Power Play

Embodied Energy in Singapore's Tall Building Facades

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Enlarging the dialogue on tropical high-rises further, *Chris Vickery* presents an analysis of the tall buildings in the Shenton Way / Marina Bay areas and urges a closer look at the embodied energy profiles of their building elements.

The tall building occupies a particular niche in the sustainability debate, with some commentators such as Fowler (2008) arguing that high-rise buildings are inherently unsustainable. However, this discussion is not concerned with arguments for and against the tall building, and we turn our attention instead to the question merely of what is a tall building? Crompton (2004, Section 1.2) suggests that the definition of a tall building is relative to the height of surrounding buildings. Crompton proposes that: "If the majority of buildings in a city are 3 or 4 storeys, then a 12-storey building would be considered tall. In locations such as New York or Hong Kong, a tall building is 40 plus storeys high." On this basis, a tall building in Singapore should follow the Hong Kong/ New York model, of around 40 storeys high. Into this category would fit a significant portion of Singapore's downtown commercial buildings.

Historical insights into the development of the tall building provide a pertinent preface to the discussion. Oldfield et al (2009) stream the high-rise typology over the past one hundred and twenty years into five distinct generations as shown in Table 1.

The picture painted by Oldfield et al is that the generations of tall buildings are marked by increasing levels of operational energy demands and increasing surface area to volume ratios. By the time of the 4th generation, however, facade U-values improve, artificial lighting levels decrease, the efficiency of mechanical systems improve and, by the 5th generation, the buildings begin to employ strategies directed at increased sustainability, thus reducing operational energy demands. Thus, it is apparent that each successive generation of tall building exhibits its own characteristic energy signature.

GENERATION	DESCRIPTION	KEY ATTRIBUTES
1st	From the birth of tall buildings in 1885, to the 1916 Zoning Law	• Natural ventilation • Low artificial lighting levels • Windows occupy 20%–40% of facade • External walls—masonry • Small envelope surface areas
2nd	From the 1916 Zoning Law to the development of the glazed curtain wall, 1951	• Increased artificial lighting levels • Some air-conditioning • Traditional facade materials (masonry) • 20%–40% glazing • Good daylight penetration at slimmer high floors
3rd	From the development of the glazed curtain wall, 1951, to the 1973 energy crisis	• 50%–75% glazing (single glazing) • Poor facade U-value • Reduced surface area to volume ratios • Deep plans—poor daylight penetration • Generally air-conditioned • Increased artificial lighting standards
4th	From the 1973 energy crisis to the present day	• Double-glazing common • Improved facade U-values • Reduced artificial lighting levels • Increased internal heat loads due to electrical office equipment
5th	From the rise of environmental consciousness (1997) to the present day	• High surface area to volume ratios • Strategies reducing reliance on air-conditioning and artificial lighting • On-site energy production

Table 1 Oldfield et al (2009) Five Generations of Tall Buildings

The Tall Building in Singapore
Oldfield et al's analysis starts in 1885. The advent of the tall commercial building in Singapore was a more recent 1954, with the completion of the Asia Insurance Building in Finlayson Green. The building was designed by Ng Keng Siang, described by Edwards & Keys (1988, p. 428) as "... one of the more prominent of the group of early overseas graduates who returned to Singapore when the influence of the Modern Movement was beginning to be felt... In the final run, his main contribution was not to advance the cause of modern architecture but rather to demonstrate that local architects were quite as competent as those from abroad. Apparently, Ng was always well dressed in bow-tie, fedora, full suit..." Ng demonstrates his competence, or at least his climatic comprehension, by his application of generous sun-shading above the windows, a lesson perhaps from his fedora.

The Asia Insurance Building could probably be classified as a 2nd generation tall building. However, also completed in 1954, 300 metres distant from The Asia Insurance Building, is the Bank of China Building in Battery Road. Designed by Palmer and Turner, the Bank of China Building is noted as being "... Singapore's 1st building to be centrally air-conditioned" (Edwards & Keys, 1988, p. 416). With this, the Bank of China Building may well take its place as Singapore's first 3rd generation building.

The Asia Insurance Building and the Bank of China Building stood for many years as the tallest commercial buildings in Singapore. However, they have long since surrendered this distinction (Figure 1).

