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Comparative life cycle costs for new steel portal frame building systems

Netra Gurung and Mahen Mahendran

Physical Infrastructure Centre, School of Civil Engineering,
Queensland University of Technology, Brisbane, Qld 4001, Australia
E-mail: n.gurung@qut.edu.au

Life cycle costs of a new steel portal frame building system incorporating energy efficient sandwich panels are compared with those of a conventional steel portal frame building system for use in industrial and commercial buildings. The economic benefits of the new building system have been demonstrated through cost assessment of energy in use. The results from life cycle cost analysis of both the new and conventional portal frame building systems indicate that, despite slightly higher initial costs, the new building system costs significantly less than the conventional system over its complete life cycle of 50 years. The new system provides improved economic performance along with a more energy-efficient model for commercial/industrial building design in the Australian climate.

Keywords: cladding, cost estimates, economics, energy, industrial buildings, life cycle cost, steel portal frame, Australia

Le coût du cycle de vie d'un nouveau système de bâtiment à portique en acier comportant des panneaux en sandwich efficaces au plan énergétique est comparé à un système classique pour un emploi dans des bâtiments industriels et commerciaux. Les avantages économiques du nouveau système ont été démontrés par une évaluation des dépenses énergétiques. Il ressort de l'analyse comparative du coût du cycle de vie du nouveau et de l'ancien système qu'en dépit d'une légère augmentation du coût de départ, le nouveau système est nettement moins onéreux que l'ancien sur un cycle de vie complet de 50 ans. Les performances économiques du nouveau système sont supérieures à celles du système classique, avec de meilleures performances énergétiques pour la conception de bâtiments commerciaux et industriels sous le climat australien.

Mots clés : bardage, estimations de coûts, économie, énergie, bâtiments industriels, coût du cycle de vie, portique en acier, Australie

Introduction

Life Cycle Cost (LCC) evaluation provides economic comparison of proposed capital investments that are expected to reduce long-term operating costs of building systems. It is especially useful for evaluating the costs and benefits of energy conservation projects in buildings (Friedman and Cammalleri, 1995; Fay *et al.*, 2000). The LCC perspective is proving to be most useful (Sterner, 2000) during the design phase where the possibilities of cost reductions related to operation and maintenance are large. The LCC approach was used to compare the performance of a new steel portal frame building system using insulated sandwich panels with that of a conventional building system. This paper presents life cycle costs of this steel portal frame building system for use in industrial and commercial buildings, and compares the results with those of conventional building systems. The improvements to the energy efficiency of industrial and commercial buildings due to the use of the new building system using sandwich panels have been numerically quantified. The paper investigates mainly the savings of life cycle energy in use for these portal frame building systems. The environmental impact is only considered in relation to reduced energy use. The comparative life cycle assessment of energy and the cost-in-use information can serve as the guidelines to the building industry regarding energy consumption, operating costs and environmental impacts in order to achieve high energy efficiency and minimize environmental impacts in industrial and commercial buildings. The new building system is environmentally and

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structurally more efficient than the conventional system. Despite the slightly higher initial cost, this new building system using insulated sandwich panels costs significantly less than the conventional system in its complete life cycle of 50 years.

Industrial and commercial building systems

The ecologically sustainable design of not only residential (Treloar *et al.*, 2000) but also industrial and commercial buildings is a necessity for any modern built environment. Building technology can improve the applicability of research results and can increase commercial income (Leppavuori, 1997). The global environmental sustainability can only be achieved by efficient use of energy and natural resources. For this purpose, life cycle analysis approach (Johnston and Mak, 2000) for a 50 year period is chosen to demonstrate the overall reward for innovative building design system. If recycling is included, the potential benefits are possible in steel frame constructions (Thormark, 2000). Portal building systems with steel portal frames and a conventional profiled steel sheeting system are therefore commonly used in commercial and industrial buildings. Its structural efficiency and more importantly, the cost-effectiveness have always been considered to be satisfactory, which have thus led to their continued use in these applications. Previous research at Queensland University of Technology (QUT) on modelling of building frame systems had revealed the possibility of a new cladding system using sandwich panels (Subaaharan, 1998), instead of the conventional profiled steel sheeting system.

Conventional building system

A conventional building system is made of a series of steel portal frames (columns and rafters), Z section purlins and girts and 0.42 mm thick profiled steel roof and wall sheeting. The steel portal frames are the main structural members with cross bracings added to the structure to carry longitudinal wind loads. The structural members were designed independently using two-dimensional (2-D) computer modelling. The schedules of members were obtained using the 2-D analysis and design method (Woolcock *et al.*, 1993). Figure 1 shows the layout of the conventional portal frame building system. Main structural sections required for this 25 m span × 36 m length × 7 m height building are as follows: section 1 – portal column (530 UB 82); section 2 – portal rafter (360 UB 60); section 3 – gable column (250 UB 31); section 4 – purlin (Z 20020); section 5 – purlin (Z 20016); section 6 – girt (Z 20020); section 7 – girt (Z 20016); section 8 – girt (Z 20020); section 9 – strut (165 × 3 CHS); section 10 – roof bracing (100 × 100 × 6 angle) and section 11 – wall bracing (75 × 75 × 5 angle).

