Hospital façades costs comparison: **Façade configuration costs and their influence on the healing environment and staff satisfaction**

Quantifiable benefits of façade configurations that either reduce length of stay or provide staff satisfaction are not necessarily considered in the funding models for healthcare facilities. This paper attempts to address this gap

Alexander Symes BArch, RAIA

During recent years, the importance of natural light as a design parameter to aid the healing environment has slipped down the design hierarchy for hospital façades. This can be attributed to a combination of: advancements in medical technology; an increased awareness of anthropogenic global warming and the resulting impetus to reduce energy use; and the typically increased capital costs of glazed façades compared with non-glazed.

In Australia, and potentially other regions in the world, this has created a perceived disconnect between the implementation of reducing operational costs for perimeter zones of healthcare facilities and the implementation of building envelopes that can benefit the healing environment.

The subject of windows' positive effect on the healing environment has been prevalent in design studies for the last four decades. The aim of this study is to consider the design of windows from a holistic perspective, to provide designers, operators and developers an understanding of the differences in various façade configurations and their respective capital costs, operational costs, and the potential benefits in reduced length of stay for patients and increased staff satisfaction.

Methods

In Australia, the percentage of windows to wall (windows-to-wall ratio – WWR), thermal transmission (U-value) and solar performance (shading co-efficient) are all subject to minimum legislative requirements, as defined by Section J of the National Construction Code (NCC). Eight typical façade configurations that comply with these minimum requirements have been developed for contrast.

As a comparison of window arrangements, this study will consider the following terms:

U-value: In simple terms, the U-value is the measure of thermal transmission of heat through a material. Typically, the denser the material, the easier it transfers heat; for example, aluminium transfers heat very efficiently, glass reasonably well, and polystyrene not very well. A high U-value means that the heat is transferred quicker than by a material with a low U-value. A single piece of glass, for example, may have a U-value of 6, compared with an insulated glass unit (glass-air-glass), which may have a U-value of 1.65; meanwhile, a typical solid façade could have a U-value of 0.36. For the purposes of this study, all configurations are assumed to include non-glazed thermal performances consistent with each other. Changing the WWR rather than the U-value of the glass is more influential on the overall thermal transmission of the façade.

Effective shading co-efficient of facade: An effective shading co-efficient is the total shading provided by a façade. The variables are WWR, external shading and the solar performance of the glass. This last variable is referred to as a solar heat-gain co-efficient (SHGC) and is a measurement of the percentage of solar gains that a type of glass transmits. High-SHGC glass allows more solar radiation through it than low-SHGC glass; for example, a glass with a SHGC of 0.6 allows twice as much solar radiation through it than a glass with a SHGC of 0.3.

Visual light transmittance: This is the percentage of visible light transmitted (VLT) through a piece of glass. A high VLT (for example, 70%) will allow a high percentage

Figure 1: Schotten District Hospital, Germany, by woernerundpartner

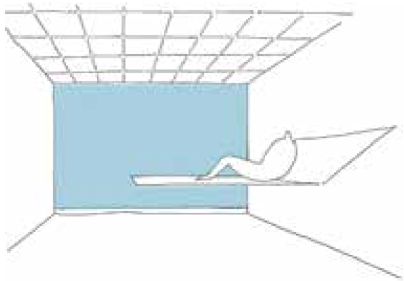
of light to be transmitted through the glass and, thus, allow a higher level of illumination from daylight to the inside space for the same area and location of window.

Room type: A single-bed arrangement has been chosen for this study based on several design studies, including: Davidson (1971);[1] Gardner (1973);[2] Kim (1987);[3] Pegues (1993);[4] Firestone (1980);[5] and Janssen (2000).[6] These demonstrate that the healing environment is improved by the provision of single rooms, which not only offer the highest levels of privacy and dignity but also reduce medical error and lower the rates of transmission of infection.