Figure 1: Asia Insurance Building (to the left of NTUC Building)

The buildings constructed in what may conveniently be referred to as "the Shenton Way corridor," an area that includes Shenton Way, Anson, and Robinson Roads, Cecil Street, and the area bounded by Church, George, and Chulia Streets, were originally generally in the 3rd generation mould. Construction of buildings along this development corridor have continued until the present day, although in the past decade, the lack of further vacant sites has resulted in a small amount of refurbishment, as with the Asia Insurance Building, converted in 2008 into a high-end service apartment block. But more generally the process has been one of demolition and replacement. As a result, the developments along the Shenton Way corridor span the 2nd to 4th generation of tall buildings, with some buildings now beginning to address the ethos embodied in the 5th generation (Figure 2).

CPF BUILDING
Completed: 1976
Re-clad: 1976
Architect:
Public Works
Department

CAPITAL TOWER
Completed: 2000
Architect:
RSP Architects,
Planners &
Engineers

DBS TOWER 1
Completed: 1975
Architect:
Architects Team 3

DBS TOWER 1
Completed: 1975
Architect:
Architects Team 3

UIC BUILDING
Completed: 1973
Architect:
Singapore
Associate Architects

Figure 2: The Shenton Way corridor showing typical buildings. (Photo: Architects Team 3)

In the 1980s, in an area to the east of the Singapore River, known as Marina Centre, and in the new millennium, in an area to the west of the river, known as Marina Bay, arose two new interesting development areas, both centred on tracts of newly reclaimed land. The interesting feature of these new areas is that whereas the buildings of the Shenton Way corridor parade practically the whole development of Singapore's post-war architectural thinking, the architectures of Marina Centre and Marina Bay stand, by contrast, as architectural time capsules representative of Singaporean styles of two very short but distinct periods.

The architecture of the Marina Centre area is dominated by stone-clad buildings, albeit of a more contemporary manifestation than might usually be conjured by that description. The fenestration is generally of the small perforate or ribbon type. The amount of curtain walling and aluminium cladding is modest. Glazing ratios of about 40 percent appear to be the norm (Figure 3).

Figure 3. Marina Centre

In a sharp departure from this pattern, the buildings in the Marina Bay, dating approximately from the turn of the millennium onwards, are clad almost entirely in curtain walling (Figure 4).

Figure 4. Glazed buildings around Marina Bay

That the Marina Bay buildings are knocking at the doors of Oldfield et al's (2009) 5th generation of tall buildings there can be no doubt. They have been constructed in Singapore in an age where compliance with statutory sustainable design requirements is mandatory. However, Singapore's Green Mark Scheme, has—despite revisions that have given greater weight to passive issues—still not moved its assessment criteria significantly beyond the business of measuring energy consumption. Its criteria are quantitative and technological in nature. Further, the criteria they choose to quantify, chiefly energy consumption, may be the easiest to quantify, but they might not be the most useful. As Dalton & John (2008, p. 4) have suggested, assessment standards might be more appropriately based on carbon emission levels than on mere energy consumption alone.

Embodied Energy

Similarly, there is the matter of embodied energy, or embodied carbon. In a narrow view of sustainability in the built environment, consideration might fall merely to the energy consumed in the operation of a building. A broader view could encompass in addition the energy consumed in the production of its construction materials, in their transport to site, the resources used in its construction, the energy demands that the building location will place on future users in travelling to and from the building, the energy the building will consume in operation, the resources consumed in implementing adaptations during the building lifespan, and finally, the recycle-ability of the building materials at the end of its life. Such a "holistic approach" is discussed by Crompton & Wilson (2004, para 1.3): "A sustainable building is one in which the design team have struck a balance between environmental, economic and social issues at all stages—design, construction, operation and change of use / end of life."

Rawlinson & Weight (2007, p. 88) offer another perspective on the holistic approach:

"Most sustainability regulations focus on the reduction of CO_2 emissions, and on the operation, rather than on the formation of the buildings. This approach, currently emphasised by Part L of the Building Regulations, adheres to the perception that more energy is consumed by running assets than in constructing them. In contrast, when cost is considered, attention is generally focussed on capital, rather than life-cycle costs."

