Appendix J
Tall Buildings Study

Arup
2016

CITY OF SYDNEY

Sydney2030 Green Global Connected

Preface

This study considers recent developments and implications of building taller towers. It discusses the impacts of increased height on tower footprint, structure, wind outcomes, energy consumption and environmental outcomes. In turn, these impacts affect architectural and urban design. The study makes observations that inform the growth strategy for Central Sydney.

Recent tall building developments typically reach an average of 350 metres in height.

Development of tall buildings has been growing overall. Notably however, the percentage of new tall buildings accommodating office space has decreased. New tall office buildings have dropped from 88 to 47 percent of new tall building construction whereas new tall buildings accommodating residential uses has increased to 47 percent. The speculative power of residential development is likely a key driver for this trend. The implications for a future Sydney are significant given it falls within the top ten of world cities in terms of tall building rental demand.

Building taller towers has significant implications for design and efficiency. Tower dimensions at street level can reach around 42 metres in length, up to 53 metres for towers of 400-metre heights. Taller towers result in less efficient floor plates due to structural and infrastructural constraints. At the lower levels, office tower cores can account for 28 percent of floor plate area whilst residential tower cores can reach 34 percent due to their tendency for slimmer floor plates.

Larger floor plates at street level affect the public realm particularly when constrained by finer street grids such as Central Sydney. Walkable dimensions of city blocks can be compromised, as can the ability to provide useable public open space around the base of tall tower buildings.

Taller towers affect the environment of the city. Clustering towers can exacerbate the urban heat island effect in a city. Dense populations of tower structures absorb and retain heat. Tower structures themselves generate heat from occupant use. The ability for urban landscapes to dissipate heat at night is compromised due to limited exposure to open sky, in turn impacting on energy consumption.

City of Sydney
Arup | July 2015

ARUP

Tall Buildings

The implications of increasing height


© Cath Drury

Tall Buildings

The implications of increasing height

This confidential report has been commissioned by the City of Sydney. The report presents a high level assessment of the implications of building tall towers higher in the urban realm.

There are many parameters that influence the design of tall buildings, and hence influence their impact on the city. Consequently, the report herein presents information which is considered typical and generic. This should be borne in mind when interpreting some of the data and recommendations.

9048

Craig Gibbons
Arup Fellow | Principal

d +61 7 3309 4370
m +61 (0)408 838
e craig.gibbons@arup.com

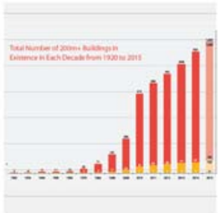
Contents | The implications of increasing height

Tall Buildings | The Implications of Increasing Height

The following presents a summary of some of the key findings in this report:

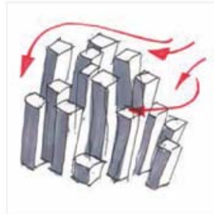
Directions

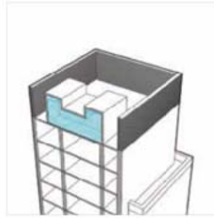
- Tall buildings around the world are getting taller, such that now the average height of the tallest 100 buildings is 350m.
- The number of residential tall buildings has increased dramatically in recent years. Prior to 2000, only 1% of the then tallest buildings were residential, by 2010 this had increased to 15%.
- Towers are becoming more slender, driven by the increase in demand for residential towers and the desire to maximise the potential of small CBD sites. This has the tendency to increase cost and the need for devices such as tuned mass dampers.
- In Sydney there is the trend towards eccentric cores – 8 Chifley being a good example. This influences the strategy for the structural design and how the building is serviced.
- The cost of tall buildings is significantly impacted by shape and geometry; size and regularity of floor plates; floor plate efficiency; structural solution; façade to floor plate ratio and the façade specification.
- The Knight Frank index, which ranks the demand for high rise around the world, ranks Sydney as 7th of world cities. This puts it ahead of Shanghai, Dubai and Chicago.



Wind

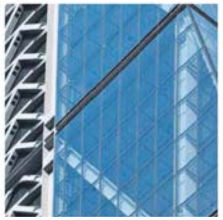
- The extreme winds in Sydney are less than some of the 'tall building cities' around the world. This reduces the lateral design loads on towers. The less frequent 'environmental wind' is however higher and will require careful consideration in terms of environmental impact at ground level.
- Taller and more slender towers, particularly residential buildings, are more likely to need tuned mass dampers to control the comfort (accelerations) at the top of tall buildings.
- The build form on plan and elevation can greatly improve the dynamic performance of the building. Typically, towers which have more rounded corners, are non-extruded, or are tapered in elevation tend to perform better.
- Tall buildings do sway in the wind. The amount of deflection increases with height, whilst the limiting lateral deflection can vary, an internationally recognised limit is height of building divided by 500 (h/500) for a wind that occurs 1 in 50 years.

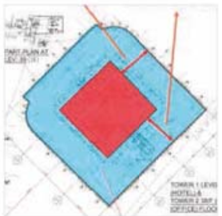




Components and Structure

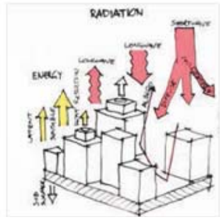
- As buildings become taller, the footprint typically increases in size. The height to base width has a typical maxima of 8 or 9 but can increase to 12 as an extreme case, particularly for residential developments.
- As buildings become taller, the efficiency tends to reduce. For example, the plan area of a core can increase from 20% of lower level GFA for a 200m high building to 30% for one of 400m.
- The structural systems required for a tower change as the height increases. It is interesting to note that 75% of all tall buildings constructed globally over the height of 300m use an outrigger system.
- Perimeter framing or braced frames become more prevalent when using eccentric cores.
- Plant floors typically occur at between 20-28 storey intervals.
- For taller towers, the use of sky lobbies and shuttle lifts can greatly optimise the vertical transportation and minimise core area.
- The geology of Sydney is well suited to building taller compared to other cities in the world. This is due to the presence of rock at shallow depths.

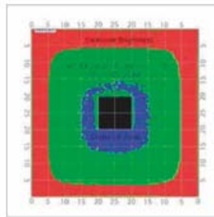




Energy and the Environment

- As buildings become taller, the energy they require per m^2 tends to increase. In general terms, the increase in operational energy is of the order of 5% for each 100m increase in height above 200m.
- The longest component contributing greatest to the increase in energy usage with height is the vertical transportation.
- Tall buildings have the potential to have a significant effect on the local environment. Most significant is the need to avoid urban canyons which impact on the environmental wind climate and heat load.
- As taller towers consume more energy per sqm, it is possible that this will make the energy targets in the Sydney 2030 plan more difficult to achieve. One solution is the need to factor in the considerations of site area and greater uptake of public transport in the assessment.





Tall Buildings | The Implications of Increasing Height

Background information and directions

Cost of Tall Buildings

Appendix A presents details of the cost of residential and commercial office towers. The data is based on buildings in London (reference 1).

Whilst the breakdown of costs between the individual components is applicable to construction in Sydney, the overall cost and ratio of cost between commercial and residential is likely to be different. The typical costs for tall buildings in Sydney are as follows (reference 2):-

	Costs/m2 Low end $/m2	Costs/m2 High end $/m2	Difference $/m2
Residential over 40 storey	3,800	4,500	700
Commercial over 40 storey	3,900	4,350	450

The key factors impacting the cost of high rise are summarised as follows:

- Shape and geometry;
- Size and regularity of floor plate;
- Floor plate efficiency;
- Structural solution;
- Façade to floor plate ratio and façade specification/repeatability.

Greening of Tall Buildings

The greening of high rise buildings is becoming commonplace around the world. This is in part due to legislation. Appendix B presents a summary of examples of high rise buildings around the world where 'vertical greening' has been used to good effect across a range of building types. The report presents the percentage of green coverage achieved for various buildings (reference 3).

Move Towards Increased Slenderness

There has been an increasing trend in recent years for buildings to become more slender, particularly residential apartments. Slenderness is defined as the height of a tower to the least base dimension on plan.

This has been driven by the demand for urban living and the premiums achievable to compensate for the additional costs of building slender. The photograph on the right shows some of the proposed towers in New York, highlighting their slenderness. Indeed these towers are referred to as New York's "skinny towers".

The aspect ratio (slenderness) of some of these towers is as follows;

Name	Aspect ratio (slenderness)	Height (m)
One Madison, New York	1:12	188
111 West 57th Street, New York	1:24	438
432 Park Avenue, New York	1:14	425

Some examples in Australia include;

Name	Aspect ratio (slenderness)	Height (m)
Meriton Tower, Brisbane, Qld	1:12	274
82 Flinders Street, Melbourne, Vic	1:15	88.5

It is expected that in meeting the demand for high rise residential development, the slenderness of apartment buildings will tend to increase.

There are a number of implications of buildings being more slender:-

- A larger premium for structural costs (the building is potentially more flexible due to its slenderness and thereby requires a more material to increase stiffness).
- The need to provide dampers in the building to improve comfort to occupants (see later).
- Possible alternate solutions are necessary to address car parking issues.

One Central Park's green walls, Sydney, NSW © Frasers Property

New York's 'skinny towers' ©

Tall Buildings | The Implications of Increasing Height

Background information and directions

Increasing Height

There is a very pronounced global trend of increasing the height of tall buildings. The data in Appendix C (reference 4) presents statistics on specific global metrics including:-

- Average height of top 100 buildings world-wide.
- Height increases relative to function.
- Geographic distribution with height.
- Timeline of height increases.

The data presented includes a timeline of all the buildings constructed in Australia over a height of 200m since 1960 compared to those constructed globally over a height of 300m.

It is evident from this that:-

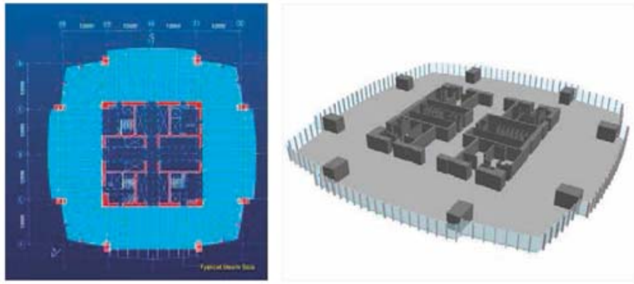
- The average height, at present, of the top 100 world's tallest buildings is 350m
- Since 2000, there has been a significant increase in the proportion of mixed use towers. It should be noted that many of the mixed use towers are premier hotel components on the upper storeys of Asian CBD commercial towers.
- Also since 2000 there has been a marked increase in the average height of the top 100 tallest buildings. This is primarily due to the highrise activity in the Middle East and China over the past 12 years and the large nuber of buildings in these locations above 300m. The opening of the Burj Khalifa tower in Dubai represented a significant increase in height of worlds tallest and fully illustrates the trend. See also Appendix C which refers to a summary of towers competed in 2011 only. The dominance of China and the Middle East is evident.
- From 1960 to 2000, 88% of the tallest 100 buildings were office buildings, and 1% were residential. By the end of 2010, the number of office buildings in the top 100 had reduced to 47% and the number of residential increased to 15%.

The Knight Frank Index

For completeness, included in Appendix D is the annual report from Knight Frank which provides background to some of the recent tall building trends. Based on a set of criteria, including rents, yields, building stock, demand for high rises and growth prospects, Sydney ranks 7th in the world ahead of Shanghai and other tall building centres like Chicago and Dubai.

Floor plates and eccentric cores.

The conventional configuration of office floor plate comprises a central core with an all-round lease span (depth) in the range of 11 – 14m. This configuration is very typical of commercial high rise in Asia.



2 International Finance Centre, Hong Kong © Arup

In other parts of the world, there has been a shift towards eccentric cores. This has been driven by preferences from high end commercial tenants centred on improved working environment, efficiency of planning and view considerations. The use of eccentric cores is particularly prevalent in Sydney.

8 Chifley Square, Sydney, NSW © Arup

The trend towards eccentric cores in Sydney also extends to residential developments due to the SEPP65 requirements precluding south facing apartments. The inclusion of an eccentric core can have significant implications on the structural design, and the way in which the building is serviced.

- Twisting forces under lateral load promote the need for exterior frames (see later).
- The non-symmetrical distribution of vertical structure tends to cause taller towers to bend under gravity loading. This can introduce complexities of pre-setting during construction to compensate for these effects.
- The service runs from the core to the perimeter can be longer and this can influence the way in which the building is serviced.

© Arup

Tall Buildings | The Implications of Increasing Height

Impact of height

Impact of height……. 200, 300, 400

This part of the report considers the implications of constructing towers with heights of 200, 300 and 400m. It intentionally draws on the experience and precedent of towers constructed elsewhere. Where appropriate, graphical data is presented to define trends and typical information.

