Commercial Building Code Development in Australia

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It has long been recognized in Australia that substantial benefits would accrue from implementation of a commercial building energy efficiency code. Preliminary work was performed by the Victorian government that was later embraced by all the states. This paper reports on a National Stringency Analysis (NSA) for Australia. The study's principal purpose was to help set the level of efficiency (stringency) for a commercial building energy code that considers the range of climates and economic conditions in Australia. The NSA was essentially a cost-effectiveness study of building energy efficiency measures. It attempted to answer this central question. If designers and owners of commercial buildings have good information about the implications on energy use for each design decision and if they consider not only the initial construction cost; but also the cost to operate their building over some reasonable time horizon, then what level of energy efficiency would they reach?

The study developed a methodology that classified commercial buildings in terms of two broad parameters: schedules of operation (24-hour vs. daytime) and internal heat gain. The cost effective level of building component performance was calculated from three economic perspectives: the owner/occupant, the people of Australia (societal) and an environmental perspective that includes externalities for greenhouse gas emissions and other factors (ASHRAE Tier Two). The methodology covered components of the building envelope as well as equipment efficiency and controls for both lighting and HVAC.

Introduction

For some years, building industry professionals in Australia have recognized that the introduction of a Commercial Building Energy Code (CBEC) would substantially benefit the commercial building industry and society at large. As a response, three linked studies were performed.

- The National Impact Study (NIS) to assess the national costs and benefits of a CBEC.
- The National Stringency Analysis (NSA) to determine the cost effective level at which to set the stringency of a national CBEC.
- The Code Structure Analysis (CSA) to determine the context, scope and applicability of a draft national CBEC.

This paper presents the findings of the National Stringency Analysis (NSA). The central purpose of the NSA study was to provide information to help set the level of efficiency or *stringency* of a CBEC, and to consider a range of climates and economic conditions that embraces all of Australia. The NSA was essentially a cost-effectiveness study of building energy efficiency measures. It attempted to answer one central question. If designers and owners of commercial buildings have good information about the implications of energy use on each design decision, and if they consider not only the initial construction cost, but also the cost to operate their buildings over some reasonable time horizon, then what level of energy efficiency would they reach?

Methodology

The way that buildings are operated and where they are located affects the cost-effectiveness of measures. To account for this, the study considered several sets of assumptions on building operation and ten different climate conditions. Building operation was characterized in two ways:

- Buildings that are operate 24-hours per day, such as hospital wards, hotels and high-rise residential, were distinguished from buildings that typically operate only in the daytime such as offices, retail, schools, etc. The study validated intuition that the longer buildings are operated, the more likely some measures, such as building insulation, will be cost effective.

- Three levels of internal gain-from people, lights and equipment—were considered to represent the range of expectation in commercial buildings. The greater the internal gains, the longer a building will be in a cooling mode and the shorter it will be in a heating mode (Table 1). This will increase the likelihood that measures that reduce cooling energy will be cost effective and reduce the likelihood for measures that reduce heating energy.

Table 1. Internal Gain Assumptions

Type	24-Hour Hotel	Daytime Offices
Lighting	12.0 (W/m^2)	17.2 (W/m^2)
Equipment	10.8 (W/m^2)	27.5 (W/m^2)
Occupancy	10.0 (m^2/person)	11.1 (m^2/person)
Latent	45.4 (W/person)	58.6 (W/person)
Sensible	71.8 (W/person)	73.3 (W/person)

The study examined the impact of climate in considerable detail. After eliminating duplicate data sets from 68 available weather data locations, approximately 24 independent sets of hourly weather data remained. Through cluster analysis and consideration of population centers, the study focused on ten climate locations that include all the capital cities as well as Alice Springs and Rockhampton.

The NSA considered three different economic perspectives. The principal perspective was that of the owner occupant. This perspective is typical of companies or institutions that own their buildings and are responsible for both the initial costs and the operating costs. With this perspective, an energy-efficiency measure is assumed to be cost effective if it can be installed in the building at a cost less than $0.79 per kWh per year of electricity savings and/or about $51 per GigaJoule of fuel savings each year. Two additional perspectives were also considered: a perspective that might represent how society would value future energy savings, and the proposed ASHRAE "tier two" perspective—intended for use in voluntary codes or utility incentive programs. The ASHRAE tier two perspective values future energy savings more highly than the other two perspectives and hence would result in a code requiring the highest level of energy efficiency.

The analysis was applied to each separate building component to help assure a cost- effective level of performance for each. If the analysis is performed for the whole building, there is a risk that measures that are not cost effective will not be carried by others that are. Conversely, measures not cost effective alone may be cost effective in combination with other measures. For example, lighting measures without cooling benefits or daylighting without light controls. This type of study would be on a project specific basis rather than implementing it in the CBEC. An outline of the steps in the methodology is presented in Table 2 below.

Table 2. Outine of Methodology

1. Identify, classify and screen all reasonable energy-efficiency measures for each component or class of measures. Gather cost and performance data. Discount maintenance and replacement costs to present value and add to the initial construction lost.
2. Estimate the energy use of each measure for the operation patters, internal load levels, and climates.
3. Calculate the life-cycle cost of all measures for each class and identify the low life-cycle cost choices. Present the results in graphic form for easy comprehension.
4. Show how the low life-cycle cost results changes with different economic assumptions and with different schedules and internal gains.