"In the same way that operating and maintenance costs need detailed consideration, it is important that both the day-one carbon impact of a project and the effects of maintenance, refurbishment, and even disposal, should be understood and mitigated."

The "day-one carbon impact" refers to the energy entombed in a development by the processes of its creation. This would include, for example, the energy expended in extracting the raw materials from their source, in processing them into building materials, in transporting them to the development site, and in erecting the development on the site. The sum of the energy expended in all these processes is known as embodied energy. But it does not stop at day one.

As Rawlinson & Weight note,

"The embodied carbon emissions of a building are from the CO_2 produced during the manufacture of materials, their transport and assembly on site, maintenance and replacement, disassembly and decomposition."

Again, this escapes the ambit of the Green Mark Scheme. With the paucity of available data that relates specifically to Singapore, it could not be otherwise. However, that does not prevent us from making reasoned speculation about what some of the particular issues might be in the Singapore context.

Energy Embodied in Facades

A study by Treloar et al (2001) provides an interesting point of departure. It examined a number of buildings of different heights. Embodied energy coefficients were established for key materials. The quantities of each of those materials were established. The product of the energy coefficients and the quantities for each material, divided by the gross floor area (GFA) of each of the buildings studied, reduced the indices derived to a common base which were then directly comparable, and showed that high buildings contained 60 percent more embodied energy than low buildings.

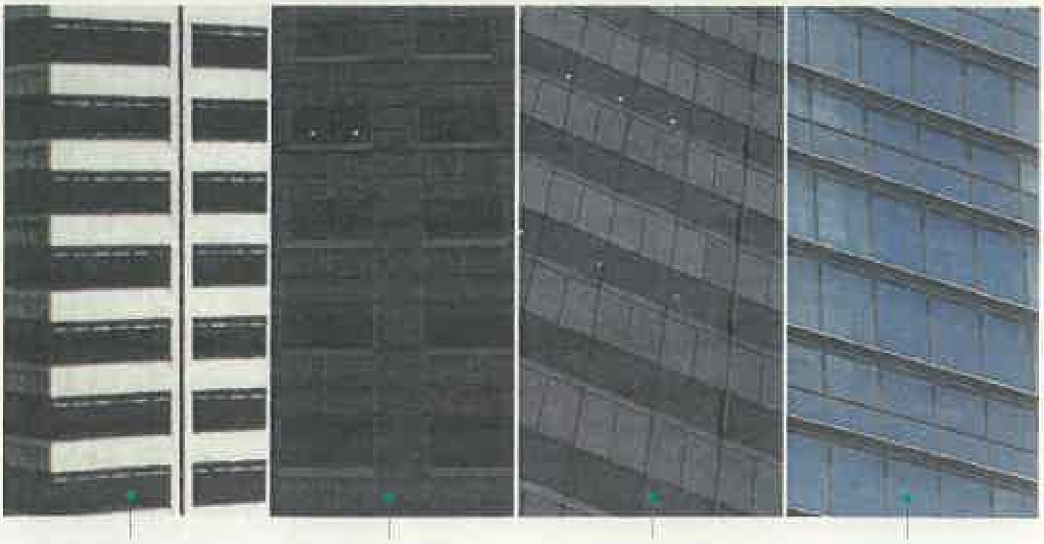
The study then analysed the embodied energy of the buildings on an elemental basis. It found that the energy embodied in a structural group of elements in a building, such as columns and beams, varied with the building height: the higher the building, the higher the energy embodied. On the other hand, elements such as windows, roof, and finishes, per unit of gross floor area, were found to embody amounts of energy that did not vary with building height.

In terms of our Marina Bay glazed structures, these findings give pause for thought. They suggest that the amount of energy embodied in the curtain walling is inherent only in the nature of the glass itself, and is not influenced by the height of the building.

But height is not the only issue. The extent to which the selection of alternative cladding systems will affect the level of energy embodied in these buildings is also interesting.

In the UK, data regarding the energy embodied in building materials are available in an inventory of carbon and energy (Hammond & Jones, 2011). The inventory, (ICE), provides both embodied energy and embodied carbon coefficients for building materials in use in the UK. The latter qualification is important. There are obvious differences between building materials used in Singapore and those in the UK. For example, although a material used in the two countries might be identical, in each case the potential for a difference in their respective transport energy amounts cannot be discounted.