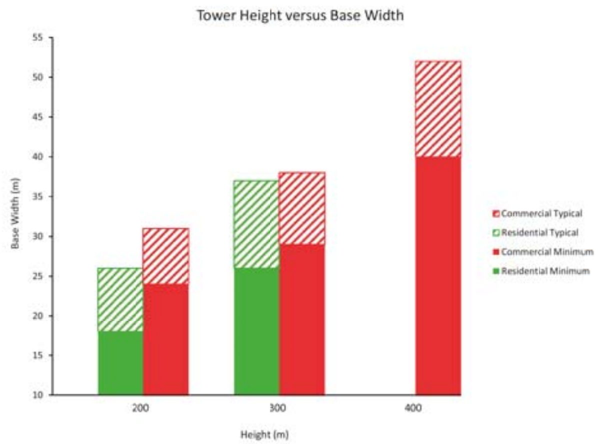
Base width

To meet with structural and comfort requirements, towers need to have a minimum lateral stiffness and strength. This is influenced by the type of structural system adopted, the materials used and most significantly by the aspect ratio of the tower. Aspect ratio is defined as the building height divided by the minimum base width dimension. A higher aspect ratio equates to a higher slenderness and potentially a more flexible tower. Drivers such as small plot size, desirable lease depths, floor plate sizes impact the aspect ratio adopted.

The following graph presents the approximate base dimension for residential and commercial building types. For these figures to be meaningful, the following assumptions have been made:-

- Office tower, floor plates 1,500m2 (net) with floor to floor height of 4m
- Residential tower, floor plate 1000 m2 (net) with floor to floor of 3m

It is noted that floor to floor dimensions in office buildings can typically vary over the range 3.8 - 4.3m, and for residential 2.8 - 3.2m. The figures chosen for this exercise are general assumptions for the purposes of comparison.



There is intensionally no data in the above graph for 400m high residential towers. This is because there are very few 400m plus solely residential towers. Towers of this height tend to be mixed use residential / office / hotel.

The plot shows a typical value for an aspect ratio of 8, but also includes a minimum value. This is recognising the trend to more slender towers and corresponds with some of the more slender extremes. In the case of residential buildings this minimum equates to an aspect ratio of 1:12 whilst for offices it equates to 1:10.

Cores Sizes

The size of cores for tall buildings vary significantly depending on the approach to vertical transportation, escape stairs and how the building is serviced. While the core will typically make a significant contribution to the strength and stiffness of the tower, invariably its size is dictated by the space requirements of the services and egress provision within. Indicative breakdown of services within the core for high rise commercial tower are as follows:

	Approx Percentage of floor plate area	Approx percentage of core Area
Building Services	3.5%	10.5%
Fire stair	2.0 %	7%
Lifts	10.5 %	35%
Lobbies	8 %	24%
WCs	2.5 %	8%
Total	26.5 %	85%

The figures above exclude the ‘structure’ of the core. It is for this reason that the total is 85%. The residual area making up the core can be considered as stricture and miscellaneous.

Plant floors

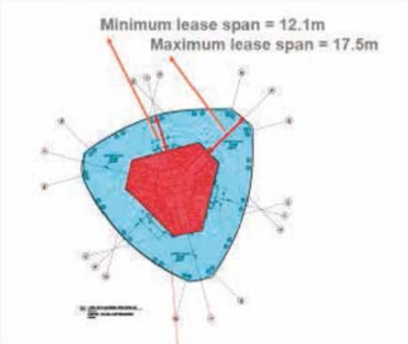
Typically there will be a plantroom every twenty (20) to twenty eight (28) floors. Plant floors will typically be between 5.5m and 6.0m floor to floor. Total building services plant requirement will be between 9.5 and 10.0% of gross floor area (GFA). Depending on the specifics of the design, there could be two plant floor levels at 20-28 storey intervals, and it may be that the floor to floor height matches that of the typical floors (for reasons of external aesthetics).

External skin allowances

For typical towers NLA is measured to the inside face of the glazing. Overall glazing thickness is typically 30mm for a high rise tower. For most commercial towers, the mullions are inboard of the glazing to maximise the NLA. However, this is not always the case. In cases where the main part of the mullion is external to the glazing it could be expected to protruded 150-200mm beyond the external glazing face. In some cases where a high performance accessible double skin cavity is used (ie. 1 Bligh Street), the glazing depth will be typically 800mm.

Tall Buildings | The Implications of Increasing Height

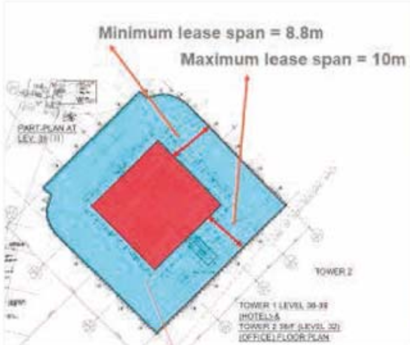
Impact of height



Guangzhou West Tower - 439m

Net Internal Area: Low Zone Floor Efficiency = 71%

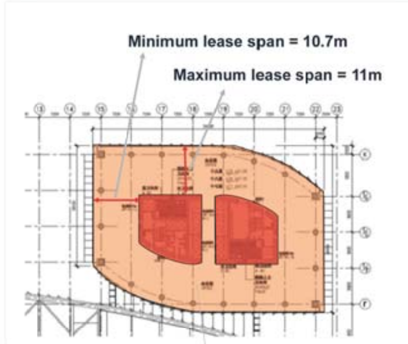
Core: High Zone Floor Efficiency = 73%



Hong Kong Nina Tower - 320m

Net Internal Area: Low Zone Floor Efficiency = 72%

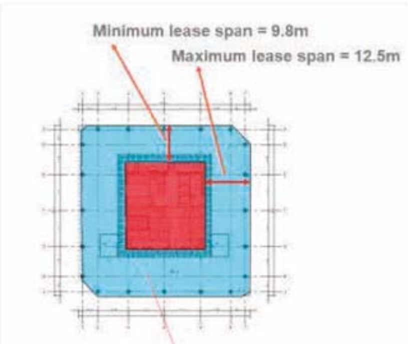
Core: High Zone Floor Efficiency = 78%



Shanghai China Merchant Bank - 208m

Net Internal Area: Low Zone Floor Efficiency = 74%

Core: High Zone Floor Efficiency = 79%



Guangzhou R & F Mixed- Use Tower - 296m

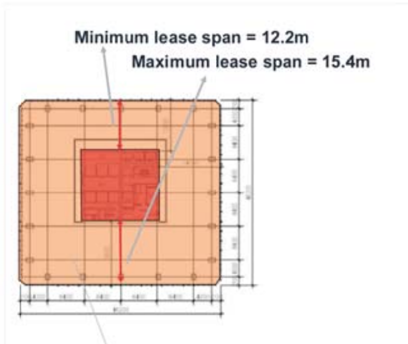
Net Internal Area: Low Zone Floor Efficiency = 74%

Core: High Zone Floor Efficiency = 77%

Shenzhen Kingkey Finance Tower - 442 m

Net Internal Area: Low Zone Floor Efficiency = 70%

Core: High Zone Floor Efficiency = 73%



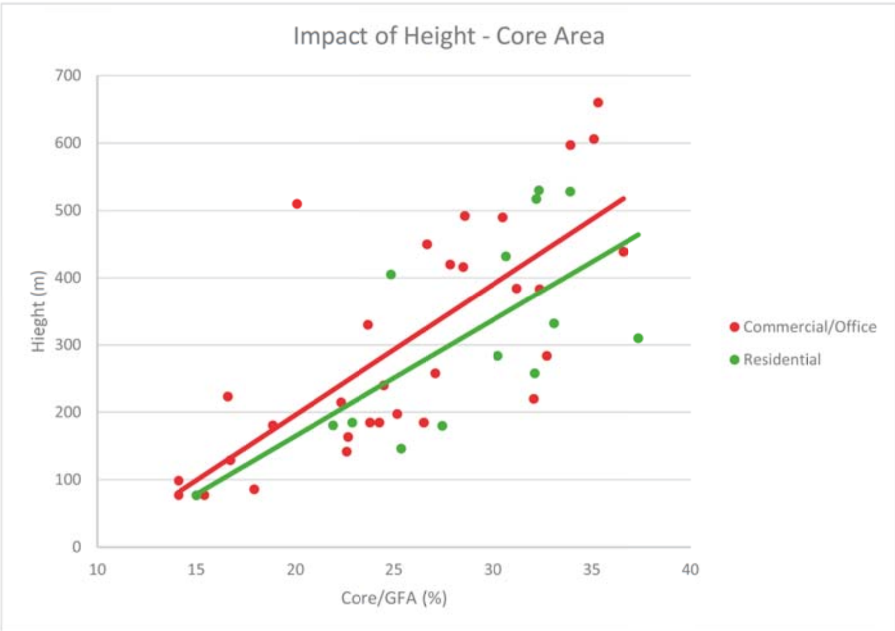
HWP Tianjin Complex - 432m

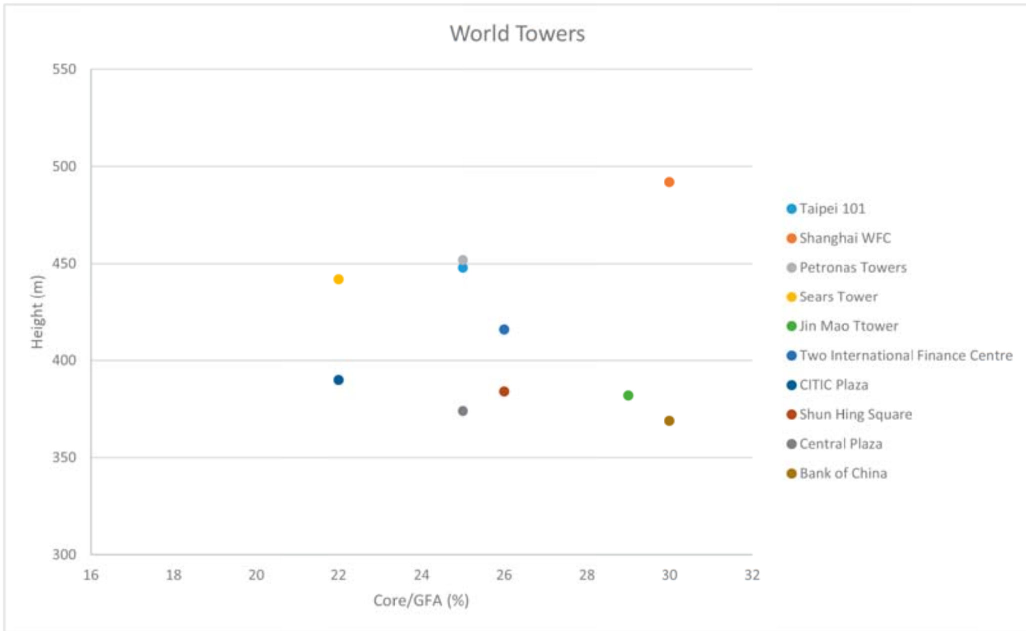
Net Internal Area: Low Zone Floor Efficiency = 75%

Core: High Zone Floor Efficiency = 80%

Tall Buildings | The Implications of Increasing Height

Impact of height





The above data comes from Arups database on towers in Asia. It comprises a range of structural systems (influenced by height) and also includes mixed use towers. The core area shown is that for the low levels of the tower, as opposed to that in the higher levels where the lifts 'drop-off' and core sizes typically reduce.

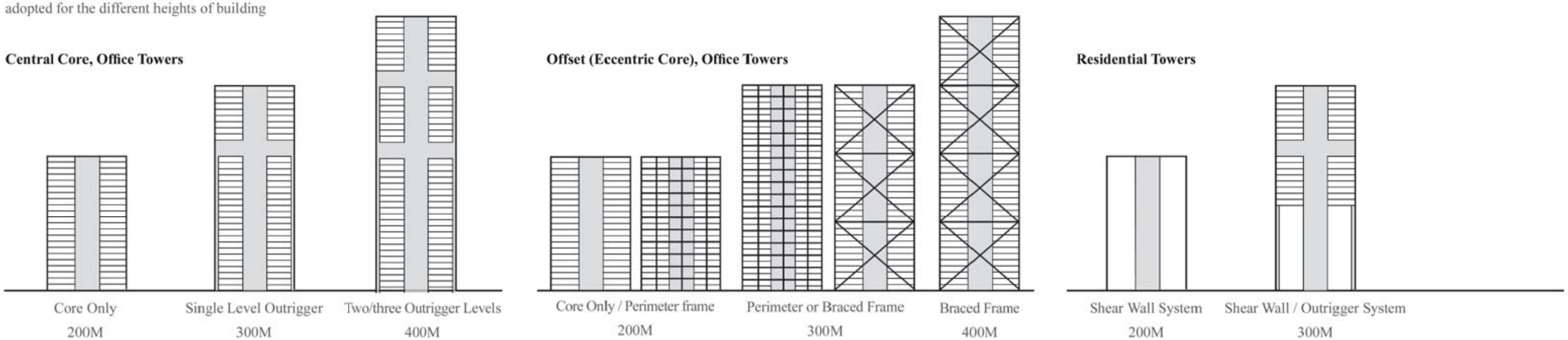
The above shows the core area for some of the more internationally recognised towers, the data of which is also included in the graph opposite.