Classification of Measures

The classes of measures were selected to minimize interactions between measures, but interactions were not entirely eliminated. The most notable interaction is between HVAC system efficiency and building envelope measures. For instance, the more efficient the system, the more difficult it is to justify insulation as being cost effective. These interactions are treated as sensitivity studies and are described where relevant.

Each building was assumed to consist of four building systems: the opaque building envelope, fenestration, the lighting system, and the mechanical system. Each building system has multiple components. For instance walls, roofs, and floors are all components of the opaque envelope system. In many instances, a building component is subdivided into more than one class. For instance exterior walls are subdivided into three classes: framed walls, single-element mass walls, and double-element mass walls. If a component is not subdivided into classes, the component becomes a class itself (Table 3). Within each class, a series of design options or measures were identified, costed and analyzed. Measures compete with each other for cost effectiveness within a class. A measure is cost effective when it has the lowest life-cycle cost among all other competing measures within the class.

Continuous and Discrete Measures

Most of the “measures” or design options evaluated in the stringency analysis are continuous, meaning that they can be characterized as points along a continuum. Interior lighting power density is a good example. The performante measure along the continuum is W/m^2, adjusted for automatic lighting controls. The building envelope measures are also continuous as are many HVAC measures. Discrete measures are either present or not. An example is an economizer for an HVAC system that is either installed or not installed.

Different approaches were used to estimate the energy use of continuous and discrete measures. There is a one-to-one correspondence between computer runs and the discrete measures, while with the continuous measures, computer runs were made to estimate the energy use at several points along the continuum and this information was used to estimate the energy use of all the other points along the continuum.

Screening of Continuous Measures

The continuous measures were screened before detailed economic analysis was performed. This reduced effort and streamlined the process. First the data was gathered for all reasonable measures, whether or not the measures may be cost effective. The screening method was then applied as illustrated in Figure 1. In this graph, all the continuous measures for a particular class are plotted in a two-dimensional space with the performance of the measure on the x-axis and the cost of the measure on the y-axis. First, all measures that do not perform as well as the measure with the lowest first cost can immediately be eliminated from consideration. After that, only the measures that form the frontier of cost effectiveness need be considered. These are shown on the figure as solid circles connected by vectors. The vectors indicate that the cost effectiveness of each improvement is justified relative to the last measure that was shown to be cost effective. While the graphic is useful in explaining the screening process, the screening was actually performed analytically.

Estimating Energy Use (Savings)

DOE-2 Computer Simulations. Energy use for most of the measures was estimated with the public domain DOE-2.1 simulation tool. The tool was chosen because it was comprehensive enough to estimate the energy

Table 3. Component Criteria and Classes

Building System	Component Criteria	Classes
Opaque envelope	Wall U-value	Framed Walls
		Single element mass walls
		Double element mass walls
	Roof U-value	Framed roofs
		Framed roofs with plenum
		Mass roofs with plenum
	Floor U-value	Framed floors
		Suspended slab floors
Fenestration	U-values	Criteria developed for a range of window wall ratios
	Shading coefficient	Criteria developed for a range of window wall ratios
Lighting	Lighting power density	Classes identified based on specific space activities
Mechanical	Economizer	Requirement varies with supply fan size in l/s
	VAV fan control	Requirement varies with supply fan size in l/s
	Fan System Efficiency	Requirement varies with supply fan size in l/s
	Motor Efficiency	Requirement varies by motor kW

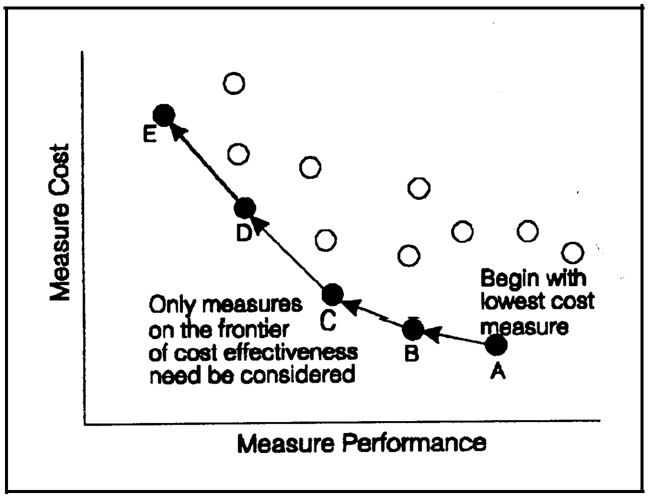

Figure 1. Screening of Measures

performance of all the measures to be evaluated. It accepts apropriately formatted weather data and will operate with SI units.

A 15-zone model was used representing a three-story building with five zones on each floor: an interior zone and four perimeter zones. Each interior zone measures 30 x 30 meters. Each perimeter zone consists of ten 3 x 5 meter rooms facing each of the cardinal orientations. A plenum space above the ceiling extends across all the zones. While the model is simple, it is very powerful and flexible in isolating the factors that make a significant difference in measure cost effectiveness.

Heating and Air-Conditioning Systems. All buildings were assumed to be air conditioned in the modeling. Heating and cooling energy was tabulated separately, however, so that heated only spaces could be considered in the analysis. Even if buildings are not air conditioned, the reduced cooling benefits manifest themselves as increased comfort. If buildings are comfortable, there is less chance that air conditioning will be installed in the future.