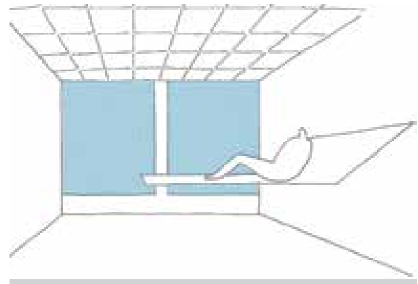
An argument against single rooms is socialisation; however, the single-bedroom layout proposed could be adapted to two-bedroom wards by the omission of a dividing wall.

Floor-to-floor height: The current design practice, based on a directive from our clients, is to design floor-to-floor heights of 4.5m. This includes a 2.7m ceiling height and 0.3m structural zone, which allows for a 1.5m services zone. This services zone is larger than required to house typical services; the rationale for this over-design being future flexibility of moving units within the healthcare facilities themselves and anticipating any future technologies that may be incorporated. This will have an impact on the WWR dependent on a floor-to-floor height of 4.5m, 4.2m or 3.6m, which will alter the façade costs. As glazing is typically more expensive than solid façade, the cost comparisons are lower for the 4.5m option as opposed to the 3.6m option. A sensitivity analysis has been conducted on the cost differences, which determines that the percentage difference between options is minimal (0.4%) and is inconsequential when comparing options; therefore, the current design trend of 4.5m floor to floor has been assumed.

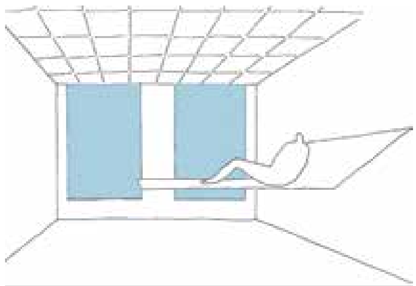
Façade configurations: The following façade configurations have been selected as representative of typical options that meet the requirements of section J. Options 1-4 are flat facades with varying WWR of 100% to 40%; options 5-8 are the same as options 1-4 with the addition of an external horizontal sunshade. Each option was tested for performance of daylight and glare on the north, east, south and west elevations. Vertical sunshades or internal



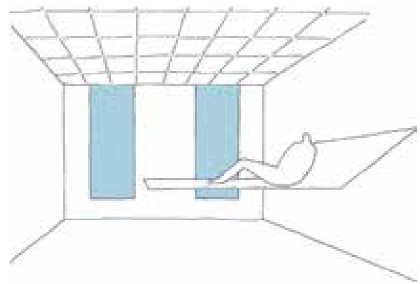
Option 1: 100% WWR with no external shading



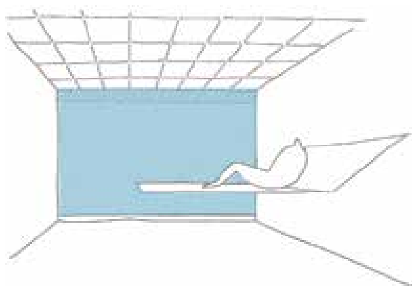
Option 2: 80% WWR with no external shading



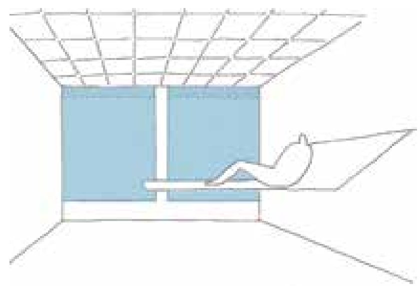
Option 3: 60% WWR with no external shading



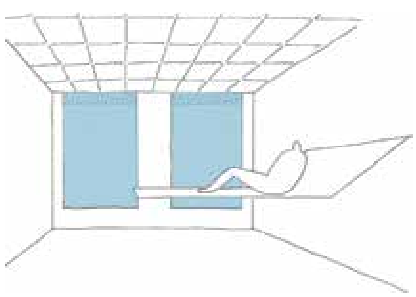
Option 4: 40% WWR with no external shading



