, and variable speed control of cooling tower fans. An experienced engineer with the ability to critically use

dynamic simulation analysis will be able to select and optimise an appropriate mix of equipment and control strategies to arrive at a cost-effective, energy-efficient solution.

While heating systems have not been the focus of this study, the authors note that similar concerns exist in this area. Heating systems (particularly for office buildings that run mainly during the day) are generally sized on extremely conservative design assumptions. These may include unrealistic night-time design temperatures, with zero occupancy, equipment and lighting loads. Such processes result in selection of boilers running at extremely low part load factors for the majority of operating hours. Most boilers, even with modulating burners, run extremely inefficiently below 25–30 percent capacity. Further research is strongly recommended in this area.

5.5 Design for flexibility

Allow for unknown future tenancies by designing flexibility into the system, and not by over-sizing the entire system. For example, generous sizing of distribution pipework and main ductwork will allow available capacity to be redistributed in the future.

5.6 Separate high load areas

A significantly greater amount of internal heat is generated in specialised areas like IT server rooms, bank trading floors and call centres, when compared to general open plan office areas. Since these specialised areas are usually a small percentage of the total lettable area of a building, one solution is to add auxiliary stand-alone systems plumbed into a dedicated tenant condenser water loop. A systems approach needs to be applied in designing these supplementary HVAC systems, with the system able to efficiently handle a wide diversity in operating capacity.

5.7 Integrated design process

The authors strongly recommend the use of an integrated load and energy-use simulation analysis. Validated whole-building simulation programs provide the opportunity to model and test the proposed design in an integrated manner, and offers sophisticated insights not available by any other method. In the hands of an expert, these models can represent the building and its interactions in far greater detail than other methods, and allow description and testing of different operational scenarios.

Whole-building energy simulation offers an interactive approach to design where the review responsibility for all major energy sub-systems are under a single entity, (e.g. an Ecologically Sustainable Design consultant with relevant expertise in façade, electric lighting and building services) would lead to right-sized outcomes in all these disciplines. The new BCA Section-J introduces mandatory energy-efficiency provisions, which can be analysed for compliance using alternative verification methods with whole-building simulation. It provides a good opportunity to change design and procurement methods for buildings from a linear to an iterative process with right-sized HVAC outcomes.

5.8 Recognise the value of design

The life cycle cost results for the Case-study 1 building with significant chillier over-sizing provide a clear indication of the lost opportunity for capital cost saving and longer term monetary benefit. This could have been avoided or significantly reduced with application of an integrated, iterative design process. This necessarily means a longer design lead time, and higher design fees for architects and engineers, but the savings far outweigh these increases as a fraction of the total project price.

5.9 **Commissioning and maintenance**

Consider commissioning and maintenance aspects for the system to reflect the right-sizing philosophy. Current commissioning procedures (using either CIBSE 'Chartered Institute of Building Services Engineers' or ASHRAE 'American Society of Heating, Refrigerating and Airconditioning Engineers' methods) concentrate on confirming system design parameters at simulated design conditions. However, energy-efficient operation depends on the ability of the system to operate in a stable manner at low load conditions. Therefore commissioning test should calibrate and test the tracking of fan speeds (supply and return fans) at lower speeds, stable part load operation of pumping systems, correct functioning of chiller scheduling algorithms, and correct implementation of chilled water and/or condenser water temperature reset strategy. All these functions, when implemented correctly, improve the energy efficiency of the HVAC system.

As systems drift from their calibrated value over time, regular maintenance should include calibration of controls and system parameters to ensure long-term part load operation.

5.10 **Life Cycle Cost Analysis**

Consider the use of a comprehensive Life Cycle Cost (LCC) Analysis for selection of the most optimal design solutions. Use an integrated design process to test the impact of a change in one system across the whole building. For example, it is possible to justify the use of high efficiency lighting systems by reviewing the drop in AHU coil and fan sizes, and potential reductions in frame sizes for chillers and cooling towers. A detailed simulation model will allow these interactions to be tested reasonably quickly and the associated costing to be reviewed. A design process that uses LCC will lead to a change in the design and procurement process. As seen in the case-study examples, there can be significant benefits by going through the process. However, the authors include a note of caution here — using a LCC analysis methodology that does not provide a truly integrated approach can potentially lead to inefficient outcomes for the project.

5.11 **Mandatory disclosure**

Regulations due to be introduced by the end of 2007 for mandatory disclosure of energy performance of buildings upon sale or leasing will place pressure on design and maintenance teams to achieve better performance — right-sizing will be part of the solution!

6.0 **Future work**

Listed below are a number of research areas, and changes to practice that we believe are urgently required to fast track an integrated and iterative design and procurement process for buildings with positive outcomes for global warming, society and cost saving for building projects.

There is an urgent need to do systematic surveys on large office building HVAC systems to investigate levels of over-sizing in Australia. The outcomes of such a survey will provide hard data on the extent of over-sizing, and help develop a strategic framework to improve efficiency and reduce greenhouse gas emissions.

Improvements in technology associated with energy use in buildings; for example, façade glazing, lighting systems, use of LCD screens and notebook computers, chiller technology, VSDs for airflow control, mean that the design check figures published in the established design guides may be significantly out of date. There is a need to commission new research to update this fundamental information. Unfortunately, this type of research does not have wide appeal and does not make front page news, but is still the basis for initial design load estimates. Research funding is difficult to find for this type of work despite its critical role in

the light of renewed urgency of global warming impacts. We would strongly encourage industry associations, governments and universities to urgently take the lead in this area.

There is an urgent need for training engineers and designers in the use of simulation-based analysis, with particular emphasis on using the unique outcomes that these methods provide. Currently whole-building energy simulation is generally used only to verify potential compliance with a building rating system. The use of these systems to inform design is very limited. These software tools are complex and require users to have a significantly broader range of skills and experience to fully exploit them.

Right-sized designs can only be delivered by a holistic, iterative, integrated design process in conjunction with careful equipment selection and construction, thorough commissioning, operation as designed and regular maintenance regimes. The current building procurement process places many barriers to achieving this goal. Research into the development and documentation of new building design and procurement processes that will help achieve this goal is vital.

The building industry has the most fractured information transfer processes, and tackling this problem is the *raison d'être* for the International Alliance for Interoperability (IAI). Adopting interoperable standards will allow faster implementation of an iterative, integrated design process.

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