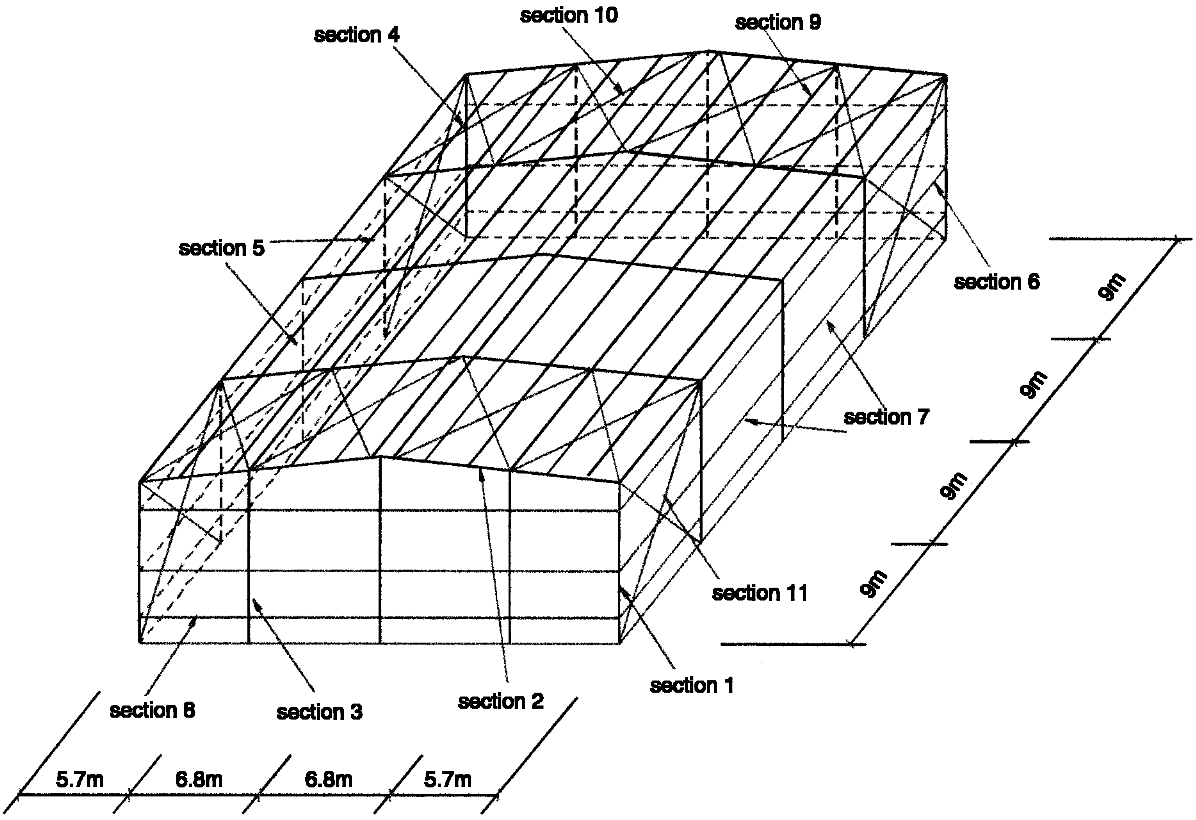

Figure 1 Structural layout of the conventional building system

Typical conventional steel sheeting (without insulating core) for roof and wall claddings is shown in Figure 2.

New building system

Unlike the conventional building system based on a two-dimensional analysis and design method, an innovative portal frame system incorporating sandwich panels as roof and wall claddings and steel rectangular hollow sections as purlins and girts at wider spacing was developed. This new building system was based on three-dimensional (3-D) computer modelling by considering columns, rafters, purlins and girts as beam elements and roof and wall claddings as equivalent truss (tension) members. The composite sandwich panels comprise light-weight polystyrene foam core sandwiched between two steel faces. The steel faces are commonly made of 0.42–0.60 mm G300 or G550 steel whereas the foam is of SL grade and 50–200 mm thick. The composition and geometry of the panels enable them to possess both insulation and structural capacities. Even the 50 mm panels are able to span up to 3 m for Brisbane wind conditions whereas conventional sheeting systems can only span up to about 1.5 m. Despite this, the sandwich panels are essentially used in cold-rooms because of their insulation properties. Subaaharan (1998) investigated the use of 50 mm sandwich panels as part of a steel portal frame building system for use in industrial and commercial buildings. The combined use of sandwich panels and steel tubular/purlin/girt system led to the following benefits in the new building system:

- reduced number of purlins and girts
- roof and wall bracing removed
- flybracing of the rafter/column removed
- less labour intensive and simpler construction process

Figure 3 shows the layout of the new portal frame building system. Main structural sections in this 25 m span × 36 m length × 7 m height building are: section 1 – portal column (460 UB 82); section 2 – portal rafter (410 UB 60); section 3 – gable column (250 UB 31); section 4 – purlin (150 × 150 × 6 mm hollow section); section 5 – purlin (125 × 125 × 6 mm hollow section); section 6 – girt (125 × 125 × 6 mm hollow section); section 7 – girt (100 × 100 × 5 mm hollow section); and section 8 – profiled insulated sandwich panels (50 mm thick) as roof and wall claddings.