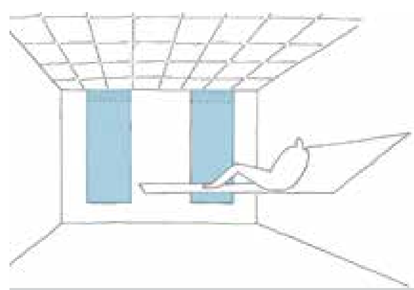
Option 5: 100% WWR with external horizontal shading



Option 6: 80% WWR with external horizontal shading



Option 7: 60% WWR with external horizontal shading



Option 8: 40% WWR with external horizontal shading

Table 1: Internal view configurations

blinds have not been included in this study as they are not recognised by the deemed-to-satisfy provisions of Section J.

From the perspective of the patient, the configurations look like the depictions shown in table 1 (previous page).

Façade capital costs: Based on feedback from façade sub-contractors in the market for Sydney, Australia, the capital costs of supplying and installing the façades have been approximated, so as to compare the likely cost differences between options. The façades compared are not exhaustive and have been chosen for their economy and durability. For ease of comparison, they have also been simplified to the following:

- windows: fixed aluminium-framed glazing with double-glazed unit glass;
- solid façades: composite aluminium-panel rain screen fixed to a steel frame with aluminium waterproofing and air-seal sheet, with insulation and internal plasterboard finish;
- sunshades: 600mm aluminium-framed horizontal sunshade. The sunshade is capable of taking abseil loading;

Façade operational costs – external maintenance: These costs were generated based on abseiling hourly rates for glass cleaning, solid façade cleaning, and sunshades based on a cleaning cycle of three times a year.

Façade operational costs – internal maintenance: These were generated based on rates for glass cleaning and internal wall surfaces (m^2) based on a cleaning cycle of 52 times a year.

Façade operational costs – Heating, ventilation and air conditioning: Owing to basing the façade configurations on minimum compliance with Section J – deemed-to-satisfy requirements, the operational energy of HVAC systems has been assumed as a constant.

Façade operational costs – Artificial lighting: Unless artificial lighting is controlled by individual users and is linked to a daylight dimming scheme, operating cost savings resulting from improved daylight access will not be generated. As the current approach in the Australian market is for ward lighting to be controlled from the nurses' station, this variable has been excluded from calculations at this time.

In relation to hospital operational costs, an average cost per bed of AU $4500 a day has been assumed,[7] along with an average staff cost of AU $350 per day. These have been loosely based on figures derived from annual reports,[8] but further clarification of these numbers is necessary for the substantiation of this paper.

Daylight modelling: This was conducted based on the protocol of the Green Building Council of Australia's healthcare daylight credit, using radiance software. This prescribes the modelling of a "uniform sky", which assumes the worst-case daylight condition of a fully overcast sky but does not take into account absolute availability of annual daylight for particular façade orientations. It is anticipated that future revisions of this study embrace a climate-based approach using a representative weather file to compare the variance in results between orientations.

Glare analysis: This was conducted using a methodology referred to as daylight glare probability developed by Wienold et al.[9] This methodology, which uses a climate-based approach with a representative climate file, has been shown to yield a much better correlation with actual user responses in two independent tests compared with previously developed methodologies, such as daylight glare index, visual comfort probability, unified glare rating, and the International Commission on Illumination's CIE glare index.

Literature review: Based on a literature review of evidence-based design studies that focused on quantifying either differences in patients' length of stay, condition and medication, or on quantifying staff satisfaction in relation to the impact design variables that can be influenced by façade design, the following summaries were used to test the façade configurations against. Using the methodology developed by Ulrich et al (2004)[10] for assessing "rigour, quality of research design, sample sizes and degree of control", each paper was assigned a grading, shown in brackets after each summary, so that the results of the papers receiving an (A) grade are deemed to have a higher weighting than those papers scoring a (C) grade.

