MEETING CLIENT NEEDS

Case Study

HVAC SYSTEM SIZE – GETTING IT RIGHT

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ABSTRACT

There is evidence that many heating, ventilating & air conditioning (HVAC) systems, installed in larger buildings, have more capacity than is ever required to keep the occupants comfortable. This paper explores the reasons why this can occur, by examining a typical brief/design/documentation process.

Over-sized HVAC systems cost more to install and operate and may not be able to control thermal comfort as well as a “right-sized” system. These impacts are evaluated, where data exists.

Finally, some suggestions are developed to minimise both the extent of, and the negative impacts of, HVAC system over-sizing, for example:

- Challenge “rules of thumb” and/or brief requirements which may be out of date.
- Conduct an accurate load estimate, using AIRAH design data, specific to project location, and then resist the temptation to apply “safety factors
- Use a load estimation program that accounts for thermal storage and diversification of peak loads for each zone and air handling system.
- Select chiller sizes and staged or variable speed pumps and fans to ensure good part load performance.
- Allow for unknown future tenancies by designing flexibility into the system, not by over-sizing. For example, generous sizing of distribution pipework and ductwork will allow available capacity to be redistributed.
- Provide an auxiliary tenant condenser water loop to handle high load areas.
- Consider using an Integrated Design Process, build an integrated load and energy use simulation model and test different operational scenarios
- Use comprehensive Life Cycle Cost analysis for selection of the most optimal design solutions.

This paper is an interim report on the findings of CRC-CI project 2002-051-B, Right-Sizing HVAC Systems, which is due for completion in January 2006.

Keywords: Size, Over-sized, HVAC, capacity, impacts

1.0 HVAC SYSTEM SIZE – GETTING IT RIGHT

1.1 DEFINITION

What do we mean by “correctly sized HVAC system”? We would say that if you examined an annual log of system cooling loads, you would see some occurrences in the 90 to 100% range.

For comfort cooling applications, standard design practice uses the concept of design day – conditions that are exceeded, on average, on 10 days per year. Thus on these ten days, you would expect to find the HVAC system fully loaded. Cooling systems can also operate fully loaded when removing heat built up after a hot weekend. However, these situations are eased somewhat by the diversity that is likely to occur in other loads, such as occupancy, equipment etc – i.e. some people will be on leave, sick etc, and not every area will have its entire allocation of equipment installed or operating.

If a 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; i.e. space temperatures will rise.

If a HVAC system is over-sized, it never runs fully loaded – a log of system loads may never reach 80 or 90%. Over-sized packaged plant will tend to “short-cycle” and is unlikely to control humidity well.

However there are a few conditions that must be imposed before this definition is adequate:

- The 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 the comfort range.
- The building must be fully occupied.
- False loading of heating and cooling systems must not be occurring, i.e. 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.

The remainder of this paper is about unintentional over-sizing of HVAC systems, i.e. provision of more capacity than is required to meet the design brief.

1.2 EVIDENCE OF OVER-SIZING

Surveys have shown that HVAC over-sizing is common in the UK:

Knight and Dunn (2004) report on a study of over 30 air conditioning systems in office buildings in Wales: “Analysis of the part-load chiller energy consumption profiles…revealed that virtually all the systems were oversized for the loads they actually encountered in practice.”

Crozier (2000) reports a survey of 50 HVAC systems in the UK, which showed that 80% of the heating plant, 88% of the ventilation plant and 100% of the chiller plant incorporated capacity above that needed to meet design requirements. See Fig. 1.