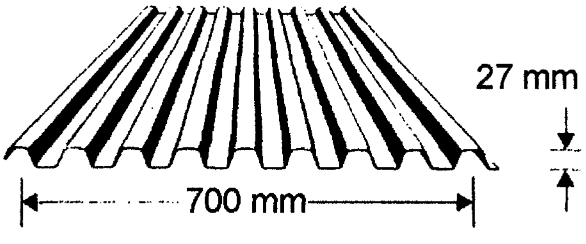

Figure 2 Conventional steel sheeting for roof and wall claddings

Instead of the conventional practice of using profiled steel claddings for roofs and walls, the new system incorporates insulated sandwich steel panels (James Hardie Building Systems, 1999). The insulated panels are a lightweight composite comprising two steel sheets glued to an inner foam core of the expanded polystyrene material. The sandwich panel is shown in Figure 4. The building system using this insulated steel panel was considered to be more structurally efficient than the conventional system (Subaaharan, 1998), however, the initial cost of procurement of the new building system was about 20% higher than that of the conventional system. This has been mainly due to the more expensive sandwich panels. The use of sandwich panels was expected to provide not only the energy savings, but also the minimization of several toxic emission, green house gases, and environmental pollution etc. because of reduced heating and cooling needs.

Australian climate

Australia can be described as the hottest and driest non-polar continent in the Southern Hemisphere. In general, three broad climate zones; temperate, hot arid and hot humid zones are categorized. The temperate climates may need greater winter heating than for summer cooling while cooling is the dominant need in the hot humid climates. Buildings in Australia consume nearly 40% of current energy production for heating and cooling the built environment. The industrial productivity and commercial success depend on the indoor comfort level of building, which in turn depends upon the thermal energy of the indoor environment. Life-cycle energy is used as guidelines in reducing the overall energy consumption for both industrial and commercial buildings. The majority of primary energy consumption is generated during the operation-phase of the building (i.e. heating, cooling, electricity consumption for appliances). Efforts should therefore be focused on the measures that would reduce the operational phase energy consumption (e.g. lowering the thermal conductance properties of the building envelope, reducing energy consumption of appliances, etc.).

Indoor environment

In a built environment facility, the Australian Standard demands that adequate ventilation be provided in all occupied buildings (AS, 1668, 1998), and even at the minimum, one needs three distinct amenities (Parlour, 1998):

- lighting, power and ventilation all year round;
- heating in winter; and
- cooling and de-humidifying in summer