- Wilson, LM (1972): Delirium in an ICU was 40% for windowless, as opposed to 18% with a window, (B);[11]
- Ulrich (1984): Patients with the window view of nature (trees) had shorter post-operative stays, took fewer potent pain drugs, and received more favourable comment about their conditions in nurses' notes, (A-);[12]
- Verderber (1986): Preference for views of nature, desire for control, preference for low sill heights, (B);[13]
- Verderber (1987): Patients were more negatively affected by 'poorly windowed' rooms, (B);[14]
- Ulrich (1991): Recovery from stress was faster and more complete when persons were exposed to natural rather than urban environments, (A);[15]
- Beauchemin, K (1996): Patients in sunny rooms in a psychiatric inpatient unit had an average length of stay of 16.9 days compared with 19.5 days for those in dull rooms – a difference of 2.6 days, (15%); (B);[16]
- Leather, P Pyrgas (1998): Sunlight penetration increased job satisfaction, reduced intention to quit, and improved general wellbeing. View of nature reduced job stress and intention to quit,

Table 2: Factors used for costing

Inpatients' length of stay

A DF >2.5% for 0% = no change in length of stay; a DF >2.5% for 60% = 20% reduced length of stay. As overnight stays for acute inpatients represent only 12% of patients,[23] this figure has again been reduced to 2.4%.

Staff productivity

A DF >2.5% for 0% = zero increase in productivity; DF >2.5% for 60% = 2% increase in productivity.

Staff absenteeism

A DF >2.5% for 0% = no change in absenteeism; a DF >2.5% for 60% = 0.5% reduction in absenteeism.

For simplification, these staff metrics have been combined to estimate staff satisfaction.

and increased general wellbeing, (B);[17]

- Eastman, C I (1998): Remissions of SAD – 61% morning, 50% evening, 32% placebo – were observed, (A);[18]
- Friberg, TR, and Borrerg, G (2000): Diminished perception of ambient light was observed as higher in severely depressed patients – 66% severely, 21% moderately, 14% mildly, (B);[19]
- Jana, M (2005): Of hospital design features as rated by staff, increased natural light ranked highest as being "very positive" for 43% of staff and received no negative feedback, (B);[20]
- Choi, Joon-Ho: (2011): An improvement of 16-31% in average length of stay between a higher illuminance ratio based on a window-to-wall ratio of 20%, a window-to-room ratio of 36%, and a VLT of 50.2%, (A-);[21]
- Browning (2012): Staff productivity has been shown to increase by as much as 6-15% with the inclusion of biophilic design. Because this study only looks at daylight factor (DF), a 2% productivity increase, from 0% to 60%DF has been extrapolated, (C);[7] and
- Browning (2012): Absenteeism and presenteeism account for up to 4.4% of staff costs. Studies have shown a 10-25% reduction owing to biophilic design, while a 10% reduction can be attributed to the building design only. A 0.5% reduction in absenteeism and presenteeism has therfore been extrapolated, (C).[7]

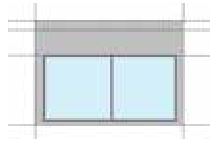
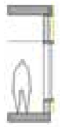
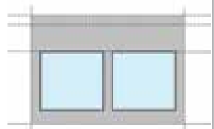
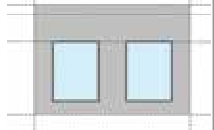
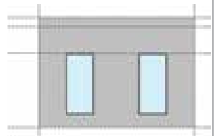
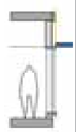
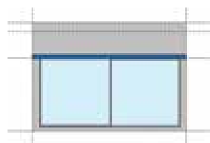
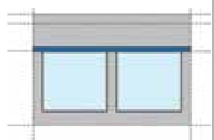
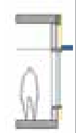
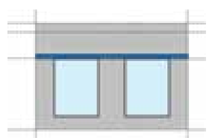
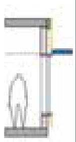
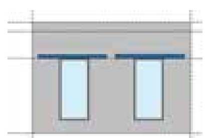
The only paper that measured length of stay proportional to variances in window performance is that authored by Joon-Ho Choi.[21] The only paper that cited an increase in staff productivity is that by Browning.[7]

These papers, however, are consistent with the results of the other papers referred to above. To make the calculations conservative, the reduced length-of-stay factors and staff-satisfaction assumptions (see table 2) have therefore been based on a conservative interpretation of the literature review.