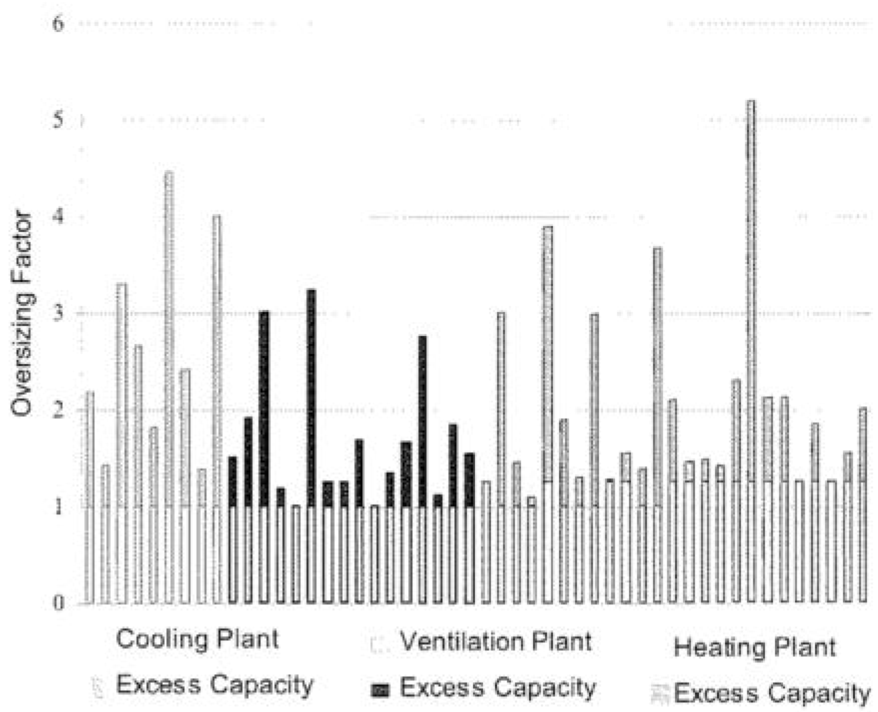

Figure 1. Summary of oversizing in 50 HVAC systems. [Crozier]

Deng (2002) presents a case study from Hong Kong, where the original design included four 2000kW chillers (total 8,000 kW) but operating records showed that the highest cooling load recorded was 3,516kW.

1.3 PROCESSES THAT LEAD TO OVER-SIZING

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 oversized. These values are based on high occupancy levels (persons/m²), which are rarely reached.

1.3.1 Occupancy loads

Traditionally, design loads for occupancy in office buildings are set at 10 m^2/person. A report by the various state governments (GREG 2000) reveals that the internal targets for NLA per “full time equivalent” employee ranged from 15 m^2 to 18 m^2. Actual numbers were even higher, ranging from 17.6 m^2 to 21.2 m^2 (Tasmania had an unrepresentative value of 26 m^2, due to having a high percentage of heritage-listed buildings with inefficient space utilisation). From this report is seems that government offices may be designed for occupancies that are 50% to 100% larger than required. There may be some automatic application of the default figure of 10 m²/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.

1.3.2 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 “premium grade” building to be **more than** 25 W/m^2. This type of grading encourages “chest beating” exercises within the real estate industry, with each property manager trumpeting higher and higher internal load capabilities. Anecdotal reports of property managers advertising internal load capabilities of 40 W/m^2 have been heard by the authors.

Anecdotal reports seem to suggest that in the Australian real estate market place activities in the top end of the market are moving in two divergent directions. In general open-plan office space, 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 in 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 is not left on overnight. Komor (1997) reported measured loads from office equipment in 44 buildings in the USA. The simple average was 8.9 W/m^2 and the highest value was 12 W/m^2.

However, there is greater requirement for areas dedicated to IT, which house 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 internal loads should not be accounted for in calculating the size of the base building chilled water system.

1.3.3 Temperature setpoints

Close control of internal temperatures, for example, 22.5°C±1°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% 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.

1.3.4 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 revised further down the track, for whatever reason, e.g. paucity of time or budget, there is good chance that the HVAC system will be oversized.

An interactive approach to design where all major energy sub-systems are reviewed together would lead to optimised façade, electric lighting and HVAC systems.

1.3.5 Conservative design approach

A number of factors can be approached from a conservative stance. If these factors are independently added together, the result could be a system that is significantly oversized. Some of these factors are :

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. If so, there would be a significant increase in cooling load on the project until an equivalent structure was re-built.

Unknown tenants

Most buildings in Australia are speculative in nature. Tenant requirements are unknown till late in the project when a real estate agent is successful in finding an anchor tenant. The PCA grading matrix recommendation provides minimum internal load capability, and the “chest beating” exercises in the market place encourage larger rather than smaller internal loads.

Contractual obligations
A correctly designed system will in fact 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 of the fact 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.

There is also the "split-incentive" that was identified as one of the major reasons for the government to propose a mandatory regulation of energy efficiency. This is the fact that the developer does not generally reap the economic benefits of an energy efficient, lower greenhouse impact design, since he/she does not normally own and operate the building. Given two alternate design solutions, the developer will pick the least-cost solution.

"Design and Construct" contracts also encourage oversizing. The contractor tenders on a rough design load that is to be confirmed before construction. The competitive tender situation under which these jobs are won means that there is little incentive to review and optimise design calculations.

This type of risk-averse, aggressive, commercial environment encourages oversizing by using a "worst case" approach as a convenient, no-hassle solution to these issues. Unfortunately it is society that is penalised in the longer term.

1.4 IMPACTS OF OVER-SIZING

Oversizing of HVAC plant has a flow-on effect through the project. Oversized chillers will also require bigger pumps, pipes, cooling towers, valves etc., and also a larger plant room. Chiller plant is usually available in discrete "frame" sizes. Oversizing to a degree where the plant selection requires purchase of the next frame size can increase the absolute cost of the bigger chiller substantially, although the cost per kW may actually decrease.