Tall Buildings | The Implications of Increasing Height

Impact of height

Typical Structural Systems

The following presents some of the typical structural systems that are likely to be adopted for the different heights of building

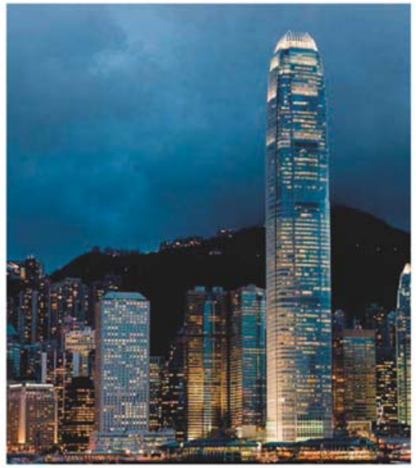


Notes regarding the above diagrams:

- 75% of all tall buildings constructed globally, over the height of 300m use an outrigger system.
- Outriggers are typically located at plant room floors. For a typical office building, the plant room floors are located at 20 to 28 floor intervals, depending on planning, mechanical systems adopted and local regulations.
- In 1960, 95% of the 100 tallest buildings were constructed in steel. In 2010, only 22% were constructed in steel. The remainder were constructed from concrete or concrete steel composite.
- Concrete is the preferred structural medium for residential buildings because of its inherent acoustic benefits and the reduced requirement for long floor spans compared to office buildings.
- Whilst externally braced or diagrid type structures have been used for office buildings, there is the obvious reluctance to use such systems for residential or hotel type towers.
- Regardless of the structural system, there is a preference for the use of reinforced concrete cores (as opposed to steel only) due to the efficiency and maturity of the climbform industry, the robustness of a reinforced concrete core (from a damage and means of escape perspective) and the acoustic benefits, mindful that cores typically enclose the plant and equipment.

122 Leadenhall Street, London, UK (c) Daniel Imade
Megabraced Eccentric Core

Guangzhou International Finance Centre (c) Zhou Ruogu Architecture Photography
Megabraced Eccentric Core



International Finance Centre 2, Hong Kong
Central Core with Outrigger

Tall Buildings | The Implications of Increasing Height

Impact of height

Building to the Limit of Height

In setting a height limit for tall buildings, it is appropriate to consider what the construction implications are in constructing to that limit.

It is conventional to use tower cranes in high rise construction. These are used to move materials to and from the work front. It is inevitable therefore that such cranes project higher than the level under construction. In addition, there are other pieces of equipment such as material and people hoists, climbing forms which can also project beyond the level of construction.

When it comes to constructing to a defined upper height limit this can present a problem. To cost-effectively construct the highest point of permanent structure will usually involve the use of cranes and hoists as above, thereby breaching the height limit during the construction. As a solution, it is common practice to apply for a dispensation to breach an imposed limit for a restricted period which follows a very detailed set of procedures. These dispensations might only apply during daytime and in periods of good visibility. In Australia, and where the height limits are defined by CASA (Civil Aviation Safety Authority), any such breach will typically involve Federal Approval.

9826

If, for any reason, there is no possibility to breach a height limit, even temporarily, then there does need to be careful consideration of the approach to construction. There are probably two main categories to consider:-

- Towers with spires, and
- Towers with flat tops

Tower with spires, or masts, are probably the easiest to construct to a height, without exceeding the height limit. On the Petronas Towers in Malaysia, and the Burj Khalifa in Dubai, the masts were constructed at a lower level, below the height limit, using cranes for the installation of material and then the completed mast was jacked vertically into its permanent location. An image below (copyright Highlights KL www.malaysia.nl) shows part way through the jacking process, with the mast progressing higher than the tower cranes.

Petronas Towers, Malaysia © Highlights KL
www.malaysia.nl

It should be noted that this approach was adopted not because of the need to avoid breaching the height limit, but is more to do with the practicalities of construction. For the scale of masts considered in these towers, it is not sensible to build the tower cranes taller than the mast, jacking up the mast is the cheaper and easier approach. In the case of more modest towers, with more modest masts/spires, it is expected that installation by tower crane would in most cases remain a preferred and cost effective approach. However, the jack-up method does provide a solution where a height breach is strictly not permitted.

Flat top towers do present a more difficult challenge. For there to be absolutely no encroachment above the final constructed level during construction, it will be necessary to construct the uppermost floors and roof at a lower level, and then jack the completed floors into position. It is envisaged that to achieve this, the larger crane used to construct the bulk of the tower would be replaced at higher level by a small crane (potentially also used to dismantle the large crane) which did not encroach on the height limit. This smaller crane would facilitate the construction of the roof and highest floor slab at (say) 8m, or two storeys, below the height limit, before these completed floors are vertically jacked into their correct position, in a similar manner to that described above for the spire/mast. Compared to conventional construction, this is expected to be a costly exercise, and as such we are not aware of this approach being adopted anywhere else in the world.

A more credible approach might be that for the construction of flat top towers there is a minor encroachment permitted. One that allows the placement of small cranes, or concrete pumps to enable the heavy material such as concrete to be placed in-situ – i.e. when the floor is in its final position. Such an encroachment might be only of the order of 2-3m, and for short period during pouring. This would represent a significant reduction of duration and encroachment compared to conventional tower cranes and might be deemed more acceptable. In situations where absolutely no encroachment is permitted, and a full jack-up solution is considered as prohibitively expensive or not practical, then building to a maximum height which is 2-3m below the no-encroachment zone would be a sensible approach.

Tall Buildings | The Implications of Increasing Height

Impact of height

Typical Building Services Systems

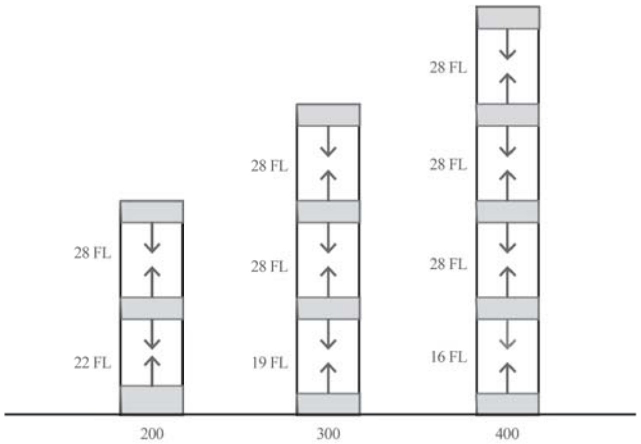
Mechanical

Key issues in the consideration of mechanical systems:

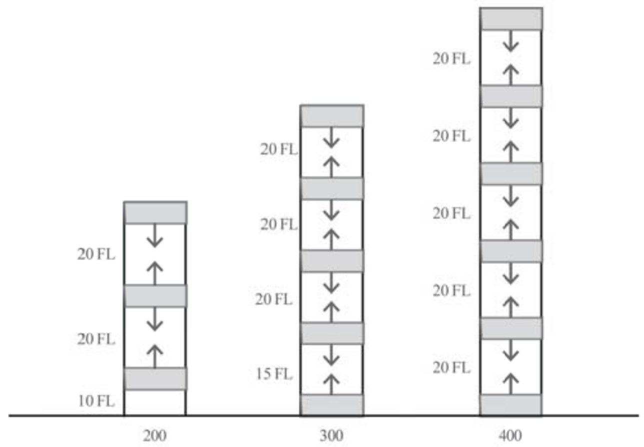
- Air verses chilled water circulation
- Central plant
- Efficiency of risers sizing
- Stack Effect issues.
- Environmental impact on the design.
- Plant replacement and maintenance.
- Tenant plant flexibility.

Mechanical Plant (Commercial Buildings)

Taller buildings are more energy intensive and require more power the taller the building becomes. The graphs on the right show the typical floor area requirements for different mechanical systems. One is all water system (eg. chilled beam approach) where as the other is all air without water on the office floors (eg. Variable Air Volume (VAV) approach).



AHU Distribution (Chilled Beam)
Maximum 14 Floors per AHU Plant

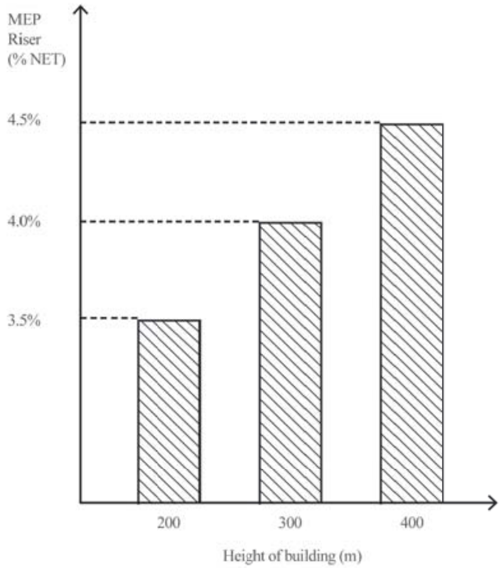


AHU Distribution (VAV)
Maximum 10 floors per AHU Plant

Vertical Risers

Typically as follows:

1. Mechanical Air - No variation with height assuming distributed plant.
2. Mechanical Water - Negligible difference albeit minor penalty due to hydraulic break.
3. Electrical - Penalty with height to reticulate HV up the building and communications.
4. Fire Services and Hydraulics - Penalty with height for multiple rising mains.

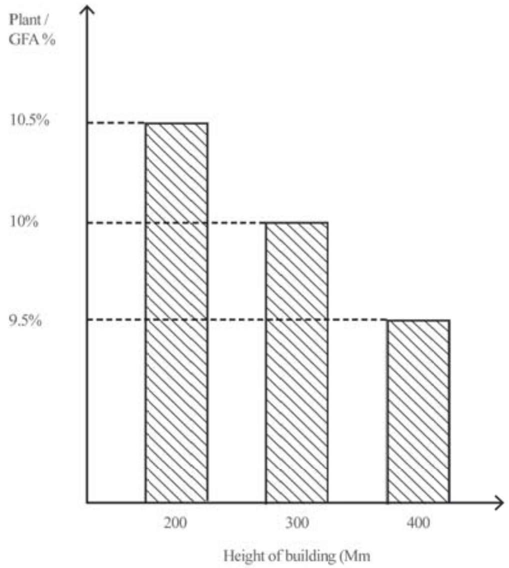


Total typical area of risers as a percentage of floor area.

Total MEP Plant

Increase in total building area leads to:

1. Increased spatial efficiency of the mechanical central plant
2. Increased spatial efficiency of fire services central plant.



Total MEP Plant area as a ratio of GFA
(Note: Above not tested)

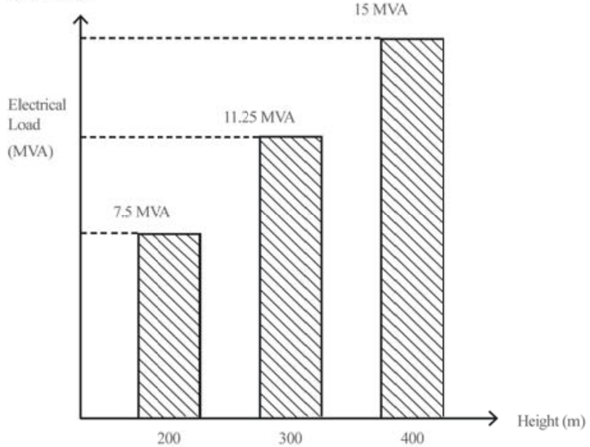
Tall Buildings | The Implications of Increasing Height

Impact of height

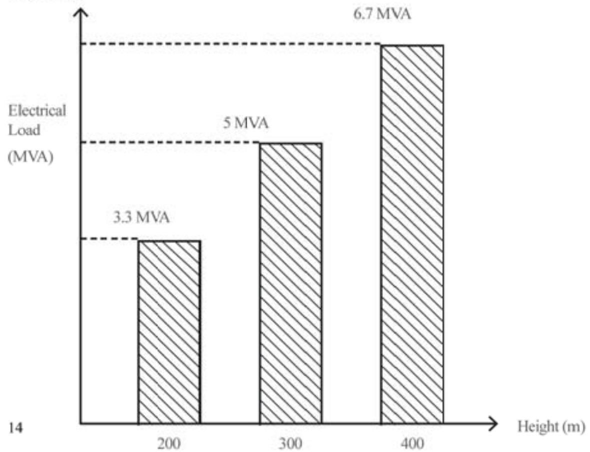
Electrical

Basically the energy density for power on the footprint of land increases the taller you make the tower.