Results

Values for achievable visual light transmission (VLT) under the section J requirements of the NCC are shown in table 3. The windows-to-wall ratio (WWR) and shading configuration result in a maximum allowable solar heat-gain co-efficient (SHGC) as per the section J deem-

Table 3: Section J and visual light transmittance (VLT) results

	Section	Elevation	Section J	Glass VLT %	WWR External	WWR Internal	Glaz m²	Solid m²
1			N = 0.23 SHGC E = 0.23 SHGC S = 0.45 SHGC W = 0.25 SHGC	N = 42 E = 42 S = 70 W = 45	48%	96% ≈100%	20.5	22.2
2			N = 0.28 SHGC E = 0.3 SHGC S = 0.5 SHGC W = 0.34 SHGC	N = 53 E = 57 S = 70 W = 57	40%	80%	17.0	25.7
3			N = 0.36 SHGC E = 0.4 SHGC S = 0.5 SHGC W = 0.47 SHGC	N = 63 E = 70 S = 70 W = 70	30%	60%	12.8	29.9
4			N = 0.53 SHGC E = 0.6 SHGC S = 0.6 SHGC W = 0.6 SHGC	N = 70 E = 70 S = 70 W = 70	20%	40%	8.5	32.2
5			N = 0.3 SHGC E = 0.28 SHGC S = 0.65 SHGC W = 0.31 SHGC	N = 57 E = 53 S = 70 W = 57	48%	96% ≈100%	20.5	22.2
6			N = 0.38 SHGC E = 0.37 SHGC S = 0.65 SHGC W = 0.41 SHGC	N = 63 E = 63 S = 70 W = 70	40%	80%	17.0	25.7
7			N = 0.49 SHGC E = 0.49 SHGC S = 0.65 SHGC W = 0.58 SHGC	N = 70 E = 70 S = 70 W = 70	30%	60%	12.8	29.9
8			N = 0.65 SHGC E = 0.65 SHGC S = 0.65 SHGC W = 0.65 SHGC	N = 70 E = 70 S = 70 W = 70	20%	40%	8.5	32.2

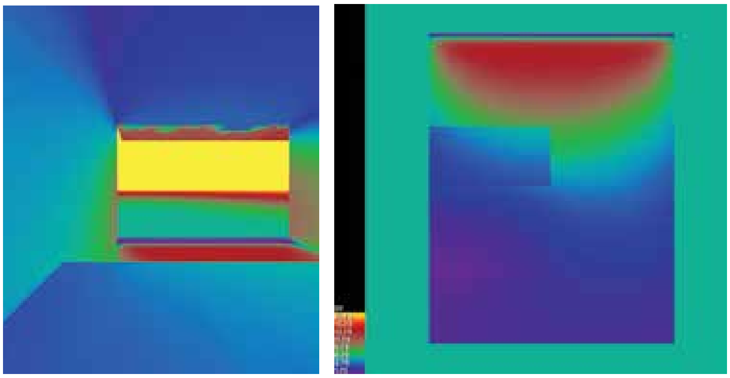


Figure 2: Daylight simulation results for option 5 (north); left: view from bed; right: plan