For the building envelope and lighting computer runs, the base case system was a gas/electric packaged single zone system. The HVAC runs also considered a variable air-volume reheat system and constant volume reheat systems.

Fuel and Electricity Energy Coefficients. Fuel and electricity energy coefficients were used for the continuous measures to manage the massive amounts of data. The energy coefficients represent the change in fuel and/or electricity energy for a unit change in building component performance. The energy coefficients were calculated for both the 24-hour and daytime occupancy schedules and for three levels of internal gains. They were also calculated for ten climate conditions. For the fenestration studies, analysis was also performed for three window-wall ratios.

The slope of the line in Figure 2 is the fuel energy coefficient. A similar process was used to calculate the electricity energy coefficient. In most cases, the straight line fit the three points with an R^2fit of 0.99 or greater. Once the fuel and electricity energy coefficients are known for a particular class of construction, any number of measures within that class can be evaluated with the following simple equation.

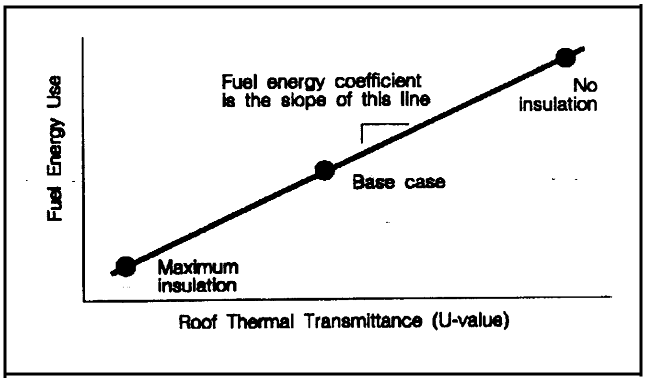

Figure 2. Fuel Energy Coefficient

$$kWh = Constant_{e,i} + U \times EC_{e,i}$$

$$Fuel = Constant_{f,i} + U \times EC_{f,i}$$

In these equations, “kWh” is electricity use; “Fuel” is fuel use; “U” is the opaque surfaces U-value; and “$EC_{e,i}$” is a regression coefficient indexed by electricity or fuel use (e or f) and orientation (i).

Similar equations were developed through regression analysis to determine the energy performance associated with fenestration constructions. The equations are a little more complicated, however, because the fenestration performance depends or three properties, not just one like opaque envelope elements. The three characteristics are the shading coefficient, glass conductance, and visible light transmission. The amount of glass in the building or the window-wall ratio also affects the results. Lighting energy, which is affected by the visible light transmission of the glass and the window-wall ratio, is accounted for in a separate equation.

$$kWh = Constant_{e,i} + WWR \times SC \times EC_{sc,e,i} + WWR \times U \times EC_{u,e,i}$$

$$Fuel = Constant_{f,i} + WWR \times SC \times EC_{sc,f,i} + WWR \times U \times EC_{u,f,i}$$

In these equations, “kWh” is electricity use; “Fuel” is fuel use; “WWR” is window-to-wall ratio; “SC” is shading coefficient; “U” is glass conductance; and “$EC_{sc,e,i}$” are regression coefficients indexed by performance characteristic (sc or u), electricity or fuel use (e or f) and orientation (i).

The constant terms in the equations drop out when two or more constructions are compared. Only the EC terms are significant.

Life-Cycle Cost Analysis

The approach was to determine the lowest life-cycle cost (LCC) construction option in each building component class. For each class the LCC was calculated using the following equation:

$$LCC = EC_h \times M_p \times PV_f + EC_c + M_p \times PV_e + Cost$$

In this equation, “LCC” is the life-cycle cost; “EC_h” is the energy used for heating in a year per unit of the performance factor (regression coefficient); “M_p” is the energy performance measure (e.g., U-value, W/m^2); “PV_f” is the present value of fuel saved \$/(GJ/y); “EC_h” is the energy used for cooling in a year per unit of the performance factor; “PV_e” is the present value of fuel saved in \$/(kWh/y); and “cost” is the initial capital cost plus the present value of maintenance and replacement costs .

When “measures had different lives or maintenance costs, then a discount rate was used to bring future maintenance and replacement costs to present value. Replacement and maintenance costs vary considerably with many lighting measures and for some HVAC systems.

Many efficiency improvements reduce peak loads enabling reduced HVAC equipment sizes. The reduced size can result in a lower HVAC capital cost. This secondary benefit was not explicitly included in the calculation because of difficulties in quantifying the costs.

Presentation of Results

A graphic approach was used to present the results to help participants in the process better understand the impact of changing assumptions on the cost- effective stringency level.

For the opaque envelope, cost-effectiveness boundaries were calculated and the fuel and electricity coefficients were plotted against these boundaries. The cost-effectiveness boundary between two wall constructions, say “i” and “j”, is the condition where the life-cycle cost of constructions “i” and “j” are equal. An equation for the boundary can be developed as shown below.

$$LCC_i = LCC_j$$

$$U_i(EC_h \times PV_f + EC_c \times PV_e) + Cost_i = U_j \times (EC_h \times PV_f + EC_c \times PV_e) + \Delta Cost_j$$

$$\Delta U \times (EC_h \times PV_f + EC_c \times PV_e) + \Delta Cost = 0$$

The boundary condition can be plotted as a straight line on a graph of heating and cooling energy coefficients.