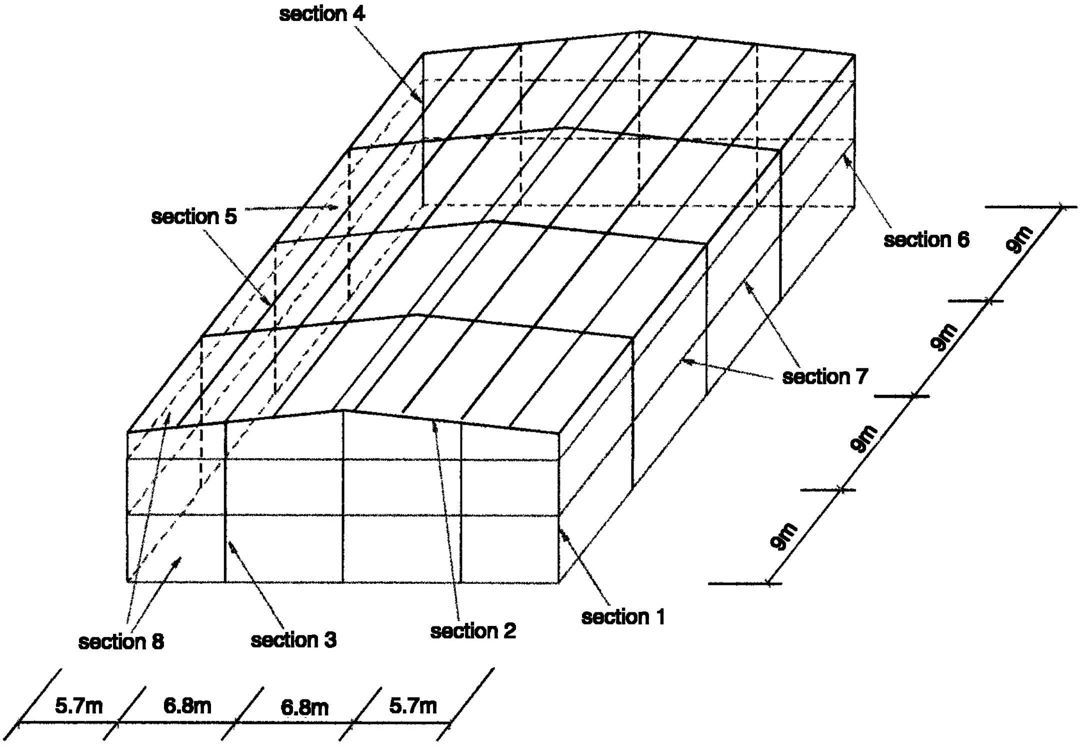

Figure 3 Structural layout of the new building system

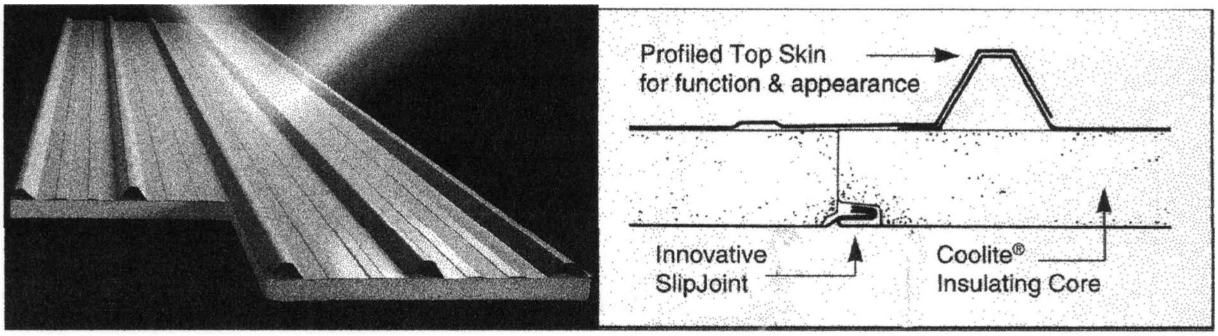

Figure 4 Sandwich panel

The cooling and heating systems may be based upon local climate, comfort level and current market pressures for other buildings that are not legislated in indoor environment. The use of energy for such facilities can be justified in view of economic viability, accepted standards, planning flexibility, floor utilization, increased productivity and freedom-of-action, etc. For daylight to make a real contribution to energy efficiency, appropriate control of electric lighting is essential. The use of energy and physiological comfort depends upon a number of factors. Some external environmental factors are: Dry Bulb temperature (DB), Relative Humidity (RH), Air movement, Mean Radiant temperature (MR), Fresh air supply, Airborne dirt and Noise level. For indoor comfort practice, the dry bulb temperature (DB) of the room air can be maintained at 22°C to 26°C in summer and 18°C to 20°C in winter. Relative humidity (RH) of about 50% is usually satisfactory. The local climates in Australia can be site specific, and past weather records for Brisbane, Queensland were obtained from the Bureau of Meteorology (Ballinger *et al.*, 1997).

In an effort to focus on the life cycle cost assessment of industrial and commercial building systems that directly influence energy use and environmental pollution, some components that are part of a building, and some external factors are not included. The excluded factors in this study are: building orientation and shape that influences the surface/volume ratio; energy consumption due to functional operation (industrial/commercial appliances); energy related to solid waste disposal and water treatment system; effect of furniture and fixtures, heat generation from industrial crews/ commercial customers; behavioural patterns of habitants, work styles, consumption habits, clothing, entertainment equipment, cleaning materials, etc. Effect of excluding these factors is minimal in this comparative study as their effects are of the same order for both systems. The environmental burdens associated with the ultimate treatment of the demolished building materials, such as landfilling, recycling, and reusing were also not evaluated. Attempting to determine the nature and efficiency of the recycling industry in 50 years would be conjectural. Basically, this paper reflects the life cycle savings due to the use of insulated sandwich panels for industrial and commercial applications.

Environmental design parameters

Brisbane has a hot, humid climate and is located just south of the Tropic of Capricorn. The summer maximum average temperate is only 30°C, the summer months having some extremely hot days. The winter is mild and very pleasant. Most winter days are sunny with average temperatures of around 15°C. The indoor environment depends upon weather, climate, solar radiation, variation of temperature, humidity, air quality, day lighting etc. including the location and orientation of the building. Typical design parameters are the values of Dry-Bulb (DBs) and Wet-Bulb (WBs) temperatures, Design Dry-Bulb (DBw) temperature, Cooling load factor (C), Heating load factor (H), heating Degree Days and Equivalent Full Load Hours (EFLH) for the locations under consideration. The values of these parameters are needed for the locations under consideration.

The main data used in this study are as follows:

- Location: Brisbane, Queensland, Australia (at 27.5°S, 153°E)
- Life span of the buildings: 50 years
- Architectural style: Portal Steel Frame Building
- Number of floors: 1
- Occupancy: 6–10 people
- Surface floor area of the buildings: 25 m × 36 m = 900 m^2
- Building volume for energy embodiment = 7 m × 25 m × 36 m = 6300 m^3

Energy assessment

The basic aim was to determine the savings due to the use of insulated sandwich panels. Therefore, the requirement for indoor air quality (i.e. humidity, air pollution), and day lighting were assumed to be comparable in both types of conventional and new building systems. The net energy used has been estimated based upon the rate of electricity consumption in terms of kWh per annum. Actual life cycle energy assessment of industrial and commercial buildings depends upon several environmental factors. Table 1 summarizes the design parameters (Parlour, 1998) adopted in the estimation of thermal energy consumption. Brisbane meteorological database and cooling and heating factors were used (Walsh and Spencer, 1980), typically as:

- C = 60% constant + 25% dependent on DBs + 15% on WBs
- H = (21-DBw)/13.8
- EFLH = (24 × Degree Days)/(21-DBw) hours per year

The energy requirements for conventional and new industrial building systems under the Brisbane meteorological conditions were calculated. The sizes for openings, external walls, roofs and floors, electrical appliances, ventilation and occupants were considered in the energy calculation. Cooling and heating energies were assessed using the recommended heating and cooling strategies for Australian conditions (Ballinger *et al.*, 1997 and Parlour, 1988). Passive energy strategies typically involve integration of south-facing windows with natural building ventilation, design of solar induced air flow through the building, clear heights for increased daylighting, and use of additional thermal storage to balance diurnal temperature swings. The annual energy consumption was estimated using load factor and floor area of the buildings. The load factor method was used to estimate the annual energy estimate for industrial building. The cooling and heating loads for conventional industrial building were estimated as 60 kW and 55 kW, respectively. The cooling and heating loads for the new industrial building system were estimated as 45 kW and 46 kW, respectively due to the use of sandwich panels (U = 0.25 W/m^2 per °C). Typical estimation for a cooling case of conventional industrial building system is illustrated in Table 2. Details of other calculations are given in Gurung and Mahendran (2000). Charts for typical cooling load factors (Parlour, 1998) for windows, walls, roofs, floors, etc. are presented in Appendix 1. The shaded values were used in the calculations. The SouthWest (SW) direction was selected to maximize the use of solar energy and longer daylight periods.