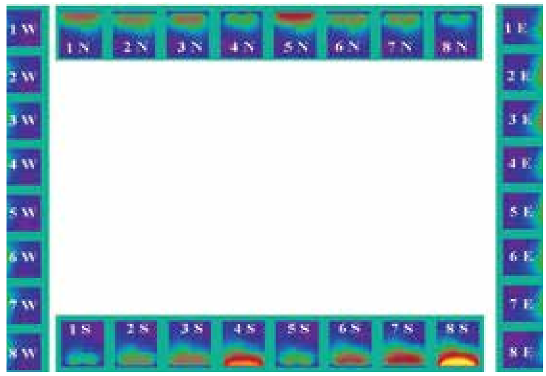


Figure 3: Daylight simulation results

to-satisfy calculator. SHGC values have been used to determine the VLT for each option by identifying commercially available glass products that achieve the SHGC at optimal transparency. Typically, the larger the WWR the lower the SHGC and VLT; for example, this results in a VLT of 48% for option 1 (north) compared with 70% for option 4 (north). The addition of a sunshade to option 5 (north) increases the allowable VLT from 42% to 57%.

Table 3 also includes the WWR (external), which is used to calculate external façade cleaning costs and capital costs, as opposed to WWR (internal), which is indicative of the patient experience of the façade and is used to calculate internal maintenance costs.

Daylight

On average, option 2 achieves the largest area of good daylight availability (DF >2.5%) of all options. The only orientation for which it does not achieve the highest daylight availability is to the south, where option 1 achieves a higher DF owing to the larger WWR and the same VLT.

Glare

The glare analysis identifies four categories of glare experience based on the daylight glare-probability methodology for each hour of the year; these categories are 'imperceptible', 'perceptible', 'disturbing' and 'intolerable'[9] (see figure 4). When comparing the options on their time percentage of 'intolerable' glare, the results show that, with the exception of option 4, the worst-performing configurations are options 1-6. The least amount of glare is received by option 8.

Results isolated for 21 June highlight that the glare peaks above the desired limit at around 8am and doesn't fall below this threshold until after 1pm. This is caused by the lower sun during the Australian winter. Between these times, the patient would need to shift their gaze away from the window, or close the blinds. As illustrated in figure 5, similar glare events (indicated by the red sections) would occur from May through to August.

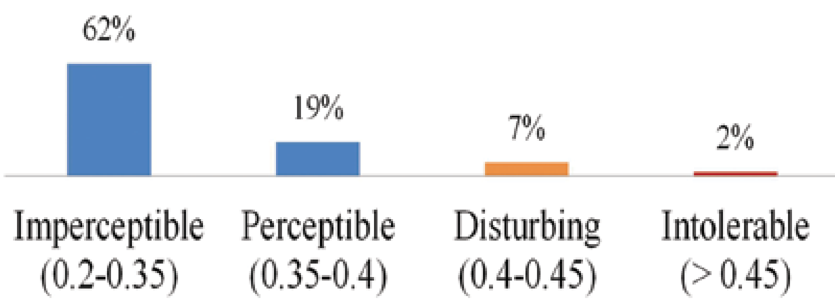


Figure 4: Example of annual glare-analysis legend

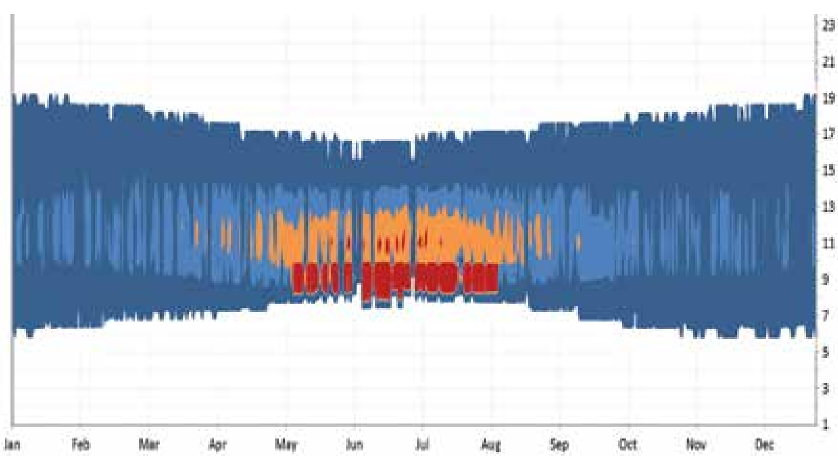
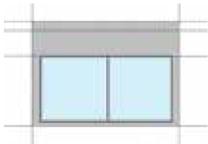
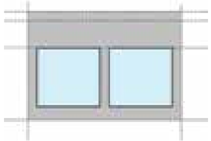
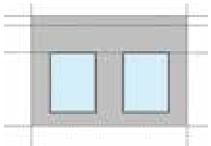
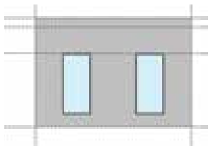
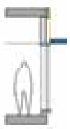
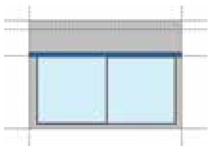
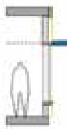
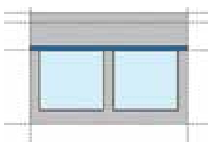
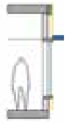
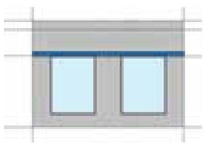
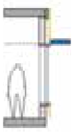
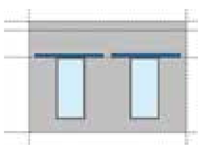