Stringency Results

The climate of a location can be used to ascertain which insulation option is cost effective in that location. The approach is illustrated for roofs with no plenum and the daytime schedule medium-gain case is shown in Figure 3. Based on the primary economic perspective boundaries, all cities should have 100mm recycled wool bats. Based on the ASHRAE tier two economic perspective boundaries, all cities should have 100mm fiberglass batts.

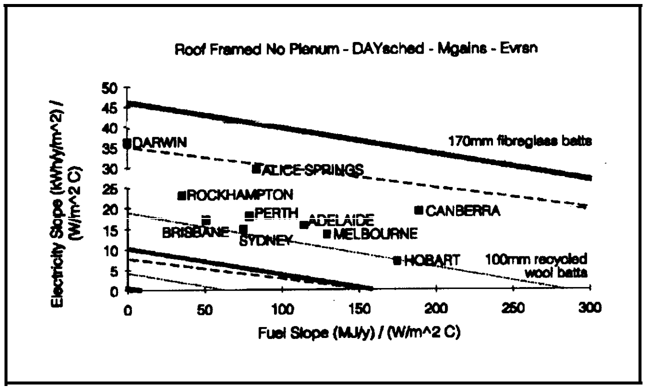

Figure 3. Stringency Results—Roof with No Plenum–Daytime Schedule

For the 24-hour schedule low-gain case the results were more stringent with Alice Springs and Darwin in the 170 mm fiberglass batt region and all other cities remained unchanged (see Figure 4).

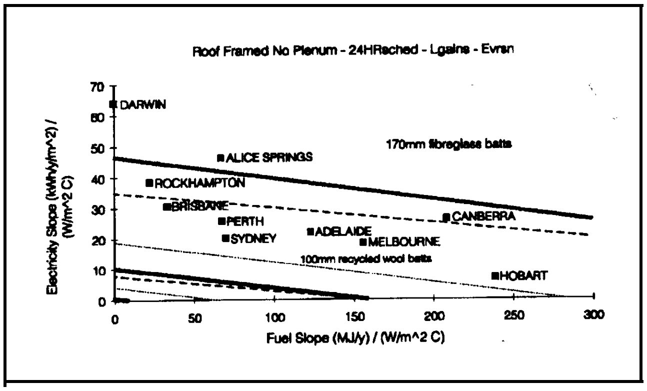

Figure 4. Stringency Results—Roof with No Plenum—24-Hour Schedule

Fenestration

The thermal and solar performance of fenestration systems can have a significant impact on both average and especially on peak load HVAC system performance. For each selected city, internal gains and occupancy schedule, and economic perspective graphs were developed that show the cost-effective level of performance against WWR. Example results are shown for Sydney in Figure 5.

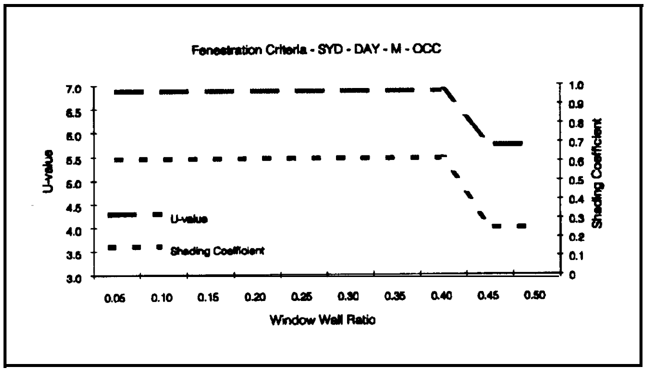

Figure 5. Fenestration Criteria-Sydney-Daytime Schedule—Occupant Perspective

Lighting

Lighting systems are required to produce appropriate illumination levels, color rendition, acceptable levels of glare, and acceptable levels of uniformity, etc. Acceptable designs were developed that all satisfy these criteria and then compared in terms of "adjusted lighting power density" (in W/m^2). The "adjustments" include allowance for both time of operation and dimming controls.

Efficient lighting systems reduce cooling energy due to less heat generation. In general a reduction in lighting energy used reduces the energy used for cooling in air-conditioned buildings by about 0.2 watt-hours per watt-hour of lighting energy reduction determined through computer simulations. There is also an impact on fuel use, but this is relatively small and was ignored. The air-conditioning impact varies by climate. In Darwin with the greatest cooling loads, the impact is about 0.3 watt-hours per watt-hour of lighting reduction. In the southern part of the country, the impact is smaller, about 0.15 watt-hours per watt-hour of lighting reduction.

For practical reasons it was decided that it was not necessary for the lighting requirements of the code to vary by climate. A mid-range value of 0.20 watt-hours per watt-hour of lighting reduction was thus selected for use nationwide in all lighting calculations. With these considerations, the equation for life-cycle cost for lighting systems is given as follows.

$$LCC = LPD \times Hours \times (1 + CoolAdj) \times PV_e + Cost$$

"LCC" in this case is for a unit area of building (one square meter) and is relative to the other competing lighting systems. "Cost" is the total cost per m^2 including maintenance and replacement costs over the life of the system discounted to present value. LPD is the lighting power density (W/m^2), adjusted to account for the benefit of automatic lighting controls such as occupant sensors, time clocks or daylighting controls. "Hours" is the full-time equivalent hours of lighting operation for a typical year. PV_e is the value placed on a unit of electricity savings. "CoolAdj" is the cooling penalty for lighting (described above).