Commercial



Residential



These demands are for the same sized footprint for each usage type and hence the energy density for the piece of land gets significantly higher. Hence in high rise designated zones the relevant utility company may need to reinforce their network locally to meet the overall demands. For example in the City of London they upgraded their network and created a dedicated 33kV new service dedicated to large projects (i.e. tall buildings) and they have already exceeded the available capacity.

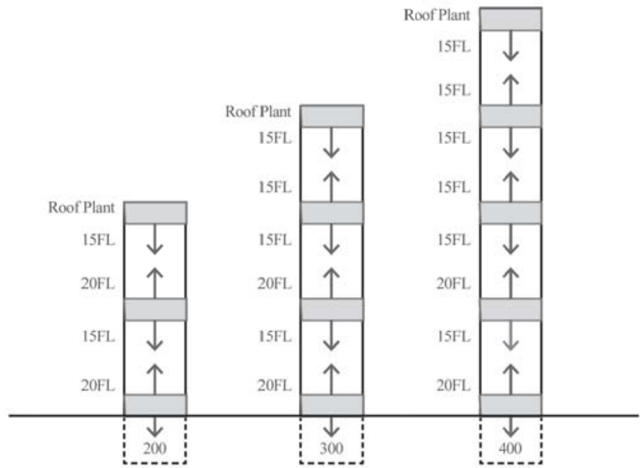
With the increase in electricity demand the amount of space required for total electrical equipment (substations, switchboards, electrical risers, generators, comms rooms, comms risers, landlords services but excludes lift shaft/plant areas) also increases. In terms of percentage the approximate electrical plant requiremnt would be as follows:

- a 200m commercial tower with 50 occupied floors and a footprint of $1500m^2$ will give an electrical plant percentage of approx. 4.1%
- a 300m commercial tower with 75 occupied floors and a footprint of $1500m^2$ will give an electrical plant percentage of approx. 3.9%
- a 400m commercial tower with 100 occupied floors and a footprint of $1500m^2$ will give an electrical plant percentage of approx. 4.2%

This assumes a standard level of resilience and backup as would be required for a premium office space. So pretty much around 4-4.2% of building area for all options for commercial.

For residential there is a lower requirement for resilience so no generators and less resilient design in the infrastructure. The percentages below are for all electrical (i.e. substations, transformers, switchboards, lv risers tenant risers, comms risers etc but no generators and excludes lift shafts/plant areas)

- a 200m residential tower with 66 occupied floors and a footprint of $1000m^2$ will give an electrical plant percentage of approx. 1.9%
- a 300m residential tower with 100 occupied floors and a footprint of $1000m^2$ will give an electrical plant percentage of approx. 2.5%
- a 400m reasidential tower with 133 occupied floors and a footprint of $1000m^2$ will give an electrical plant percentage of approx. 3.1%



Typical Substation Locations

For a commercial office electrical plant percentage will be approximately 4- 4.2% of GFA.

For a residential tower electrical plant percentage will be between 1.9% to 3.1% for 200 - 400m towers respectively.

Tall Buildings | The Implications of Increasing Height

Impact of height

Vertical Transportation

The following section considers the impact on the design and specification of vertical transportation systems, as buildings become increasingly taller.

The development of vertical transportation technologies has been a key driver in the successful endeavour to build functional, high rise buildings. A well planned and designed vertical transportation system should enable the architectural requirements of the site while transporting people and goods seamlessly with minimal time and stress. To this end we will consider the impact on vertical transportation designs in terms of:

- Performance
- Design Arrangements (Stacking)
- Equipment Technology
- Occupant Safety

Performance

Vertical transportation systems are designed to meet the performance levels as agreed with the building owner or developer.

The main variables having influence over the design of vertical transportation systems include:

- Building height
- The number of occupied floors
- Building population
- Building Type (Commercial, Residential, Hotel, Mixed use)
- Specific architectural requirements

For commercial buildings, the Property Council of Australia stipulates required performance levels for Premium, A and B Grade type developments. There is however no comparative body in Australia for residential buildings, therefore we would reference The Chartered Institute of Building Service Engineers (CIBSE) Guide D – Transportation Systems in Buildings.

In commercial buildings, both the morning up-peak and mid-day two way traffic conditions are considered. For residential and hotel developments a 2-way traffic profile is assessed.

The performance of vertical transportation systems is defined in terms of:

Handling Capacity (HC) - The percentage of a buildings population that can be transported by the elevator system, during the most demanding 5 minute period for the traffic profile under consideration

Average Waiting Interval (AWI) - The average time between successive elevator arrivals at the main floor. Average interval is a good measure of the elevator systems quality of service when a conventional control system is being used.

Average Waiting Time (AWT) - The time period between when a passenger registers a landing call or joins a queue, until the responding elevator begins to open its doors at the boarding floor. This measure is applicable when Destination Control Service (DCS) is used.

Typical performance targets for commercial and residential buildings are summarised below.

Commercial

Performance Level	Premium Grade	A Grade
Handling Capacity (Up Peak)	> 14% of total building population during peak 5 minute period	> 13% of total building population during peak 5 minute period
Handling Capacity (Two - way)	> 12% (6% incoming + 6% outgoing) of 80% of total building population during a 1 hour period	> 11% (5.5% incoming + 5.5% outgoing) of 80% of total building population during a 1 hour period
Average Interval / Waiting Time (Up-peak)	< 25 seconds	< 30 seconds
Average Interval / Waiting Time (Two - way)	< 35 seconds	< 40 seconds
Car Loading	< 80%	
Occupancy	12m² (per person) of total NLA	

Reference 5 – Property Council of Australia - A Guide to Office Building Quality 2012

Residential

Performance Level	Luxury	Normal	Low Income
Handling Capacity (Two - way)	8%	6% to 8%	5% to 7%
Average Interval / Waiting Time (Up-peak)	45-50 seconds	50-60 seconds	50-70 seconds
Population			
Studio	1 person	1.5 persons	2 persons
1 Bedroom	1.5 persons	1.8 persons	2 persons
2 Bedroom	2 persons	3 persons	4 persons
3 Bedroom	3 persons	4 persons	6 persons

Reference 6 – (CIBSE) Guide D

Tall Buildings | The Implications of Increasing Height

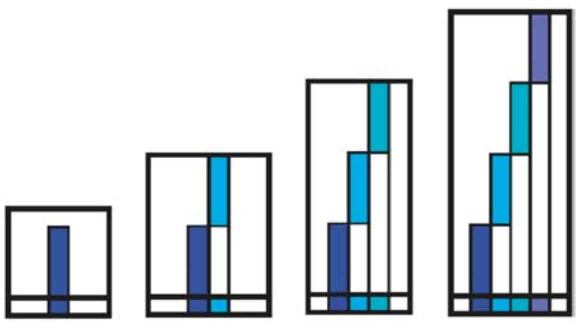
Impact of height

Design Arrangements (Stacking)

As towers increase in height, the vertical transportation design must respond to achieve the required performance and enable the seamless flow of tenants and visitors throughout the building.

While increasing the number, size and speed of elevators is possible, there comes a point where this is no longer an effective design strategy in order to maintain the floor plate efficiencies required to make a development viable. At this point the design of vertical transportation systems must adopt design strategies and equipment technologies different to those the Sydney market may be familiar with.

To maximise floor plate efficiencies elevators are arranged in groups. Subject to the number of elevators in each group (low, mid, high rise etc) the below stacking arrangements are typical.



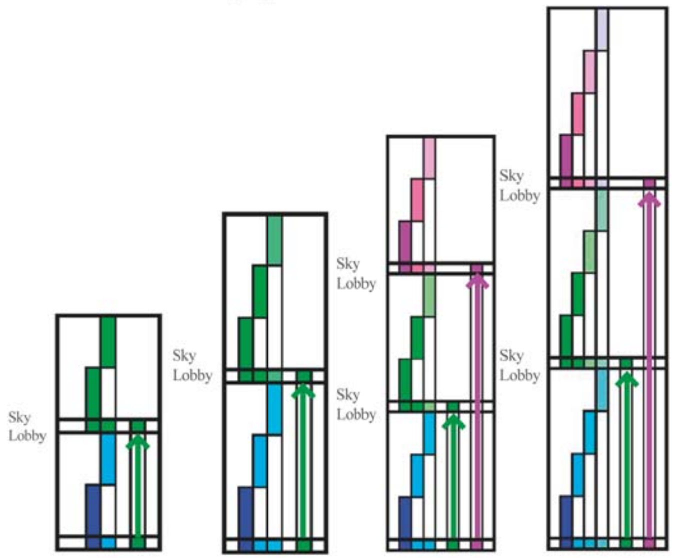
1 group of lifts services approximately 20 floors

2 groups of lifts services approximately 20 - 35 floors

3 groups of lifts services approximately 30 - 45 floors

4 groups of lifts services approximately 40 - 55 floors

As commercial towers increase in height or where mixed use towers are being developed, sky lobbies can be introduced as depicted below. Sky lobbies require the use of shuttle elevators to transport passengers to the sky lobby where they transfer to local elevator groups.



Approximately 55 - 80 floors

> 80 floors

Sky lobbies can provide a number of design benefits to the development such as:

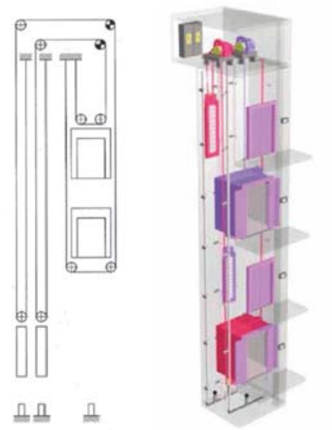
- Increased core efficiency by stacking "local passenger elevators" atop each other.
- Ability to quickly transport a large percentage of the buildings occupants.
- A location for social amenity particularly in residential towers where a local township can be created.
- A line of security between commercial, residential & hotel components of mixed use developments.
- In comparison to a conventional single deck system with all elevators serving from the ground floor, sky lobbies can reduce the core size by up to 25%.

Equiptment Technology

As towers increase in height, it is necessary to consider the use of various equipment technologies to achieve the required performance levels. There are several equipment technologies that have been specifically developed to maximise the handling capacity of each elevator shaft. These include:

- Multi-car systems (Double Deck and TWIN Elevators)
- Destination Control Service

Double deck



Twin

Double Deck elevators comprise two permanently connected passenger cars, positioned one above the other and connected to a common suspension and drive system. The upper and lower decks are therefore limited to serving two adjacent floors simultaneously.

The Twin system is unique to ThyssenKrupp and has 2 elevator cars running independently in the same elevator shaft. Each car has its own ropes, counterweight, safety, control and drive equipment while sharing common guide rails and landing entrance doors.

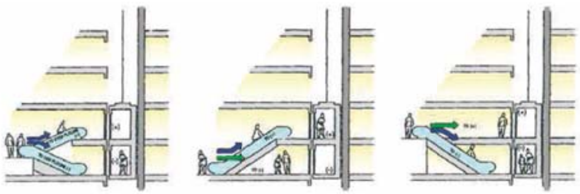
Multi-car elevator systems have been specifically developed to increase the handling capacity of each elevator shaft. This in turn provides the opportunity to reduce the overall number of elevator shafts while achieving comparable levels of service to a traditional single deck system.

Tall Buildings | The Implications of Increasing Height

Impact of height

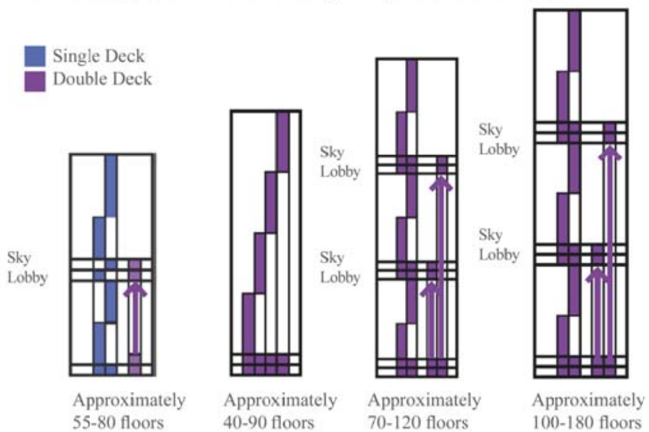
There are a number of similarities between Double Deck and TWIN elevator systems, with the most important being:

- Both require Destination Control Service to maximise efficiencies. On Double Deck elevators, DCS is used to minimise non-coincidental calls and on Twin to maintain safe operational distances between elevator cars;



- Both require dual lobby loading to allow the upper and lower cars to load simultaneously;
- Increase handling capacity of each elevator shaft;
- Fewer elevator shafts;
- In comparison to a conventional single deck system with all elevators serving from the ground floor, the use of multicar elevator systems combined with sky lobbies can reduce the core size by up to 35%.