Oversized air-handling plant will also require larger fans, ducts and riser sizes. Oversized HVAC systems in larger projects may also lead to poor thermal comfort in the conditioned spaces, as the plant may not be able to turn down enough to provide stable operation and may lead to poor air distribution as cold air "dumps" from diffusers at low flows, instead of flowing along the ceiling.

Oversized equipment can also impose a penalty in terms of peak demand charges for electricity, as the larger motors would draw higher currents when loaded. The impacts can flow through the energy supply chain with thicker cables, larger switchboards and sub-stations. Other impacts as listed by Hourahan (below) also apply to the larger systems.

Hourahan [2004] lists the effects of over-sizing of unitary air conditioning systems, which are typically found in residential and small commercial buildings:

- Marginal part-load temperature control
- Large temperature differences between rooms
- Degraded humidity control
- Drafts and noise
- Occupant discomfort and dissatisfaction
- Larger ducts installed
- Increased electrical circuit sizing
- Excessive low-load operation
- Frequent cycling (loading/unloading)
- Shorter equipment life

- Nuisance service calls
- Higher installed costs
- Increased operating expense
- Increased installed load on the public utility system
- Increased potential for mould growth
- Potential to contribute to asthma and other respiratory conditions.

Proctor, Katsnelson and Wilson [1996] explain why air conditioners that cycle ON/OFF to control temperature are less efficient when they are oversized. Air conditioners are very inefficient when they first start, only reaching peak efficiency after about 10 minutes of operation. An oversized air conditioner will cool the space quicker and may often operate in this inefficient "zone". They estimate that if an air conditioner is double the required size the energy consumption would increase by 10%.

Crozier [2000], estimates that over-sized plant is "responsible for approximately 10-15% of HVAC related energy consumption" in U.K.: "Oversized air handling systems and components can incur increased space requirement, capital costs and energy consumption. Furthermore, difficult plant control can lead to compromised occupant comfort and shortened plant life."

1.5 SOLUTIONS/SUGGESTIONS

- Challenge "rules of thumb" and/or brief requirements which may be out of date. For example, obtain current equipment load data that matches the intended use.
- Conduct an accurate load estimate, using AIRAH design data, specific to project location, and then resist the temptation to apply "safety factors". Do not use W/m² or other approximate methods.
- Use a load estimation program that accounts for thermal storage and diversification of peak loads for each zone and air handling system.
- 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% load. Individual chillers usually become less efficient once the load falls below 50%. This problem is exacerbated if the chiller is oversized.
- Allow for unknown future tenancies by designing flexibility into the system, not by over-sizing. For example, generous sizing of distribution pipework and ductwork will allow available capacity to be redistributed.
- Provide an auxiliary tenant condenser water loop to handle high load areas.
- Consider using an Integrated Design Process, build an integrated load and energy use simulation model and test different operational scenarios
- Consider commissioning/maintenance aspects for the system
- Use comprehensive Life Cycle Cost analysis for selection of the most optimal design solutions.
- Mandatory disclosure regulations due to be introduced by the end of 2007 for energy performance of buildings upon sale or leasing will place pressure on design teams to achieve better performance – right-sizing will be part of the solution.

2.0 REFERENCES

Australian Building Codes Board (ABCB) (2004) Regulation Document – Energy Efficiency BCA Volume 1: Proposal for Class 5 – 9 Buildings, November.

Crozier, B. (2000), "Enhancing the Performance of Oversized Plant", BSRIA Application Guide AG1/2000.

Deng, S. (2002), "Sizing Replacement Chiller Plants", *ASHRAE Journal*, June.

GREG (Government Real Estate Groups) (2000), "National Office Accommodation Benchmarking", December.

Hourahan, G.C. (2004), "How to Properly Size Unitary Equipment", *ASHRAE Journal*, Feb.

Knight, I. and Dunn, G. (2004), "Size Does Matter", *Building Services Journal* 08/04.

Komor, P. (1987), "Space Cooling Demands from Office Plug Loads", *ASHRAE Journal*, December.

Proctor, J., Katsnelson, Z. and Wilson, B, (1996) "Bigger is not better: Sizing air conditioners properly", *Refrigeration Service and Contracting*, vol 64, No. 4, April. (Also published in Home Energy magazine, May/June 1995)

Vieira, R.K., Parker, D.S., Klongerbo, J.F., Sonne, J.K. and Cummings, J.E. (1996), "How Contractors Really Size Air Conditioning Systems", Proceedings *ACEE Summer Study on Energy Efficiency in Buildings*.