Figure 6 shows an example for lighting systems where the life-cycle cost is plotted against the adjusted lighting power density. Minimum life-cycle cost and the most cost-effective set of performance measures is represented by the minimum point on the curve. In this example, the ASHRAE two tier economic criteria results in a different set of measures than the societal or owner occupant criteria.

Mechanical Results

Adequate data was unavailable to support rigorous LCC analysis for a number of the mechanical system and equipment items. The NSA study recommends that as a minimum, standardized test and reporting procedures be developed and that ideally a set of labels and associated equipment efficiency standards be developed to ensure that adequate information and/or efficient equipment is available in the marketplace.

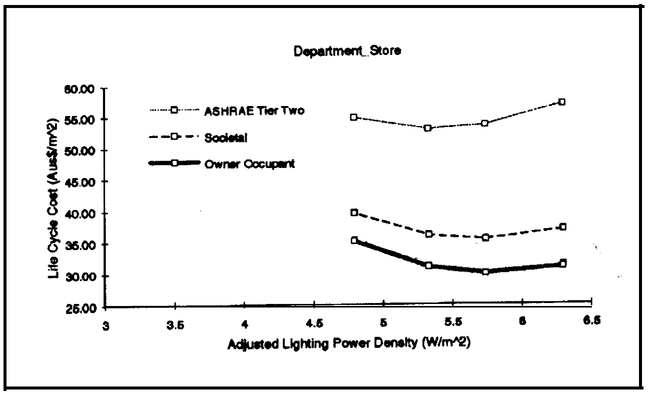

Figure 6. Department Store Lighting Systems—LCC vs Adjusted Lighting Power Density

Classes of equipment efficiency may be considered continuous, where most controls are discrete. Discrete classes require that each measure be modeled explicitly (e.g. economizers), while for continuous measures a. regression analysis or interpolation process was used.

The effectiveness of many of the measures depends on a diversity of loads in the building. The 15-zone model was selected to provide adequate diversity.

The majority of the HVAC measures were evaluated only for the daytime schedule with medium internal gains. This is believed to be reasonable since most of the measures evaluated are appropriate for commercial buildings that operate on this schedule.

System Type. To study the impact of system type on energy use, the performance of a constant volume reheat system was compared to that of a variable air volume system for all ten climate locations. In general, the cooling energy is about one-half with a VAV system and the heating energy is about one-third. These are very significant savings and hence clearly justify a requirement that restricts the use of constant volume re-heat type system.

Economizers. Several types of economizers were evaluated as part of this study: the *non-integrated drybulb* type, the *integrated drybulb* economizer, *enthalpy* economizer, and the *integrated enthalpy* economizer. Controlling the position of the outside air damper based on the total heat content of the air enthalpy improves economizer performance particularly in climates with moist air conditions.

Economizers were studied for both packaged systems, where a separate system is present for each thermal zone of the building, and for central variable air volume systems.

The cost effectiveness of economizers depends on whether the present value of the energy savings is greater than the present value of the additional system cost. When this condition exists, the life-cycle cost of the system with the economizer is less than the cost of the system without one. The cost premium for economizers varies with the size of the fan system.

The larger the fan system, the lower the cost of the economizer per unit of air volume (1/s). The benefits, on a per unit of air volume basis, however are constant. The question of interest is the fan size at which the economizer becomes cost effective. The benefit and cost lines are shown in Figure 7 for an integrated drybulb economizer for packaged single systems in Perth. Similar results were plotted for other conditions.

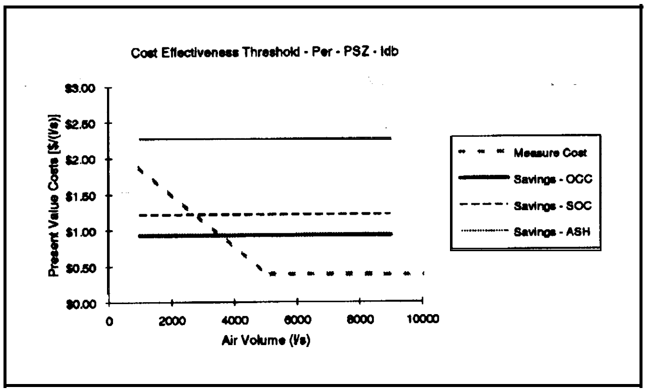

Figure 7. Economizer Cost Effectiveness—Perth—Packaged Single Zone–Integrated Dry Bulb

Fan System Efficiency. Fan system efficiency is defined to characterize the total efficiency of the fan system; it is the product of the fan mechanical efficiency, the motor efficiency, and the drive efficiency.

Fan mechanical efficiency is a function of the pressure and air delivery volume at which the fan is operating. Both of these variables can take a variety of values in differing commercial buildings. A system pressure of 700 Pa. was assumed with three flow rates based on “typical” system sizes. These assumptions allowed values of efficiency to be gathered and compared.

When all other features of a building are held constant and the fan system efficiency is varied, the change in electricity use of the building prototype is relatively linear and fan system efficiency is treated as a continuous measure.