When considering a multi-car vertical transportation system in conjunction with the use of sky lobbies the below stacking arrangements are made possible.



Occupant Safety

In many parts of the world, including East Asia, Europe and the Americas, the use of appropriately designed elevators is considered a safe and reliable means of evacuation to support the use of fire stairs. In Australia there are however few developments where the use of elevators for evacuation has been considered or allowed.

There are several emergencies which may result in a building, or a part of a building, needing to be evacuated. These emergencies include fire, earthquake, explosion, a security threat, impact, flooding, storm damage and chemical, gas or biological release. The likelihood of one or more of these occurrences leading to an evacuation will vary depending upon the location and the use of the building. For some of these emergencies it may be appropriate for an elevator to be used for evacuation, noting the warning sign displayed at each lift landing advising "do not use lifts if there is a fire" is with specific regard to fire.

There are several discussion papers regarding the use of elevators for evacuation in Australia. The most recent being the Information Handbook "Lifts Used During Evacuation", from the Australian Buildings Codes Board (ABCB). This is however a non-mandatory or regulatory document, with the formal position nominated in the current National Construction Code (NCC) being to prohibit the use of elevators in the event of a fire.

The main drivers for using elevators for evacuation, which become increasingly critical as buildings increase in height include:

- Demographic changes with ageing populations and greater obesity leading to issues of fatigue when using fire stairs;
- An increase in different forms of disability, making use of stairs impossible or problematic for some persons. In Australia up to 20% of the population is considered to have some form of disability.
- The need to provide safe, equitable and dignified egress for all building occupants under Occupational Health and Safety legislations (OH&S).
- A desire for more rapid evacuation in the event of non-fire threats by using elevators and stairs in combination;
- A design ambition to provide better fire fighter access.

There are two primary design concepts for egress using elevators;

1. Transfer/ Refuge Floors - in this concept, building occupants travel down the fire stairs to a protected transfer/refuge area from where they are transported by shuttle elevators to a point of egress.
2. Direct Evacuation - in this concept, building occupants enter a protected lobby and directly into the elevator at each floor.

The International Organization for Standardisation (ISO) is developing a standard specifically on requirements for lifts to be used to assist in building evacuation. Some of the lift operational goals required are still under development and to ensure a harmonised approach, are being developed through the ISO process.

In consideration of the above, it is possible for elevators to be used, for the evacuation of occupants in emergencies outside of a fire event. Should elevators be used in this way, the co-ordination of multiple engineering disciplines will be required to achieve:

- Building Structure designed to protect elevators from;
  - Smoke
  - Heat
  - Water
- Provision of a reliable power supply during evacuation.

Ultimately, an evacuation strategy using elevators, which does not negate or reduce the requirement or application of current life safety statutory requirements, could be a condition of consent for towers over a certain height or which have a particular set of characteristics.

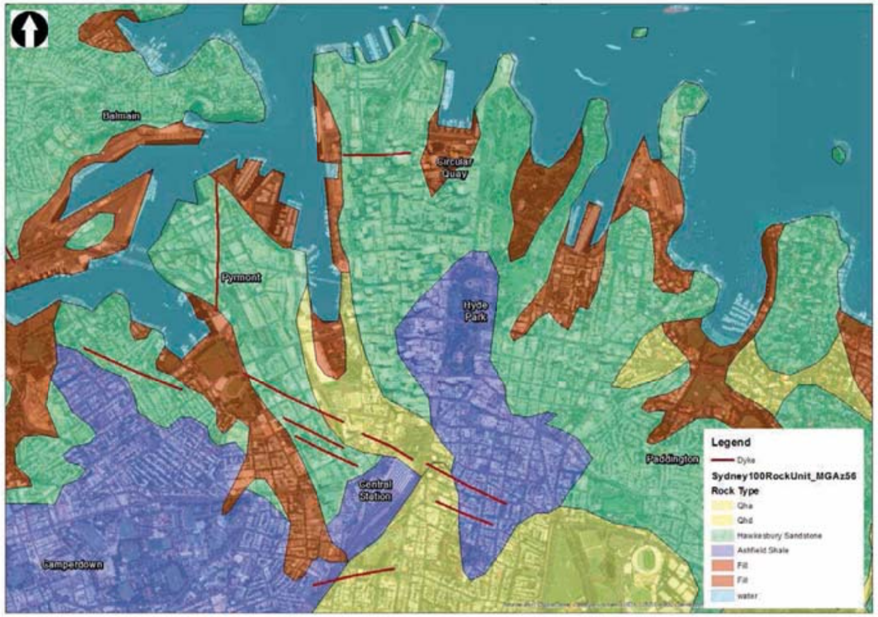
Tall Buildings | The Implications of Increasing Height

Below Ground

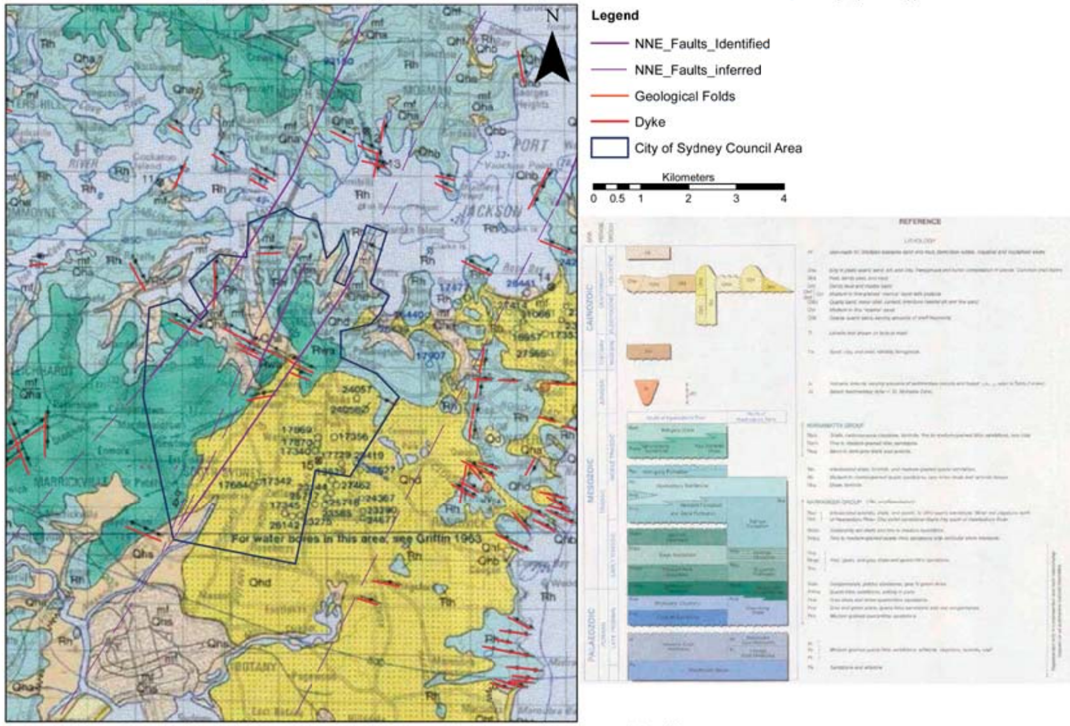
Geology and Foundations

The 1:100,000 Geological Map of the Sydney Region indicates the city of Sydney is underlain by Hawkesbury Sandstone and Ashfield Shale.

- The CBD is typically founded on Hawkesbury Sandstone
- Ashfield Shale is present to the south of the CBD in the areas of Hyde Park, Central Station and Camperdown. Ashfield Shale overlies the Hawkesbury Sandstone
- Quaternary alluvium deposits and reclaimed land (fill) are present at the harbour edges and within some bays. Prominent intrusions of quaternary alluvium deposits extend from Darling Harbour to north of Central Station then Surry Hills and Moore Park. Depths to rock can be in the order of 10 to 25m.



Geology of Sydney CBD (1:100,000 Geological series sheet 9130 - Sydney (1983))



Geological Map Reference: Geology of the Sydney 1:100,000 Sheet 9130, compiled by C. Herbert, published by the Department of Mineral Resources, Sydney, 1983.

Tall Buildings | The Implications of Increasing Height

Below Ground

The presence of fractures and defects, including major structures such as faults and dykes, may reduce allowable bearing capacities for foundations, increase groundwater inflow, and present unstable conditions for vertical excavation faces. The "Map and selected details of near vertical structural features in the Sydney CBD" indicates the presence and whereabouts of these geological features with the Sydney CBD.

In accordance with Pells et al, typical allowable bearing pressures for Sandstone Class III/II/I are in the order of 6MPa to 12MPa and for Shale Class III/II/I 3.5MPa to 8MPa. The classification system is based on the rock strength, defect spacing and allowable seams of which all three must be satisfied.

The Sandstone and Shale prevalent in Sydney across the CBD and beyond, provides good founding material for high rise towers (higher than the present limit) and results in foundation solutions which are significantly more cost effective compared to that of other tall building cities around the world.

Numerous high rise buildings up to 245m exist in the Sydney CBD, each of these buildings typically comprise of multi-storey underground car parking or basements. The depth of these structures are normally sufficient to encounter competent rock at bulk excavation level permitting the use of spread footings for present building foundation loads. Where this is not the case piled foundation solutions of varying diameter can be adopted where compressive loads cannot be achieved by spread footings or required founding material is at depth or below groundwater. Where buildings or groundwater exert tension or uplift loads to foundations these can be resisted by permanent ground anchors or tension piles socketed into the rock.

During excavation the release of high in-situ horizontal stresses within the rock results in ground movement that may affect adjacent properties, existing foundations, existing and future underground infrastructures. Assessment of the impacts of ground movement is normally a development condition of City of Sydney and to also satisfy TfNSW and other relevant stakeholder requirements.

Groundwater is present and needs to be considered for the selection of drained or tanked basements.

MAP AND SELECTED DETAILS OF NEAR VERTICAL STRUCTURAL FEATURES IN THE SYDNEY CBD

Basement Parking

As the area of a site increases, more efficient car parking layouts can be provided resulting in a high number of parking spaces per level. However, the number of spaces is greatly affected by a number of factors including, but not limited to:

- Service vehicle manoeuvring and loading;
- Circulation roads and ramps;
- Access driveway and locations;
- Shape of site;
- Area required for general building services (i.e. substations, storage, refuse area, bike store, lift core); and

This results in a range of parking spaces able to be provided for different site areas as shown below.

As one would expect, the number of car parking spaces becomes inefficient as the site area reduces. For small sites, there is a limiting width of site necessary in order to achieve a core, full round core circulation, and parking bays either side. This minimum site width equates to 23m plus the width of core plus perimeter wall thickness and tolerances. Some sites that are being developed for residential buildings greater than 250m do not achieve this criteria. As a consequence, the number of car parks achieved per level is very low and car stacking solutions have to be considered.

Tall Buildings | The Implications of Increasing Height

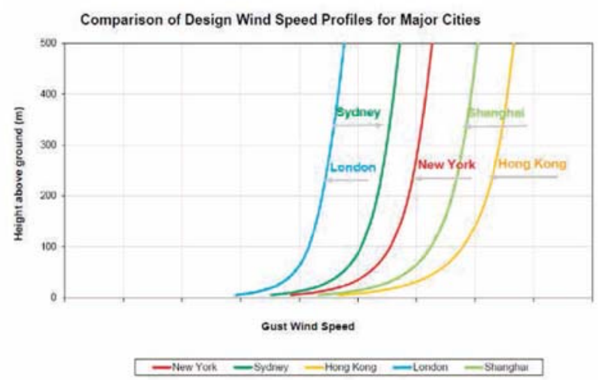
The Impact of Wind

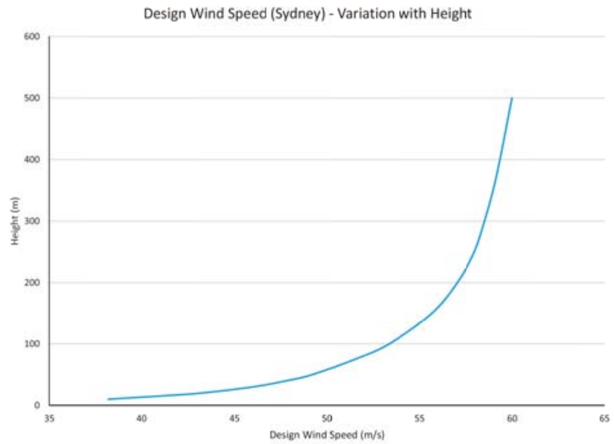
Wind Speeds

Below presents a graph of the approximate relative gust wind speeds of a number of tall building cities around the world. It should be noted that different countries treat the ultimate wind condition, used to design for the safety of buildings, quite differently. As such the relative magnitude of wind loads adopted in design might differ compared to that shown below.