Figure 5: Annual glare analysis for option 7 (north)

Capital costs comparison

Table 4 illustrates that, owing to the typically increased façade costs of glazed windows compared with non-glazed facades, the options with a higher WWR are more expensive than those with a lower WWR. In all cases, the addition of a sunshade make the capital costs of options 5-8 more expensive than the corresponding options without sunshades.

Table 4: Capital and operational costs; daylight factor; glare-hour results; and life-cycle costing for reduced length of stay and staff satisfaction
Percentages for daylight reflect the percentage of floor area that achieves a DF > 2.5%; the glare-hours percentage refers to the percentage of hours during which either disturbing or intolerable glare events occur.

	Section	Elevation	Capital	Operational cleaning (40yr)	Daylight %	Glare hours %	Length of stay – payback in years	Staff satisfaction – payback in years
1			$646/m^2$	$3895/m^2$	N = 48.8 E = 48.6 S = 64.7 W = 50.8 A = 53	N = 12.4 E = 8.2 S = 1.1 W = 18.5 A= 10	N = 0.97 E = 0.97 S = 0.77 W = 0.97 A = 0.91	N = 13.22 E = 13.18 S = 10.53 W = 12.8 A = 12.43
2			$605/m^2$	$3462/m^2$	N = 53.9 E = 56.0 S = 62.7 W = 55.9 A = 55	N = 16.4 E = 11.6 S = 0.2 W = 21.6 A = 12	N = 0.64 E = 0.62 S = 0.56 W = 0.62 A = 0.61	N = 8.71 E = 8.44 S = 7.65 W = 8.45 A = 8.31
3			$601/m^2$	$2951/m^2$	N = 51.4 E = 54.5 S = 54.6 W = 54.5 A = 53	N = 13.9 E = 9.9 S = 0 W = 20.6 A = 11	N = 0.33 E = 0.33 S = 0.32 W = 0.32 A = 0.33	N = 4.48 E = 4.44 S = 4.43 W = 4.43 A = 4.44
4			$591/m^2$	$2412/m^2$	N = 40.8 E = 40.5 S = 40.7 W = 40.7 A = 42	N = 7.7 E = 3.9 S = 0 W = 9.6 A = 5	Benchmark	Benchmark
5			$757/m^2$	$3941/m^2$	N = 49.4 E = 47.3 S = 56.3 W = 49.5 A = 53	N = 12.8 E = 8.1 S = 0.2 W = 16.5 A = 9	N = 1.01 E = 1.04 S = 0.92 W = 1.01 A = 0.99	N = 13.75 E = 14.19 S = 12.56 W = 13.73 A = 13.56
6			$716/m^2$	$3508/m^2$	N = 50.3 E = 50.4 S = 53.6 W = 53.8 A = 53	N = 13.4 E = 10.2 S = 0 W = 21.2 A = 11	N = 0.75 E = 0.72 S = 0.71 W = 0.71 A = 0.72	N = 10.2 E = 9.84 S = 9.7 W = 9.72 A = 9.87
7			$712/m^2$	$2996/m^2$	N = 45.5 E = 45.5 S = 45.5 W = 45.5 A = 48	N = 9.5 E = 6.6 S = 0 W = 12.9 A = 7	N = 0.46 E = 0.46 S = 0.46 W = 0.46 A = 0.46	N = 6.29 E = 6.3 S = 6.3 W = 6.29 A = 6.29
8			$690/m^2$	$2458/m^2$	N = 30.1 E = 29.8 S = 30.1 W = 30.2 A = 36	N = 2.3 E = 3 S = 0 W = 4.9 A = 3	N = 0.13 E = 0.13 S = 0.13 W = 0.13 A = 0.13	N = 1.72 E = 1.72 S = 1.72 W = 1.72 A = 1.72