Table 1 Meteorological design parameters (Parlour, 1998) of Brisbane, Queensland

Parameters	Value
Design summer dry bulb temperature, DBs (°C)	31.9
Design summer wet bulb temperature, WBs (°C)	24.9
Winter dry bulb temperature, DBw (°C)	9.3
Cooling load factor, C	1.1
Heating load factor, H	0.85
Heating degree days (days)	41
Equivalent full load hours, EFLH (hours)	84

Based upon these cooling (60 kW) and heating (55 kW) load requirements and the heating and cooling periods in the Brisbane climate, the annual energy requirements for a conventional industrial building were estimated as 41 706 kWh per annum (see Table 3). Using a standard electricity rate of 11.59 cents/kWh (Commerce and Industry Electricity Prices, 1999), the annual cost at 65% efficiency was estimated as $7437. Similar exercise was repeated for the new building system. Owing to the better quality of the new sandwich panel system, the new building system was optimized based upon thermal insulating characteristics (James Hardie Building Systems, 1999) and the energy requirements for new industrial building was about 18 440 kWh. The annual cost for the new industrial building system was estimated to be $3288 at a standard electricity rate of 11.59 cents/kWh and assuming 65% efficiency. As this analysis was intended to demonstrate the annual energy saving due to the use of the new building system, the annual energy consumption was estimated using these load factors for Brisbane meteorological conditions. The assessment of annual energy costs shows that the new system can save $4149 annually, which means a total saving of $122 217 in 50 years at an interest rate of 7%.

The pattern of energy requirement in the case of commercial buildings can be more sophisticated than that of the industrial buildings due to business activities and other socio-economical interactions. The energy assessment in the case of commercial building system has been calculated using the guidelines on the floor area method (MCPC, 1989). In this method, the annual energy consumption has been estimated based upon the gross floor area (GFA) of 900 m^2. Typical annual energy estimates based upon the requirement for lighting, power and air conditioning for conventional commercial buildings are given in Table 4. For daylight to make a real contribution to energy efficiency, appropriate control of electric lighting is essential (Paul, 1998). Moreover, artificial cooling and heating of the work environment in hotter and cooler weathers are necessary. In the case of commercial buildings, assuming 24 working days in a month and four hotter months in a year, the air conditioning time is estimated as a minimum of 7 hours daily. Similarly, the heating period has been adopted from the Equivalent Full Load Hours (84 for Brisbane region as taken from local Meteorological records, see Table 1) considering the extra commercial business hours. The energy requirements for conventional and new commercial buildings were 84 960

Table 2 Typical thermal energy estimation for the cooling case of conventional industrial building system

Items/Component	Size	Chart used*	Value*	Load, *W*
Openings in sun (2 nos)	2 × 2 m^2	1	1.3 × 213 W/ m^2	2215 W
External wall in sun	36 × 7.5 m^2	2	28 W/ m^2	7560 W
External wall in shade	36 × 7.5 m^2	2	16 W/ m^2	4320 W
Roof	25 × 36 m^2	3	11 W/ m^2	9900 W
Floor	25 × 36 m^2	4	7 W/ m^2	6300 W
Light + appliances	25 × 36 m^2	5	18 W/ m^2	16 200 W
People	6 Nos.	6	220 W/Nos.	1320 W
Ventilation	40 Lps.	7	17 W/Lps.	680 W
Total				48 495 W
Cooling capacity needed for Brisbane = C × 48.495 = 1.1 × 48.495 =				53.35 kW
Including allowances, cooling capacity is 1.1 × 53.35 = 58.7 say 60 kW				

* Note: See selected chart values in Appendix 1 for derivation of value figures.

Table 3 Estimates of annual energy cost for conventional industrial building system using load factor method

Item	Load (kW)	Periods (hours)	Usage (kWh)	Remark
Cooling energy	60	4 × 24 × 7 = 672	60 × 672 = 40 320	4 months of 24 work days 7 hours of usage
Heating energy	55	84	55 × 84 × 0.3 = 1386	Brisbane EFLH = 84 hours 0.3 usage factor
		Total	41 706 kWh	
∴ Cost per annum = 41 706 × $0.1159/0.65 = **$7437**				Assuming 65% efficiency

kWh and 67 896 kWh, respectively (Gurung and Mahendran, 2000). Thus, the annual energy was calculated as $9847 and $7869 for conventional and new commercial buildings, respectively (see Table 4). Using the new building system, annual saving of $1978 can be achieved. Typical cumulative saving in 50 years of life cycle will be $58 266 at an interest rate of 7%.

The design of energy efficient buildings, while maintaining functional equivalency and correct estimation of energy usage is a difficult task. A predicted value of energy consumption is only estimation (say about ±30%) since it depends very much on the way the buildings are managed.