It is evident however that, compered to other tall building cities around the world, the wind climate in Sydney is not particularly onerous. It would not be a factor in limiting the building height.

It should be noted that one characteristic of the wind in Sydney is that the serviceability wind, i.e. the magnitude of the regularly occurring wind is relatively high compared to other cities. As a consequence it is likely that making buildings comfortable, as discussed later, is likely to be the key consideration in the design.





Tower Height versus Lateral Displacement

Deflections, movements, accelerations

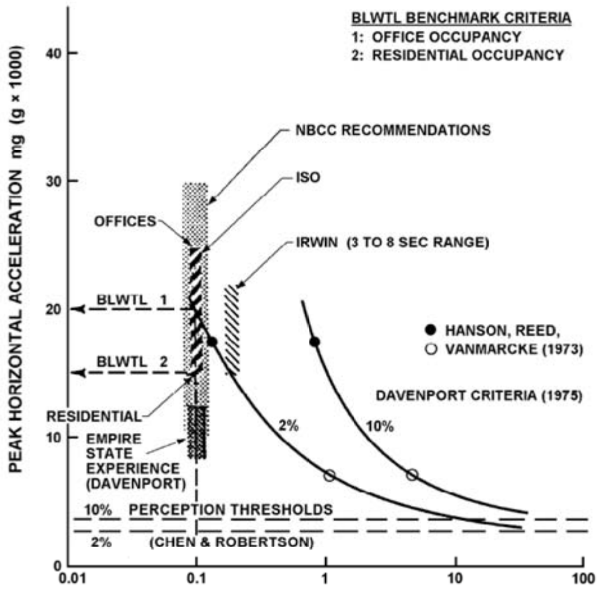
One of the key considerations in the design of tall towers is the extent by which they move laterally under wind and the need to ensure the comfort of occupants within. Key to achieving a comfortable environment is to make sure that the accelerations on the occupied floors are within acceptable limits.

The graph below shows the typical deflection limits adopted for tall buildings. This is based on a value of h/500 for a 50 year return period wind. It should be noted that this is not a mandated limit, and as such there is some variation from these typical limits depending on the specifics of the building. For a 400m high building, it is credible that the building will deflect 800mm from vertical under extreme winds.

Tall Buildings | The Implications of Increasing Height

The Impact of Wind

The comfort requirements limit the lateral accelerations to acceptable levels when the building deforms under wind loading. The graph below shows a number of internationally recognised limiting criteria. Some of the criteria depend on the dynamic period of the building, recognising that humans are less perceptive to a given acceleration if the period is longer. Some of the criteria also consider an acceptable limit as being that where the person objecting fall within a 2%-10% range.



A very simple rule of thumb, and on that is sufficient accuracy for the nature of this study is that the following acceleration limits should apply:-

- Commercial Buildings 20 mg
- Hotels 15mg
- Residential 10mg

'mg' is milli g, or put another way, 10 mg is 1% of the acceleration due to gravity.

The significant issue is that the acceleration limits for residential is significantly more stringent than that for an office building. There are a number of reasons for this:-

- Where a person owns the property, as in say a high rise apartment, there is increased awareness and anxiety of movements and 'things that might be wrong'. Less so if it is a place where you visit to work.
- People are more pereeptive to accelerations when they are relaxed, lying down – i.e. typically at home.

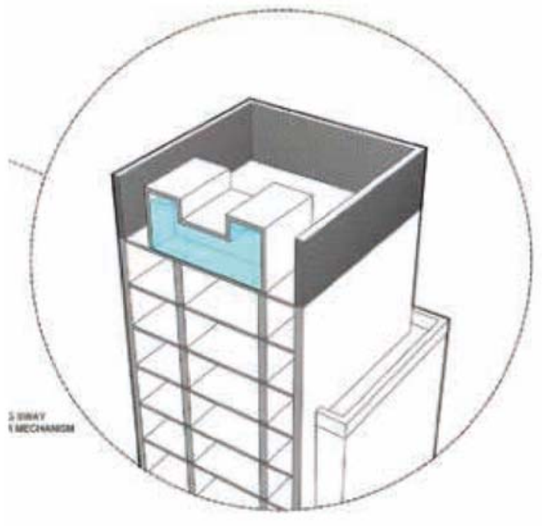
The limiting of accelerations is often a key driver of the design of residential apartments, and can have a big implication on office buildings which are mixed use and have a hotel or penthouse type accommodation in the top floors.

Ways to reduce the acceleration include:-

- Make the building stiffer
- Change the shape (make less slender)
- Increase the mass of the building (to increase period)
- Increase the damping

An approach to reducing accelerations, which is becoming increasingly more common, is to incorporate dampers into the building. Common in residential towers in Australia is to use Tuned Liquid Dampers (see figure).

The system relies on the 'tuned' sloshing of water within large tanks to dissipate energy and increase damping. For residential towers of 300m high, with an aspect ratio of 12, it could be expected that two such tanks would be required at the top of the building, each 20m long, 6m wide and 6m high (2 storey).



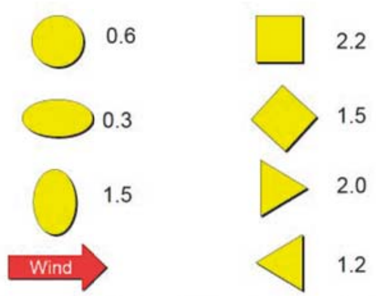
Tall Buildings | The Implications of Increasing Height

The Impact of Wind

Effect of Tower Shape

The plan shape of a tower will greatly influence the wind loading to be resisted as well as the dynamic response and accelerations. Below presents in very simplistic terms the relative 'drag factors' for different shapes. As a general rule:-

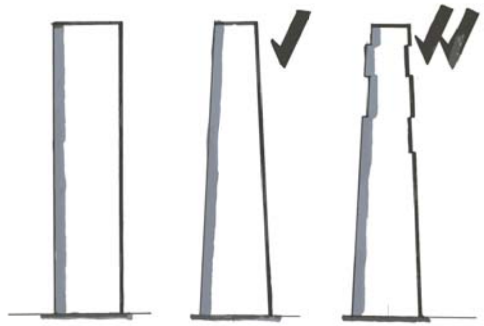
- A square shape is not ideal
- Sharp corners are best avoided.
- Chamfered or rounded corners greatly reduce wind loading.
- Overall rounded forms typically behave better.



Drag Factors - directly proportional to along-wind loading.

The above is a little simplistic, as the biggest influence on loading and dynamics of a tower more often than not dictated by its proximity to other towers, prevailing wind direction and the like.

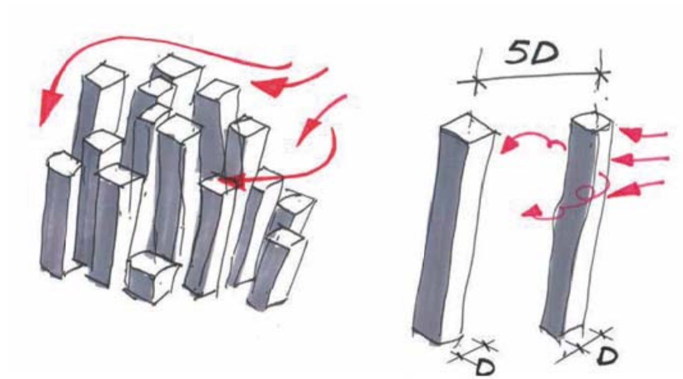
The shape of a tower in elevation is also a factor in influencing its performance under wind. In the case of tall towers, or towers with high slenderness, departures from a pure extruded form can greatly improve the dynamic response by 'confusing the wind' and reducing the effects of vortex shedding. A gentle taper over the height of the building is effective in this respect, or as an extreme, a non-symmetric elevational profile. The worlds tallest tower, the Burj Khalifa in Dubai, uses this latter effect to benefit the performance of the tower and the comfort of occupants within.



Effect of Tower location

Towers in CBD locations typically benefit from the 'cluster effect' – i.e. beneficial wind shielding due to the close proximity of similar sized towers. It should be noted however that this is not always the case. The plan form of certain buildings (triangular being a good example), can have a disturbing effect on immediately adjacent towers.

What should be avoided are significant tall towers being located 5D apart (where D is a base of tower width) and with little obstruction in-between. This approximate dimension is the classic stand-off distance where vortex shedding of one tower directly impacts the other. The impact on the behaviour of the affected tower is potentially very significant.



Tall Buildings | The Implications of Increasing Height

Fire and Life Safety

Building Code of Australia (BCA) currently treats all buildings of the same class of use >50m effective height in the same way, ie identical minimum prescriptive and the same performance requirements for

- fire resistance, compartmentalisation and protection of openings
- access and egress
- services and equipment

Australian Building Codes Board is driving more economy in construction and encourage performance based fire engineering alternative solutions. BCA 2016 will become fully performance based, with less emphasis on simple prescriptive or Deemed to Satisfy (DTS) rules.

However, historical practice has frequently adopted minimum "deemed to satisfy" BCA prescriptive provisions the design of tall buildings rather than extensive use of performance based fire engineering risk assessment. Hence typically tall buildings > 50m have adopted DTS fire resistance level requirements of 120 minutes for office areas and 90 minutes for residential areas, independent of building height.

Likewise typical tall office buildings of 1500m2 GFA have two exit stairs and residential buildings 1000m2 commonly have two exits. There have been a few engineered buildings with a single exit stair, however current trends are against these solutions due to lack of redundancy for fire brigade access.

Therefore, the future trend in fire safety design of very tall buildings is that simple prescriptive DTS rules may no longer be considered adequate. Instead, a Fire Safety Strategy will be required to be developed on addressing key aspects of the building, its fire hazards, fire safety systems and the related design approaches, aimed at meeting fire safety goals and objectives.

For very tall buildings (>200m height) Arup would recommend building owners to obtain a fire safety strategy from a professional fire safety engineer in order to ensure the most appropriate design for occupant safety and protection of adjacent properties. Building owners and their insurers also have additional requirements which can influence the fire safety design, e.g.

- property protection
- business continuity
- security against malicious attack
- marketing image

A fire safety strategy for a very tall building starts with establishing the fire and life safety goals and objectives in conjunction with overall design objectives. Key considerations will likely be:

- the building will house a large number of occupants
- occupants will have limited evacuation options
- the building needs to remain standing for the time necessary to protect occupants in place or safely evacuate them
- fire fighters will have limited access opportunities
- potential hazards include natural fire hazards and deliberate events
- potential accidental or deliberate failures of fire safety systems

Once the fire safety strategy has been established, the architect and client can then proceed with confidence with the Concept Design.

Tall Buildings | The Implications of Increasing Height

Environmental, Light and Energy

Energy Use for typical towers.

For commercial buildings energy use is typically split between tenant power and lighting and base building services such as air conditioning, ventilation, hot water and lift energy. As a tower increases in height the most significant differences in energy use per sqm are lift energy and pumping. Based on current commercial systems design with state of the art efficiency and technologies such as lift energy reclaim the variation in energy per sqm of 5% is expected per extra 100m height in Sydney.

For residential buildings the lift energy is a higher proportion. The second major impact for residential towers are degree of air-conditioning hours. Most residential tenancies are designed to use natural ventilation for the majority of the year. Mid to low rise towers wind pressures are appropriate to ventilate the building. For taller towers wind pressures increase and have the potential to change the ability to ventilate the tenancy, as a result of disturbing wind patterns residents in taller buildings may choose air conditioning to condition premises rather than natural ventilation. Typical residential energy use estimates are shown for increase in lift energy and reliance on air conditioning.

Sydney 2020 Discussion

The Sydney 2020 plan advocates a net reduction in carbon and energy however it is a typical outcome that the taller the tower the more energy they consume per sqm. They become less efficient per person than more efficient. The net outcome is that it becomes harder for Sydney to reach the 2020 energy targets. One solution might be to develop energy or carbon and water footprints based on site area. Further peak demand fooprints may be considered to help reduce impacts to distribution and support infrastructure that greater demands generate.