The collections of measures for fan systems include various types of fans in combination with drive and motor possibilities. The fan systems sizes selected were: fans smaller then 5,000 1/s, fans between 5,000 and 10,000 1/s and fans greater than 10,000 1/s. An example of the analysis results is presented in Figure 8. This curve is for small fans (less than 5,000 1/s) in Sydney. The most efficient fan has the lowest life-cycle cost regardless of the economic perspective. This pattern existed for all climate locations and for all fan size classifications, indicating a need for better cost and performance data.

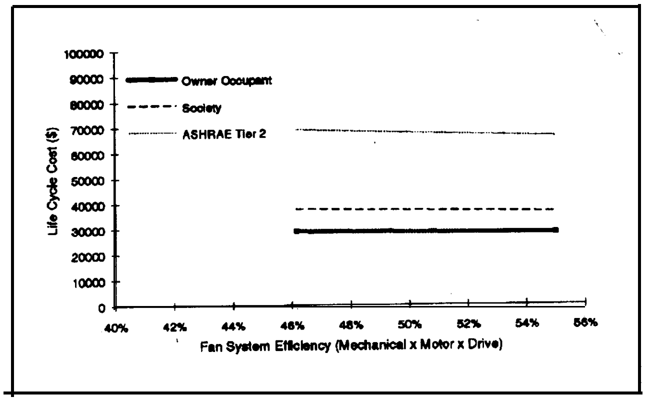

Figure 8. Life-Cycle Cost Curves for Fan System Efficiency

Variable Air Volume Fan Type and Control. The way that fans are controlled in variable air volume systems has a significant impact on energy use. Several types of fan control were evaluated in the stringency analysis including discharge dampers, speed drives, and inlet guide vanes.

The costs of variable speed drives is highly variable, so a range was provided in the analysis. The cost of inlet vanes is more stable and only one set of cost data is provided. The costs are given per unit of air flow (1/s) and decline with larger fans. Data is plotted for fan sizes ranging between zero and 10,000 1/s. Data was collected for three fan sizes (1,000, 5,000 and 10,000 1/s). The cost data between these points is assumed to fall along a straight line.

Figure 9 shows the cost effectiveness for variable speed drives, in Darwin. Again the horizontal lines are the economic life-cycle benefits and the sloping lines are the life-cycle costs. In this case there are two sets of sloping lines, one for the high and low of the cost range assumed in the analysis. At the high end of the cost range, variable speed drives become cost effective for fans that are larger than about 5,000 1/s with the owner occupant economic perspective. With the societal perspective they become cost effective at about 4,000 1/s.

HVAC Equipment. HVAC equipment includes motors, packaged air conditioners and heat pumps, water-cooled and air-cooled chillers, boilers, furnaces, unit heaters, and water heaters. Cost data were collected for most of the equipment and cost-effectiveness analysis was performed when appropriate. One of the problems encountered with all HVAC equipment is reliable data on equipment performance. There are no standard test conditions for much of the equipment and it is very difficult to obtain reliable and comparative data.

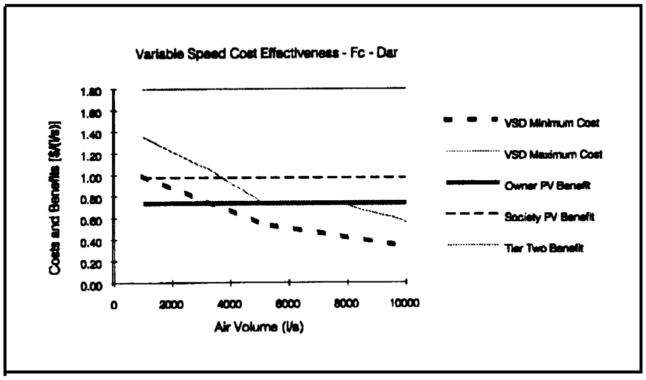

Figure 9. Cost Effectiveness of Variable Speed Drives—Darwin-Forward Curved Fans

The absence of reliable data made it impossible to perform a reasonable cost-effectiveness analysis for HVAC equipment and it was recommended that consideration be given to adopting test procedures and performance standards from other codes.

Motor efficiency was the only mechanical equipment measure analyzed. Data on motor efficiency and cost is provided in Figure 10. This shows that as motor size in kW increases, the efficiency of both standard and premium efficiency motors also increases slightly. The cost is highly dependent on motor size and increases at a faster rate. This graph includes motors with sizes ranging from 0.8 kW up to 22 kW.

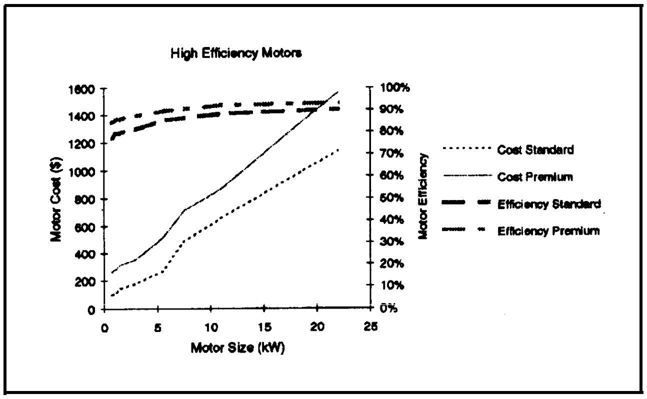

Figure 10. Motor Efficiency and Costs

For a given motor size the cost effectiveness of premium motors over standard motors is entirely dependent on the annual hours of operation. Figure 11 shows the relationship for 3kW motors. The horizontal line is the cost premium, which is independent of the hours of operation.