Life cycle costs

Life cycle costing can be employed as a design tool for the comparison of the costs of different designs, materials, components and constructional techniques. Life cycle cost analysis results in an estimated distribution of costs throughout the life cycle of the system. The total cost of constructing, operating, repairing, cleaning and maintaining can be broadly divided in terms of initial capital cost and cost-in-use. Guidelines on LCC techniques, problems, and applications can be found elsewhere (Dhillon, 1989; Flanagan *et al.*, 1989; MCPC, 1989; Seeley, 1996). Application of life cycle costing to the design process requires detail information on site location, alternatives, orientation, building material, shape, size, engineering systems and energy sources, etc. In this section, life cycle costs of the four building systems were evaluated and compared. The building models and environmental design parameters have been described earlier. Material rates were taken from the manufacturers' supplied prices. Cost of steel portal frame fabrication, transportation and erection costs were collected (AS, 1668) for four different types of buildings, which were based upon conventional as well as new building design systems.

Table 5 shows initial cost estimate of industrial building systems. Contingency of 10% of the total manufacturing

Table 4 Estimates of annual energy cost for conventional commercial building system using floor area method

Item	Estimate (W/m^2)	Load (kW)	Periods (hours)	Usage (kWh)	Remark
Lighting	20	0.02 × 900 = 18	2500	18 × 2500 = 45 000	GFA = 900 m^2 for 2500 hours per annum
Power	6	5.4	2500	13 500	for 2500 hours per annum
Air-conditioning	40	36	4 × 24 × 7 = 672	24 192	4 months of 24 work days 7 hours of usage
Heating	20	18	126	2268	Allowance 1.5 × 84 hours
		Total 84 960 kWh			
		∴ Cost per annum = **$9847**			

Table 5 Capital cost estimates of conventional and new industrial buildings

Details	Conventional ($)	Rate/GFA ($/$m^2$)	New ($)	Rate/GFA ($/$m^2$)	Remarks
1. Material supply cost	53 702	59.67	79 814	88.68	Base year
2. Fabrication	19 016	21.13	12 680	14.09	Cost 1999
3. Cost of transportation	4340	4.82	2120	2.36	
4. Cost of erection	12 330	13.70	7890	8.77	
5. Internal finishing	24 000	26.67	24 000	26.67	
6. Fittings/fixtures	4500	5.00	5100	5.67	
7. Sanitary appliances	10 200	11.33	10 200	11.33	
8. Electrical services	31 000	34.44	34 000	37.78	
9. Sub-structure @15%	15 375	17.08	15 375	17.08	
10. Demolition	18 000	20.00	20 000	22.22	
Sub-total	192 463		211 179		
11. Miscellaneous contingencies	19 246		21 118		
Tax (GST) @ 10%	1924.63		2111.79		
Initial capital costs	**211 709**		**232 297**		

Note: Items include labour costs.

cost has been assumed. The initial costs of conventional and new industrial building systems are calculated as $211 709 and $232 297, respectively. The new industrial building system costs about $20 588 more than the conventional building system at the beginning. Similarly, the initial costs of conventional and new commercial building system are estimated as $222 709 and $241 427, respectively (Gurung and Mahendran, 2000). The commercial buildings seem relatively costlier than industrial ones due to the detail requirements such as the greater number of windows and doors, demanding internal finishing and greater external aesthetic requirements. At the initial stage of construction, the new commercial building system costs about $18 718 more than the conventional building system. However, the cost-in-use represents the most intensive phase of the life cycle in industrial and commercial building systems.

To determine the contributions of maintenance and building improvements on life cycle cost, a schedule of activities was created based on a building life of 50 years. In fact, there are several different categories of cost-in-use, but some of them more apparent and some other costs may be irrelevant for the decision process. In this case, the cumulative energy cost due to the operating thermal inputs plays an important role. Annual costs of heating and cooling were taken from the energy calculation. The interval of maintenance activities that are needed to keep the building in good condition (e.g. re-fix, re-paint, repair and maintenance of columns, rafters, purlins, claddings, floor and roof system) were kept the same for both new and conventional building systems. In this preliminary study, the replacement frequencies were simplified as first 20 years and then at the rate of 10 years. Costs for these activities were quantified, and their life cycle values were calculated (see Table 5).

As the life cycle costing method considers the balance between initial and future expenditures by using a series of economic analysis, this method usually incorporates basic discounting and financial appraisal techniques (Johnston and Mak, 2000). Discounting method may be defined as the application of a selected rate of interest to adjust the values of the cost distribution to a common reference point in time. This point is generally the present time when the decisions are to be made. This procedure assures that the alternatives are evaluated on an equivalent basis.

In this research, life cycle costs were calculated using the discounting method. The initial capital cost of conventional industrial building system is $211 709 compared to $232 297 of the new building system. But the total annual operational cost for this conventional industrial building is $11 067 (energy cost of $7437 and cleaning cost of $3630 per annum) whereas the total annual operational cost of the new building system is just about $6918 (energy cost of $3288 and cleaning cost of $3630 per annum). The repair and maintenance periods for the building systems were taken as 20, 30 and 40 years and the cost was assumed to be $30 000 based on the initial capital cost. Table 6 shows typical life cycle costs analysis for a conventional industrial building at 7% discount rate. Figure 5 depicts typical life

Table 6 Life cycle cost illustration (conventional industrial building system at 7%)