Discussion

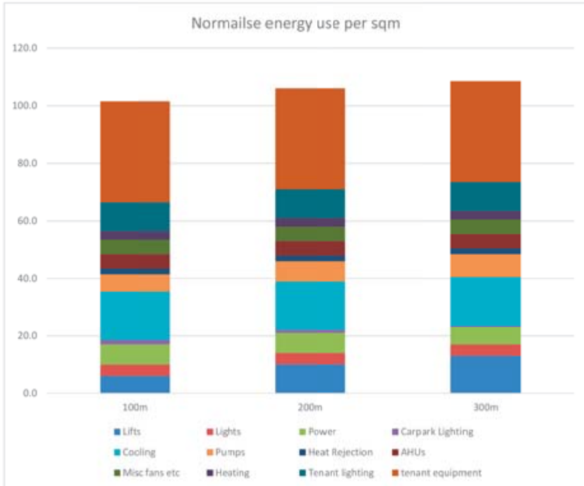
One of the major differences in energy use for towers is lifting energy. How does a 300m high tower compare to building more 100m high towers?

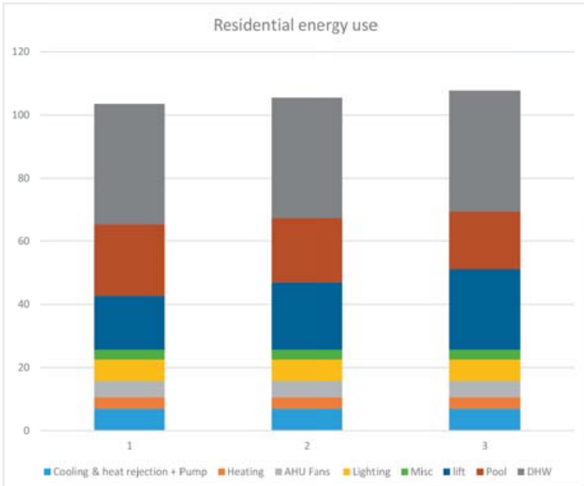
For one 300m tower, it is estimated that lifting energy increases by approximately 5kwh/m² per annum for a tower occupied typically at 1 person per 12 sqm. Thus 60kwh/person per annum.

Assuming 3 x 100m (say) spaced on average 100m apart. Using simple efficiency of car energy usage of 20kwh/100km we see that the additional horizontal travel per person is 20/1000 so 0.2 kwh.

In conclusion lift energy of a tower is not offset by horizontal travel required to build the same area for a low rise solution. As a result it is more energy efficient to space low rise towers apart assuming public transport systems are efficient.

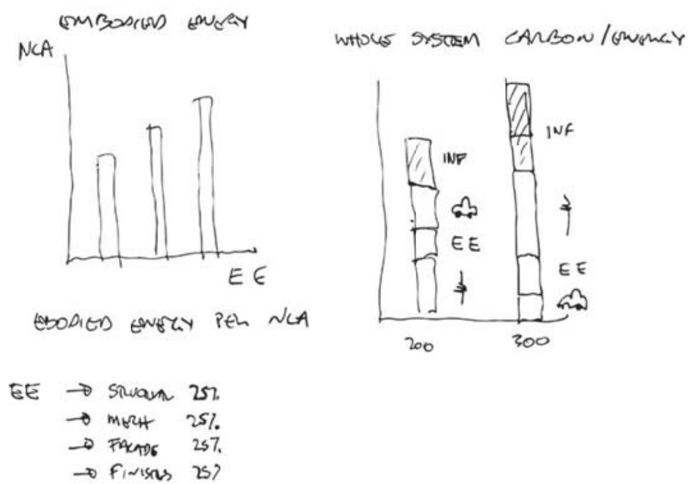
The second key discussion point is that as towers get taller the NLA efficiency decreases as lift banks take up more space as do mechanical risers. Normalizing for these times we see the following energy impacts.





Embodied Energy

The embodied energy of construction is closely related to cost and volume of construction as it is typically associated with mass. The embodied energy for construction based on energy scopes that include mining of raw materials, processing and manufacture (scope 1-3) for a typical highrise tower add to roughly 2000 MJ m2 which when considered over a 50 year design life



Environmental Impacts

As towers increase in height they have the follow key environmental impacts on the public ground plane;

- Wind impacts
- Overshadowing
- Thermal load
- Daylight.

These environmental changes may have the following impacts on public space:

- Warmer areas and heat island effects
- Colder windier areas
- Changes in tree canopy due to changes in microclimate

Some area may experience a combination of increased heat island effect and warming of the ground plane, increase evaporation, decrease in general wind speed

While others areas may see increases in localized cooling wind speeds and decrease in heat island due to overshadowing.

This following is based primarily on public space and ground plane issues. It is worth noting that different building programs will also have different environmental requirements. For example residential towers like sunlight with design guidelines nominating minimum number of hours key for areas of residential apartments should receive sunlight and ventilation whereas commercial towers try to reject sun and heat and are generally sealed away from ventilation.

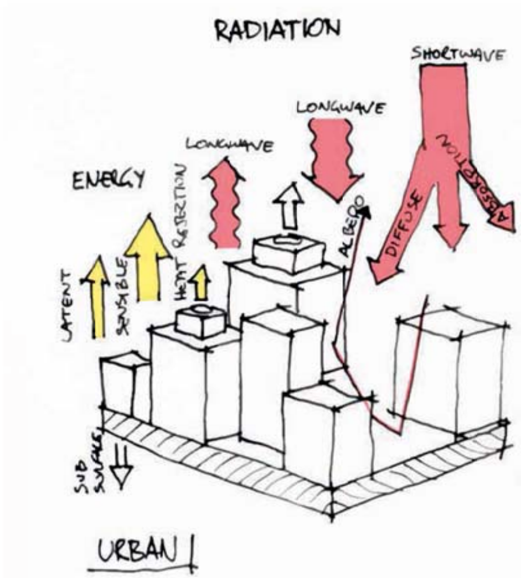
Heat Island Effect

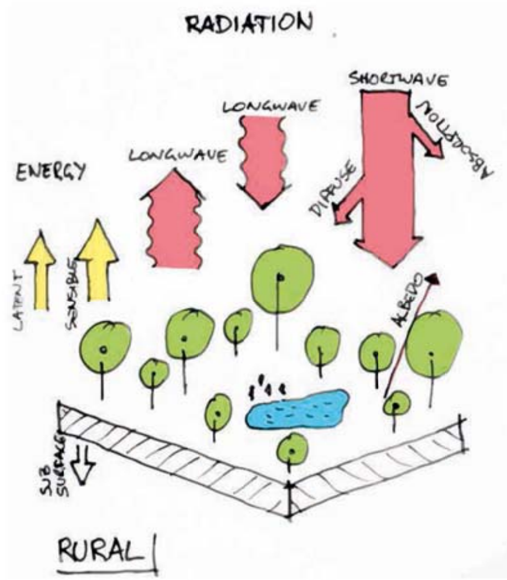
Due to high density urban development high rise cities suffer from the Urban Heat Island (UHi) effect. Urban areas are significantly warmer than the rural surroundings. As a result of the UHi effect, the number of very hot days and hot nights can increase dramatically. This leads to uncomfortable urban living, heat stress and related health problems, and an increase in energy consumption. There is a need to consider this in the planning and design of our city.

Buildings in cities are mostly constructed of concrete and reflective glass. They have higher thermal capacity than the natural environment, and therefore store a lot of heat during daytime. The heat that is stored elevating urban temperature. At night, tall buildings block the urban area's sky view and hence limit their ability to release the heat back into the atmosphere, thus elevate the night time temperature. Secondly, the tall buildings disrupt and slow the natural wind patterns especially deep in canyons created by buildings. This reduces the ability to flush out stored heat load. The residual heat carries forward to the next day and the viscous circle continues. As a result the city generates its own urban climatic conditions that are different from the rural and natural areas. Cities typically gain more heat than they lose resulting in Urban Heat Island effects (UHi).

The image below shows the difference in heat flows for Urban and Rural locations. In Urban areas incoming solar radiation is scattered by buildings, the subsequent reradiated energy is absorbed by buildings so finds it harder to escape. In addition the building themselves reject heat associated with the occupancy and their equipment. This all increases the temperature of the urban area. The rural areas however can reradiate energy to the sky more effectively as well as utilizing the foliage albedo effect to reflect energy as well as absorb excess thermal radiation.

When considering the cities whole of life energy or carbon footprint the embodied energy of a building may contribute 20% to 30% of the entire whole of life energy. Operational energy contributes the bulk of rest of the energy however embodied energy in infrastructure is also a contributor. The images show typical whole of life energy of cities. Based on typical energy uses of city systems, cities with taller building have a bigger whole of life energy impact due to the points discussed previously, namely lift energy, floor plate efficiencies and limits to ability to utilise natural systems.





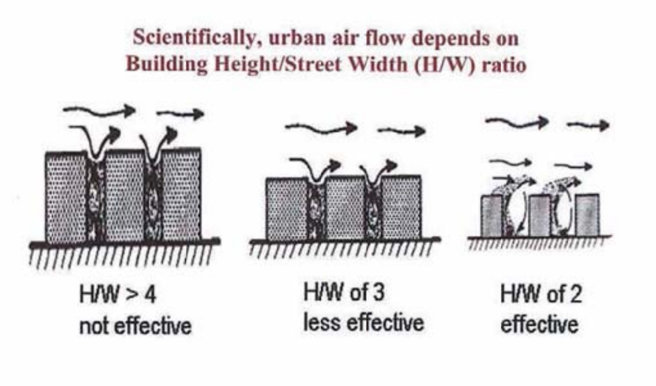
Tall Buildings | The Implications of Increasing Height

Environmental, Light and Energy

Wind

Sydney has a wind environment that has lower gust speeds than other cities with tall buildings as seen earlier in the report. The mean or average wind speeds however are higher than these cities with the exception of Hong Kong. Refer to table on page 18 - *Comparison of Design Wind Speed profiles for major Cities.*

Tall buildings affect the wind environment in two ways. Generally they increase surface roughness of the area and reduce wind speeds in Urban canyons when spaced closely together. Tall towers however also act as tall sails that can capture and funnel wind. As wind speeds are greater higher away from the ground, these towers then have the potential to funnel higher wind speeds down to ground level. Thus tall buildings will reduce general wind speeds at ground level but simultaneously increase it in some areas. Sydney's wind environment can be characterised with summer cooling breezes from the North and North East while

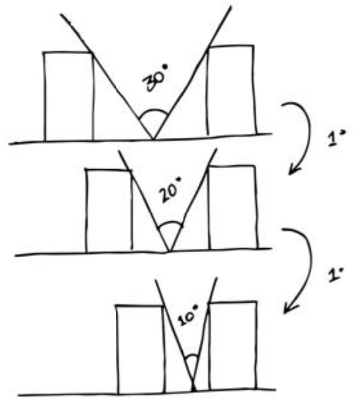


cold stronger winds come from the West and South.

Thermal Loads

Downward reflected solar load increases thermal load. Of particular note for modern towers is the use of glass and the use of high performance glazing. Modern glass is highly reflective to thermal radiation. With glass the reflectivity is relatively specular and as result it is directional. This means that solar load is reflected downward till it is caught by inter-reflections deep in the urban canyon. The ability to release this energy to the sky and atmosphere is related to the degree of sky that can be 'seen' to radiate to (Sky view) and wind driven air movement. In Urban canyons both these items are limited thus heat loads will be captured deep in urban canyons.

Finally heat island and wind driven air movement have big impacts on tree and shrub growth. Plant selection and sensitive planting needs to be well considered in urban canyons.



Discussion

Hong Kong has developed studies and planning issues on Heat island effects in the publication *Urban Climatic Map and Standards for Wind Environment - Feasibility Study, Stakeholders Engagement Digest.* This study discusses concepts of Thermal Load impacts and Dynamic Potential.

Thermal Load is affected by issues such as:

- Building thermal reflectance,
- Building spacing, massing and orientation,
- Internal building loads (lights, equipment, people),
- And tree canopy ratio.
- These defines the spacial heat balance.

Dynamic Potential is associated with ground height plane variations. This affects wind speeds, its heat flush potential, and physiological comfort. It is affected primarily by; massing, existing air paths, open spaces and ground coverage. The dynamic potential of the urban space can be mapped by using topographic and land use data. The Hong Kong studies generated maps of sensitive areas that classed areas ranging from areas with low thermal loads and high dynamic potential to remove heat impacts to areas with a high thermal load and low dynamic potential. Further consideration to this type of mapping and the associated climate resilience should be considered when establishing tools or recommendations around urban microclimate impacts of tall buildings.

It should also be noted that tall buildings cast long shadows. There guarantee localised impacts around tall building that decrease heat island as thermal loads are reduced. Urban comfort conditions in these area can be further compromised by local increases in wind speed due to down draft from tall towers. In summary, tall buildings can affect various microclimates that may be exasperate thermal discomfort due to both heating and cooling.