The sloping lines represent the present value of the savings that increase steadily with greater hours of operation. Three sloping lines are provided, one for each of the economic perspectives considered in the study. With the owner occupant perspective, premium 3kW motors become cost effective any time the hours of operation exceed about 800 hours. The threshold is only about 600 hours with the societal perspective and about 400 hours with the ASHRAE tier two perspective.

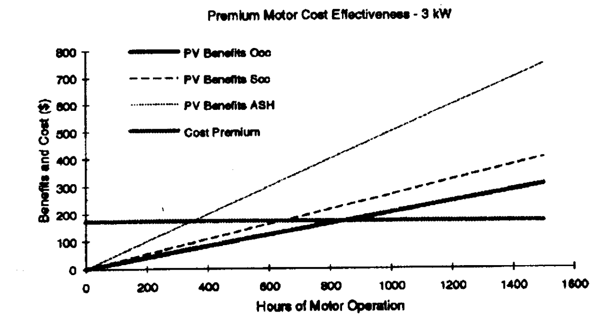

Figure 11. Premium Motor Cost Effectiveness—3kW

Summary of Results

Tables 4 through 10 summarize the cost-effective level of building component performance for the opaque envelope, fenestration, lighting, and mechanical systems. The tables are based on the owner occupant perspective, the daytime schedule with medium internal gains, and the 24-hour schedule with low internal gains.

In the following tables, the abbreviations are:
Ade—Adelaide, South Australia
Ali—Alice Springs, Northern Territory
Bri–Brisbane, Queensland
Can-Canberra, Australian Capital
Dar-Darwin, Northern Territory
Hob—Hobart, Tasmania
Mel—Melbourne, Victoria
Per—Perth, Western Australia
Roc-Rockhampton, Queensland
Syd–Sydney, New South Wales

Table 4. Summary of Results—Owner Occupant Perspective

	Ade	Ali	Bri	Can	Dar	Hob	Mel	Per	Roc	Syd
24 Hour Occupancy Results	*Minimum U-value*									
Framed Walls	0.71	0.71	0.86	0.71	0.71	0.71	0.71	0.71	0.71	0.86
Single Element Mass Walls	0.52	NIL	NIL	0.79	0.57	0.79	NIL	NIL	NIL	NIL
Double Element Mass Walls	0.33	0.33	NIL	0.33	0.33	0.33	0.33	0.47	NIL	NIL
Framed Roofs	0.99	0.89	0.99	0.99	0.89	0.99	0.99	0.99	0.99	0.99
Framed Roofs with Plenum	1.03	1.03	NIL	1.03	1.03	1.03	1.03	1.03	1.03	1.03
Mass Roofs with Plenum	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
Framed Floors	1.05	1.05	NIL	0.43	1.05	0.43	1.05	1.05	NIL	1.05
Suspended Floor Slabs	0.31	0.31	NIL	0.31	0.42	0.31	0.31	0.31	1.02	1.02
Daytime (All Other Occupancy) Results	*Minimum U-value*									
Framed Walls	0.86	0.71	0.86	0.71	0.71	0.86	0.86	0.86	0.86	0.86
Single Element Mass Walls	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
Double Element Mass Walls	0.81	0.47	NIL	0.33	0.47	0.47	0.47	NIL	NIL	NIL
Framed Roofs	0.99	0.89	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Framed Roofs withPlenum	0.53	0.53	1.03	0.53	0.53	0.53	0.53	0.53	0.53	1.03
Mass Roofs with Plenum	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
Framed Floors	1.05	1.05	NIL	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Suspended Floor Slabs	0.42	0.42	1.02	0.31	1.02	0.42	0.42	0.42	1.02	1.02

Table 5. Key for U-Values

Opaque Envelope Class	U-Value	Low LCC Construction Used	Alternative Construction
Framed Walls	0.86	Aluminium Foil	N.A.
	0.71	100mm Recycled Wool Batts	75mm foil/fibreglass batt
Single Element Mass Walls	0.79	Aluminium Foil	N.A.
	0.57	100mm Recycled Wool Batts	75mm foil/fibreglass blanket
Double Element Mass Walls	0.81	Aluminium Foil	N.A.
	0.47	80mm Recycled Wool Batts	75mm fibreglass batts
	0.33	100mm Recycled Wool Batts	100mm foil/fibreglass blanket
Framed Roofs	0.99	100mm Recycled Wool Batts	145mm fibreglass batts
	0.89	170mm Fibreglass Batts	N.A.
Framed Roofs with Plenum	1.03	Aluminium Foil	N.A.
	0.53	100mm Recycled Wool Batts	145mm fibreglass batts
Mass Roofs with Plenum	0.49	80mm Recycled Wool Batts	60mm foil/fibreglass blanket
Framed Floors	1.05	Aluminium Foil	N.A.
	0.49	50mm Triple Cell Batts	100mm fibreglass blanket
Suspended Floor Slabs	1.02	Aluminium Foil	N.A.
	0.6	40mm Double Cell Batts	50mm pure wool batts
	0.37	50mm Triple Cell Batts	100mm fibreglass blanket