Year	Costs Capital	Operation, repair & maintenance				Tax (GST)	Total	PV of $1 @7%	Present value
		Annual	Interim	Residual	Total				
0	211 709	–	–	–	211 709	0	211 709	1	211 709
1		11 067	–	–	11 067	1107	12 174	0.935	11 377
2		11 067	–	–	11 067	1107	12 174	0.873	10 633
. . .		. . .			. . .	. . .	. . .	. . .	. . .
19		11 067	–	–	11 067	1107	12 174	0.277	3366
20		11 067	30 000	–	41 067	4107	45 174	0.258	11 674
21		11 067	–	–	11 067	1107	12 174	0.242	2940
. . .		. . .			. . .	. . .	. . .	. . .	. . .
29		11 067	–	–	11 067	1107	12 174	0.141	1711
30		11 067	30 000	–	41 067	4107	45 174	0.131	5934
31		11 067	–	–	11 067	1107	12 174	0.122	1495
32		11 067	–	–	11 067	1107	12 174	0.115	1397
. . .		. . .			. . .	. . .	. . .	. . .	. . .
39		11 067	–	–	11 067	1107	12 174	0.0715	870
40		11 067	30 000	–	41 067	4107	45 174	0.0667	3017
41		11 067	–	–	11 067	1107	12 174	0.0624	760
. . .		. . .			. . .	. . .	. . .	. . .	. . .
49		11 067	–	–	11 067	1107	12 174	0.036	442
50		11 067	–	–27 000	–15 933	–1593	–17 526	0.034	–595
							Total Net present value = $393 774		

Note: PV – Present value.

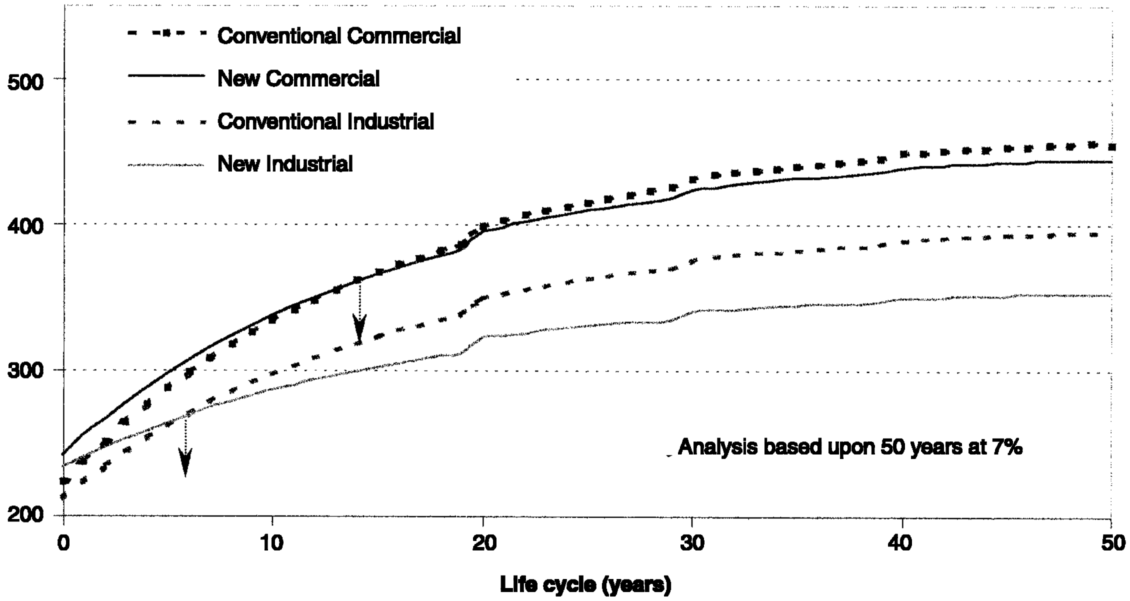

Figure 5 Life cycle costs of building systems at 7% discount rate
Note: Arrows indicate payback period.

cycle costs of the four building systems at 7% discount rate. Figure 5 clearly demonstrates the reduction in life cycle costs for the new building systems. This occurs after 13 years for the commercial building system and 6.5 years for the industrial building systems, referred to as pay back periods.

The forecasting process needs decision on uncertain future events and the numbers of environmental, technical, social and economical factors may influence the cost distribution. A period of 50 years for steel framed buildings may seem long for an economic analysis, given the uncertainties in simulating building energy use. But the life cycle cost analyses for 30 years (Treloar, 2000) to 50 years (Johnston and Mak, 2000) are not uncommon in Australian building cases. Approximate prediction and optimization of life-cycle costs in early design are possible by careful planning, design and choice of materials (Bogenstätter, 2000). The building system for commercial applications is relatively costlier due to the larger number of windows and doors, demanding internal finishing and greater external aesthetic requirements. Economic factors such as interest rate, inflation, and GST affect the profile of cost significantly. In particular, inflation has increased costs of products and services in the past. Such analysis enables an evaluation of the expected effects and the comparison of different designs in an early phase (development/planning). Due to the uncertainties mentioned above, a series of parametric analyses were conducted at different discount rates of 5, 7, 9 and 11% (Gurung and Mahendran, 2000).

Table 7 shows the summary of life cycle cost estimates for conventional and new industrial and commercial building systems. This analysis helps to calculate an approximate life cycle cost in terms of a single sum that is the annual equivalent cost or the present value of all costs over the life of the building. Figure 6 shows the life cycle costs for the building systems at various discount rates.

Despite slightly higher initial costs, the new building system always demonstrates the total economy over a life cycle period. The new design is more efficient than traditional one in terms of life cycle cost. Further optimization of construction method, workmanship and operating styles can be accompanied during the construction and operation.