Assume however that the UK data are, broadly speaking, applicable in Singapore. It could be used to assess the energy embodied in the typical facades from each of the Shenton Way, Marina Centre, and Marina Bay building typologies. These typologies are shown in Figure 5.



SHENTON CORRIDOR
DBS Building
1975

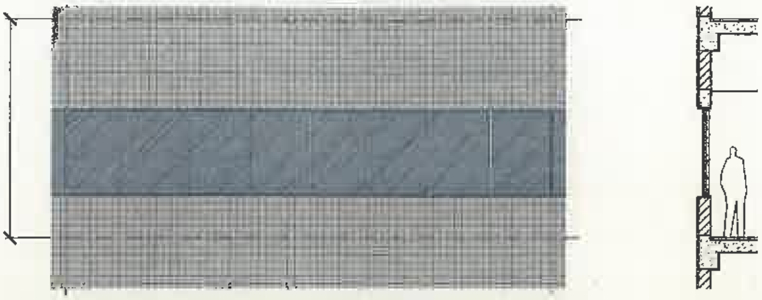
MARINA CENTRE
Suntec City Tower 3
(granite-clad model)
1994

MARINA CENTRE
Suntec City Tower 1
(aluminium cladding)
1994

MARINA BAY
Marina Bay Financial
Centre (office tower)
2011

Figure 5. Prototypical Facade Models

We may postulate typical facade assemblies that are roughly synonymous with each of these prototypical facades. Assume that the constructions of these prototypical facades are as shown in Figure 6.



ASSEMBLY 1 Masonry facade early Shenton Way model
230mm thick brickwall with 19mm render internally & externally with mosaic tiles externally
Glazing 6mm-thick single-glazed

ASSEMBLY 2 Granite slab-clad facade Marina Centre model
(with individual windows to represent actual circumstances in Marina Centre)
Granite thickness 25mm
Vision glazing 24mm-thick double glazed units—glass layers 6mm thick each

ASSEMBLY 3 Aluminium-clad facade Marina Centre model
Aluminium panel thickness 3mm
Vision glazing 24mm-thick double-glazed units—glass layers 6mm thick each

ASSEMBLY 4 Curtain-wall facade Marina Bay model
Vision glazing 24mm-thick double glazed units—glass layers 6mm thick each
Spandrel glass Single-glazed 8mm thick

Figure 6 Construction of Prototypical Facades

Using the ICA data, the embodied energy in a single typical module size (10m wide x 4.5m high) may be estimated for each of the assembly types. Table 2 shows, by way of example, the calculation of the embodied energy for Assembly Type 1.

MATERIAL	VOLUME	DENSITY KG/M³ SOURCE: EVERETT (1970, P. 22)	TOTAL WEIGHT KG	EE COEFFIENT MJ/KG SOURCE: ICE
ASSEMBLY 1	Description: Masonry walls with plaster finish internally, render & tile finish externally and ribbon single-glazed windows.			
SINGLE-GLAZED WINDOW 6MM THICK	10 x 1.8 x 0.006 = 0.108 m³	2,520	272	17.98 (glass: virgin glass)
ALUMINIUM FRAMING TO WINDOW	Say members = 150 x 50 x 3mm thick, total length = 34.4m @ 0.0012m³ / metre run = 0.041 m3	2,700	111.46	155 (Aluminium: general aluminium)
CAVITY BRICK WALL	10 x 1.9 x 0.230 = 4.37m³	1,700	7,429	3 (clay & bricks: general clay bricks)
EXTERNAL RENDER 19MM THICK	10 x 2.7 x 0.019 = 0.513m³	1,778	912.11	1.8 (plaster: general plaster)
EXTERNAL CERAMIC MOSAIC TILES 6MM THICK	10 x 2.7 x 0.008 = 0.216m³	2,403 (estimated)	519.05	12 (ceramics: tiles & cladding panels)
INTERNAL RENDER 19MM THICK	10 x 1.2 x 0.019 = 0.228m³	1,778	405.38	1.8 (plaster: general plaster)
TOTAL EMBODIED ENERGY FOR ASSEMBLY 1	53,599			

Table 2. Assembly Type 1

Application of this method for each of the Assembly types provides results as summarised in Figure 7.