Table 6. Summary of Results—Fenestration—Owner Occupant Perspective

	Ade	**Ali**	**Bri**	**Can**	**Dar**	**Hob**	**Mel**	**Per**	**Roc**	**Syd**
Day Occupancy	***Maximum U-Value***									
10% Window Wall Ratio	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8
20% Window Wall Ratio	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8
30% Window Wall Ratio	6.8	5.8	6.8	6.8	5.8	6.8	6.8	6.8	6.8	6.8
40% Window Wall Ratio	6.8	5.8	5.8	6.8	5.8	6.8	6.8	6.8	5.8	6.8
50% Window Wall Ratio	5.8	5.8	5.8	6.8	5.8	6.8	6.8	5.8	5.8	5.8
	Maximum Shading Co-efficient									
10% Window Wall Ratio	0.6	0.6	0.6	0.6	0.6	0.7	0.6	0.6	0.6	0.6
20% Window Wall Ratio	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
30% Window Wall Ratio	0.6	0.25	0.6	0.6	0.25	0.6	0.6	0.6	0.25	0.6
40% Window Wall Ratio	0.6	0.25	0.25	0.6	0.25	0.6	0.6	0.6	0.25	0.6
50% Window Wall Ratio	0.25	0.25	0.25	0.6	0.25	0.6	0.6	0.25	0.25	0.25
24 Hour Occupancy	***Maximum U-value***									
10% Window Wall Ratio	6.8	5.8	6.8	6.8	5.8	6.8	6.8	6.8	6.8	6.8
20% Window Wall Ratio	6.8	5.8	5.8	6.8	5.8	6.8	6.8	5.8	5.8	5.8
30% Window Wall Ratio	5.8	5.8	5.8	5.8	5.8	6.8	5.8	5.8	5.8	5.8
40% Window Wall Ratio	5.8	5.8	5.8	5.8	5.8	6.8	5.8	5.8	5.8	5.8
50% Window Wall Ratio	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8
	Maximum Shading Co-efficient									
10% Window Wall Ratio	0.6	0.25	0.6	0.6	0.25	0.6	0.6	0.6	0.6	0.6
20% Window Wall Ratio	0.6	0.25	0.25	0.6	0.25	0.6	0.6	0.25	0.25	0.25
30% Window Wall Ratio	0.25	0.25	0.25	0.25	0.25	0.6	0.25	0.25	0.25	0.25
40% Window Wall Ratio	0.25	0.25	0.25	0.25	0.25	0.6	0.25	0.25	0.25	0.25
50% Window Wall Ratio	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25

Table 7. Summary of Results—Lighting—Owner Occupant Perspective

Class (i.e. area type)	Selection (W/m^2)	Class (i.e. area type)	Selection (W/m^2)
Auditorium	23.00	General Storage 6m	1.96
Bulk Storage 10m	1.63	Hospital Ward	11.63
Bulk Storage 15m	2.17	Hotel Room	8.50
Classroom	8.20	Interior Carparks	1.21
Computer Room	9.00	Laboratory	10.50
Corridors	8.20	Lift Lobbies	6.83
Department Store	5.74	Open Offices noVDU	8.00
E ntrance Foyers 06m	8.71	Open Offices VDU	9.00
Entrance Foyers 10m	13.07	Partitioned Offices	10.17
Exterior Carparks	0.94	Restaurant	10.25
Food Preparation	7.65	School Hall	5.24
Function Room	6.56	Shops-General	10.25
General Storage 3m	1.68	Supermarkets	4.19

Table 8. Litres/Second at Which These Economizer Types Become Cost Effective

Economizer Type	Ade	Ali	Bri	Can	Dar	Hob	Mel	Per	Roc	Syd
	Owner Occupant Perspective									
VAV - Ndb	2400	1800	4400	1000	never	1200	1400	3800	4400	2500
VAV - Nen	3400	3000	4800	2400	never	2200	2600	4200	4800	3400
VAV - Idb	2400	always	always	always	never	3000	2000	3800	5000	always
VAV - Ien	3200	always	always	1800	never	3600	2800	4000	4900	always
Psz - Ndb	never	never	never	never	never	never	never	never	never	never
Psz - Nen	never	never	never	never	never	never	never	never	never	never
Psz - Idb	3800	4500	3800	4400	never	4600	4000	3500	3800	3200
Psz - Ien	4500	5000	4800	4900	never	4900	4800	4400	5000	4400

Table 9. Summary of Results—Vav Fan Type and Control—Owner Occupant Perspective

Fan Type and Control	Ade	Ali	Bri	Can	Dar	Hob	Mel	Per	Roc	Syd
				Owner Occupant Perspective						
Airfoil/Backward Inclined - Inlet Vane	all	all	all	all	3000	all	all	all	1000	all
Airfoil/Backward Inclined - Vsd	all	all	all	all	1000	all	all	all	all	all
Forward Curved - Inlet Vane	all	all	1000	all	3400	all	all	all	1400	all
Forward Curved - Vsd	all	all	1600	all	5400	all	all	all	2000	all

Table 10. Summary of Results—Motors—Owner Occupant Perspective

Motor Size (kW)	0.8	1.1	1.5	3	5.5	7.5	11	15	18.5	22
Hours p.a. at which Efficient Motor is Cost Effective	2400	2000	1500	850	1000	700	500	550	600	700
"Efficient" Motor Efficiency %	84%	85%	86%	87%	89%	90%	92%	92%	93%	93%