Conclusions

A new steel portal frame building system for industrial and commercial purposes, incorporating insulated sandwich panels as roof and wall claddings, has been described. The new building system is structurally superior than the conventional system. Moreover, due to the use of thermally insulated sandwich panels, the energy consumption is reduced. Attempt has been made to assess the life cycle costs and energy savings in these building systems. The estimates are included for the total life cycle of 50 years for the buildings. The assessments of the new steel portal frame building system are compared with those of the conventional building system. Life cycle costing is an analytical tool that can be used to identify and measure savings due to the reduced energy use in the building systems.

Life cycle cost assessment helps to evaluate the total costs and net savings among uncertain alternate design systems by using parametric studies. The LCC methodology used in this

Table 7. Summary of life cycle costs

Industrial building			**Life cycle cost at various discount rates**			
Designs	**Capital cost**	**Annual cost**	**5%**	**7%**	**9%**	**11%**
Conventional	211 709	11 067	456 122	393 774	354 180	327 661
New system	232 297	6918	392 940	351 159	324 613	306 892
Difference A$	–20 588	4149	63 182	42 615	29 567	20 769
% saving	–8.9	60.0	16.1	12.1	9.1	6.8
Commercial building			**Life cycle cost at various discount rates**			
Designs	**Capital cost**	**Annual cost**	**5%**	**7%**	**9%**	**11%**
Conventional	222 709	14 347	532 989	454 567	404 736	371 283
New system	241 427	12 370	511 622	443 123	399 550	370 314
Difference A$	–18 718	1977	21 367	11 444	5186	969
% saving	–7.8	16.0	4.2	2.6	1.3	0.3

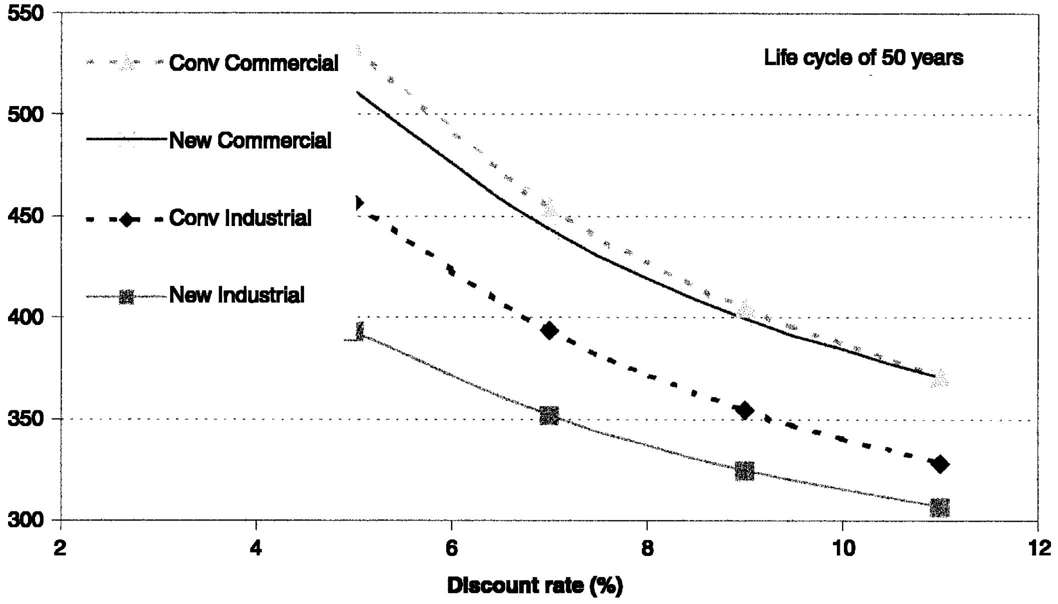

Figure 6 Life cycle costs versus discount rates for various building systems

paper incorporated the basic discounting method. The life cycle cost assessments clearly reveal the life cycle economy in using the insulated sandwich steel panels for roof and wall claddings. The new building system using insulated sandwich panels costs slightly higher initially, but the life cycle costs are always lesser than the conventional system. The new building system, thus, demonstrates a better energy-efficient model for commercial and industrial building design in the Australian climate.

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Appendix 1

Cooling load factors: adopted from load estimates (Parlour, 1998)

Chart 1 Windows

Zone facing	NE	E	SE	S	SW	W	NW	N
W (R) per m^2 value	219	232	179	105	213	260	240	211

Note: For metal frame windows multiply by 1.3.

Chart 2 External walls

Zone facing	NE	E	SE	S	SW	W	NW	N
W (R) per m^2 value	21	21	18	16	28	32	30	27

Chart 3 Roofs

Zone facing	NE	E	SE	S	SW	W	NW	N
W (R) per m^2 value	5	5	1	11	11	11	9	5

Chart 4 Floors

Zone facing	NE	E	SE	S	SW	W	NW	N
W (R) per m^2 value	2	3	2	8	7	7	5	0

Chart 5 Electric lights: commercial buildings

Lighting (fluorescent)	W (R) per m^2 floor area
200 lux illumination	12
300 . . .	18
400 . . .	24

Chart 6 People

Activity	Sensible	Latent	Total value W (R)/person
Sleeping	68	32	100
Sitting	72	58	130
Office Work	82	78	160
Light factory work	86	134	220
Dancing	95	155	250

Chart 7 Ventilation

Zone facing	NE	E	SE	S	SW	W	NW	N
W (R) per L/s	27	18	16	19	17	17	26	17

Positive supply:

General living and sleeping areas	5 L/s per person
Kitchen, bathroom, WC	10 L/s per person