Operational costs comparison

Table 4 also shows the operational costs associated with façade maintenance. It illustrates that maintenance costs for both the external and internal finishes are less expensive when there are fewer external façade elements and a smaller WWR. The least operational cost is option 4 and the most expensive is option 5.

Discussion

The final two columns of table 4 also demonstrate that, owing to the operational costs required to service a bed in a hospital, the design variables of increased WWR or the addition of adding a sunshade are easily offset within a year from the lowest cost benchmark (option 4). The operating cost per bed includes the cost associated with staff. If, however, only staff-satisfaction factors are considered, the final column (staff-satisfaction payback) shows that the cost of installing an additional sunshade (comparing options 4 and 8) is paid back within two years.

The appropriateness of design studies that demonstrate benefits to the healing environment has been questioned, as clinical treatment has developed and overnight stays at hospitals have become less frequent. But these financial models assume that overnight stays only account for 12% of all patients[22] and, even if the length-of-stay benefits were factored down a further 500%, the payback for a design such as option 5 compared with the benchmark option 4 would still only be five years.

The question is: how do we procure and operate healthcare facilities to take advantage of considered design that delivers life-cycle costing benefits and a more positive outcome for both patients and staff? The results from this study firmly suggest that reducing the capital cost of façades is not within the life-cycle costing benefit of a hospital if the funding model for health delivery is payment to the service provider per treatment, as opposed to length of stay.

Next steps

This study is by no means definitive and there are many assumptions that must be confirmed around operational pricing for hospitals. The daylight methodology should be updated to be climate-based, as opposed to a uniform sky, as this will produce results that are differentiated more by orientation.

This study has been simplified to basic design options for clarity purposes. More complex design variables that could increase the performance and amenity of hospital designs should therefore also be tested in future iterations. Such additions include: incorporating daylight dimming into the capital and operational costs to take advantage of reduced energy use via artificial lighting; thermal modelling of the various configurations; and their impact on capital and operational costs of mechanical systems. The variable of mixed-mode ventilation with an electrical switch on the window linked to the mechanical system, should also be incorporated into this scenario.

Further issues to consider include: use of vertical sunshades; view quality of urban versus natural elements; comparison of the capital and operational costs associated with use of curtains, interstitial blinds within a jockey-sash, and operable interstitial blinds; how the colour of glass influences the healing environment; and the benefits of designing operating theatres that have access to daylight.

Acknowledgements

The author wishes to acknowledge the following individuals: Haico Schepers, Jorg Kramer, Peter Hartigan, Katie Wood, Phil Nedin, Christoph Gruenaug, Ayrley McDougall, Phil Guthrie, Peter Romeos, Claire Moore and Tania Milinkovich – all of Arup; and Matt Hartley of Empire Glass, Jeanine Zhang of China Southern Glass Australia, Elizabeth Goodal, and Julian Ashton of BVN Donovan Hill.

Author

Alexander Symes is a registered architect who also works for Arup in its building-envelope team.

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