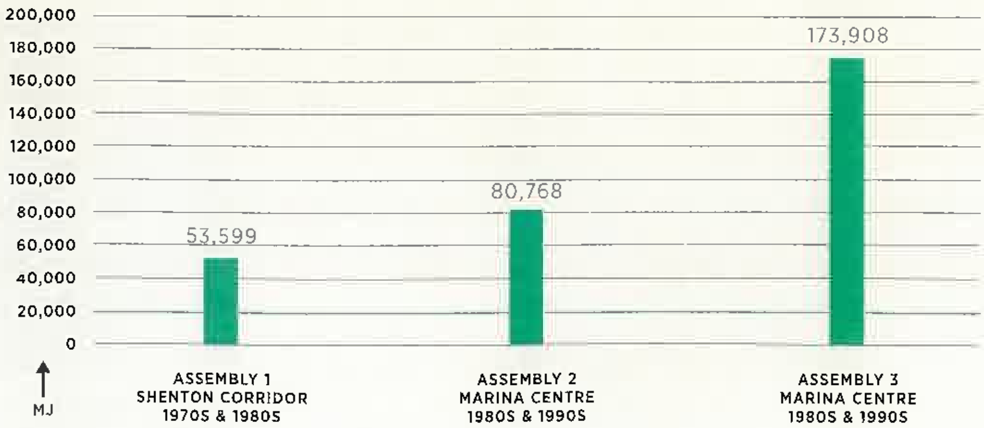


Figure 7. Embodied Energy in Selected Facade Units, 1975-2011

Emerging from this analysis is the suggestion of a fourfold increase in the embodied energy in the contemporary facade designs compared with the conventional facade design of the early Shenton Way tall building type. Ironically, the four facade types studied represent a journey from Oldfield et al's 2nd to 5th generations of tall building types. In theory, this journey should embrace a peak in per unit area operational energy requirements at the 4th generation, in say the 1990's, and then, in approaching generation 5, a decline. But it certainly does not appear to reflect a corresponding decline in embodied energy, at least for the facade elements.

In truth, the embodied energy of the facade components represent but a small part of the whole. Treloar et al's paper (2001, p.8), includes a case study of Casseldon Place, a 42 storey office building in Melbourne, Australia. The external wall (pre-cast polished concrete facade panels) accounted for 79,698 GJ of embodied energy, and the windows (aluminium-framed curtain-wall) for 23,638 GJ, resulting in a total facade embodied energy level of 103,336 GJ. The total embodied energy for the building is reported as 1,787,073 GJ. Thus, the facade accounts for barely 6 percent of the total embodied energy.

In addition, the use of lightweight claddings, albeit of higher embodied energies than heavier masonry facades, may bring savings in terms of consequent structural lightness. The positive effects of structural lightness are significant in view of the finding that the embodied energy of structural elements is height dependent.

Future Developments

As operational energy requirements decline, as they must do under the influence of more stringent statutory environmental controls, of rising energy costs, of resource depletion, and of widening aspirations to achieve zero carbon buildings, the focus will inevitably shift to embodied energy, and specifically to the means of reducing it. As Hammond and Jones note (2008, p. 97):

"The tendency, both in Europe and the UK, over recent years has been to move in the direction of 'zero carbon' housing. This is certainly the case with the current version of the UK Building Regulations, Part L. However, this notion only addresses the operational energy use and carbon dioxide emissions emanating from homes ... In the UK, Rawlinson and Weight noted

However, Singapore's Green Mark Code, has—despite revisions that have given greater weight to passive issues—still not moved its assessment criteria significantly beyond the business of measuring energy consumption. Its criteria are quantitative and technological in nature.

(sic, Rawlinson and Weight (2007, p.89) that embodied carbon is becoming more important in comparison with operational emissions as codes tighten. They suggest that the embodied energy in domestic buildings might be ten times the annual operating energy requirements and in commercial buildings the ratio could be as high as 30 : 1."

If this is so, then there is a clear need for an elevation in the Singapore sustainability consciousness of the embodied energy issue. To make this meaningful, there is a concomitant need for a greater understanding of the embodied energy profiles of the building elements that are used in Singapore. With such elevated consciousness might we also look forward to the embrace by the Singapore sustainability codes of concepts of embodied energy? ▰

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