Any development of high rise buildings should consider the existing microclimate and Urban Heat island and set out sensitivity maps and comfort benchmarks that includes wind and thermal effects.

Daylight

There are no code requirements to provide minimum levels daylight to developments in Australia. There is no case in which 'poor' daylight performance could be considered as 'breaking the law'.

Internationally there are several documents proposing 'good practice' daylight performance. This includes the British Standard BS8206 part 2: 1992 – 'Lighting for buildings: Code of practice for 'daylighting'. This document sets targets for daylight penetration into residential dwellings in terms of the Average Daylight Factor. The Green Star sustainability good practice tool calls up similar metrics.

There is also BRE report BR209 – "Site layout planning for daylight and sunlight: a guide to "good practice". The BR209 document provides advice on the planning of the external environment to provide good daylighting and sunlighting within buildings and in the open spaces between them. The document does not address high rise construction impact however the principles will remain the same in Urban settings and have been used for projects such as the Athletes village isn't London. This document sets targets for Vertical Sky Components (VSC)

The 2 key Daylighting Metrics typicaly used for considering daylight in urban spaces are then:

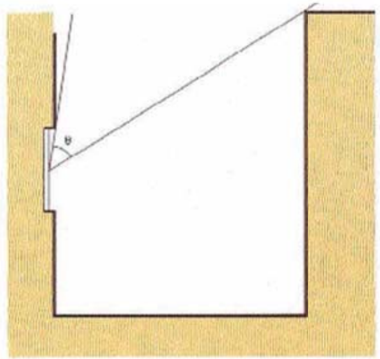
- Average Daylight Factor
- Vertical Sky Component

Average Daylight Factor (ADF)

The level of daylight penetration into a room is measured by use of the ADF. The daylight factor requires computer simulation and can be allpied to a variety of functional types such as domestic, commercial and retail spaces. Each of these spaces, or parts of these spaces, will usually have a target ADF as good practice and it is recommended that any consideration of high rise development consider developing these targets.

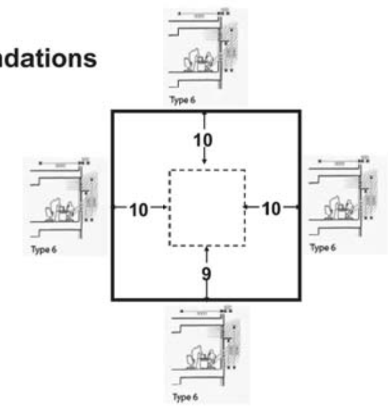
The VSC is a measure of daylight received on the outside of a window (or where a window could be placed). As a result this metric is a good metric to use for massing. Appropriate VSC targets for urban areas should be investigated for Sydney. Targets around 25% have been considered for British projects.

Most daylight and sunlight considerations are based on human occupation requirements however the prevalence of Photovoltiac technology should be considered in future considerations to rights to light.

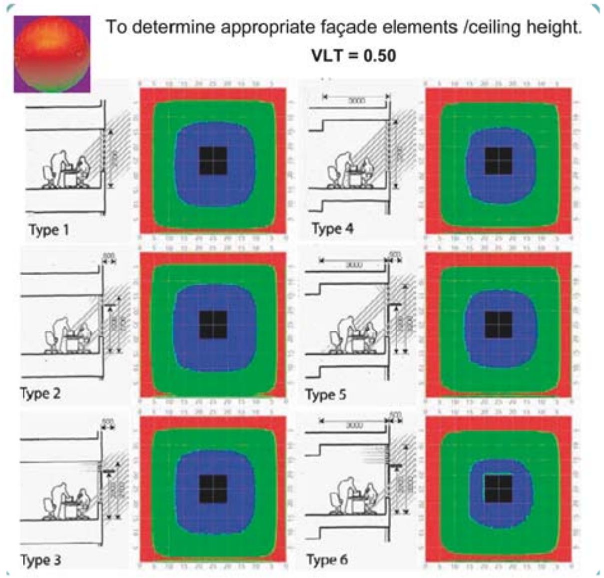


Angle of Sky View from Window Centre (plan/section)

Design Recommendations



	VLT	Light Shelves	Daylight Redirectors	Maximum Floor Plate Depth
North	0.3 - 0.5	✓	✓	10
East	0.3 - 0.5	✓	✓	10
South	0.3 - 0.5	✓	✓	9
West	0.3 - 0.5	✓	✓	10



Sydney has a mix of overcast, intermediate and clear skies. Areas with bright daylight levels appear up to 5 inwards. Brightness areas appear up to 2 m along the southern facade. The UDI depth is generally 7 to 8 m for the lower ceiling configurations and between 8 and 10 m for the higher ceiling configurations.

For the lower ceiling configuration the UDI depth does generally not increase with external light shelves and daylight redirectors. All facades with a higher ceiling configuration benefit from having light shelves and daylight redirectors. The UDI depth can be increased by approximately 1 m. Light shelves alone do not significantly increase the UDI depth for any of the facades.

Although very similar, the UDI along the eastern and western facade is slightly less for the simulation with the cumulative direct + diffuse sky, as the influence of the sun increases the bright area but does not significantly reduce the dark area. This suggests that shading devices may be appropriate along those facades.

Tall Buildings | The Implications of Increasing Height

Environmental, Light and Energy

Other potential impacts

Ground plane issues

As the number of people occupying the building increase the energy demands of the site increase. This is particularly true for single program building, for example commercial. The infrastructure services outside the building footprint to support this increases density include;

- Electrical distribution and substations
- Water and Sewer reticulation
- Gas reticulation and boosters
- Communication systems
- Roads, Bike lanes, pedestrian walkways and public transport.

The augmentation of these systems to support greater development is by third party providers and part of economic development. This augmentation may present disruption to public space during construction and enhancement of this infrastructure. For example electrical distribution and connections may need to upgraded local to the building but also back to zone substations. Similarly, sewerage pipes may need to be increased in size and capacity to remove larger blackwater flows.

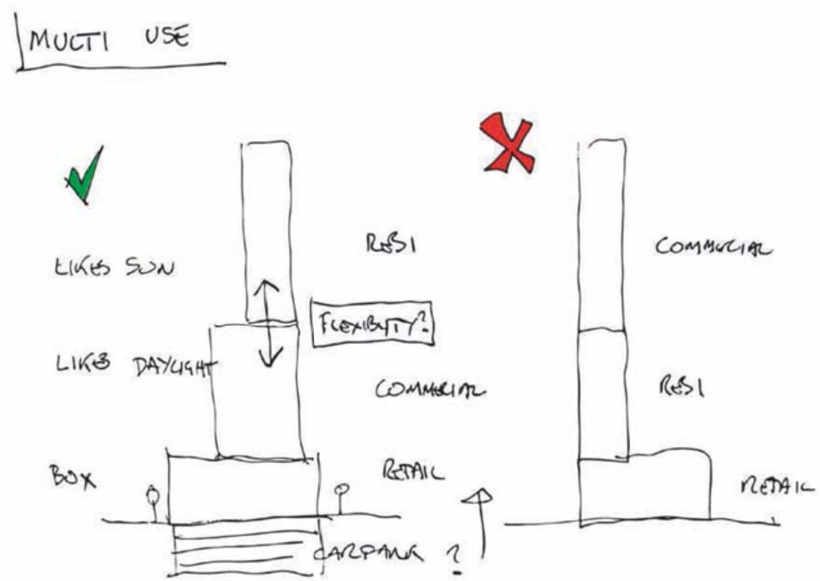
It may also add to congestion of the ground plane with back of house connections to infrastructure such as access to sub stations, carparks and loading bays. This limits the ground plane activation.

Substations

Currently buildings that require substations are required to have one at road level however they may apply to place a basement substation one floor down from road level as long as there is access to replace transformers. This affects the ground plane. Tall buildings often require 2 or 3 substations. These additional substations may be located up the building as long as there is one at ground or basement level. However it is sometimes cheaper to have them all at the ground plane having significant impact on the ground plane. This should be considered when developing the building ground plane impacts.

Pollution

Increased congestion on roads may be limited by limiting the number of car parking spaces, however additional usage of roads for supply and removal of goods and waste, taxis and occasional pick up and drop off will also increase, this leads to a net increase in pollution in the city environs.



Tall Buildings | The Implications of Increasing Height

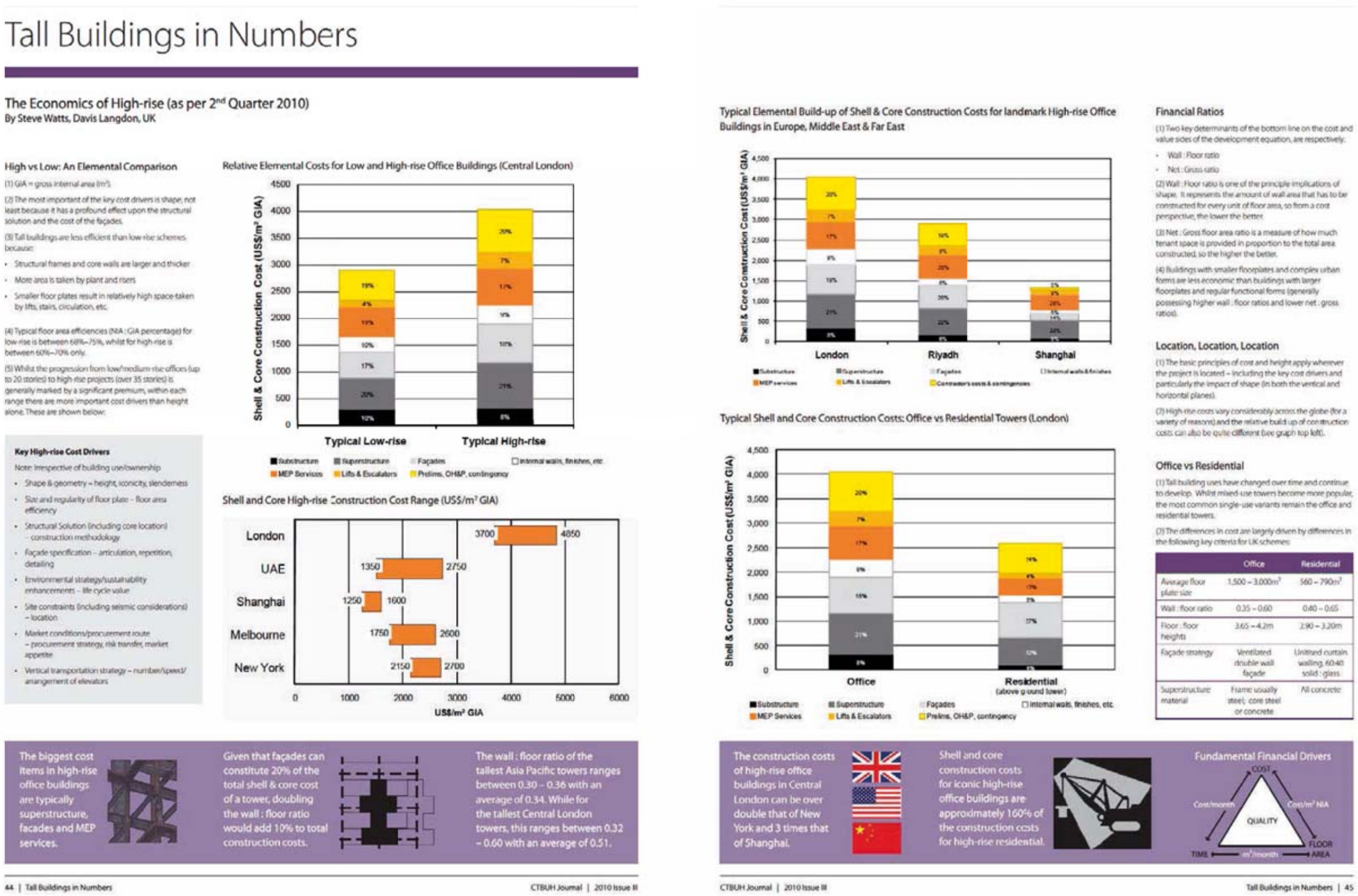
References

1. Council of Tall Buildings and Urban Habitat (CTBUH), Website, Tall Buildings in Numbers, Economics of High Rise - 2010.
2. RLB Construction Cost Guide 2015.
3. Council of Tall Buildings and Urban Habitat (CTBUH), Website, Tall Buildings in Numbers, Green Walls in High Rise Buildings 2014.
4. Council of Tall Buildings and Urban Habitat (CTBUH), Website, Skyscraper Centre Database.
5. Property Council of Australia - A Guide to Office Building Quality 2012
6. Chartered Institution of Building Services Engineers (CIBSE) - Guide D

Tall Buildings | The Implications of Increasing Height

Appendix A | Tall Buildings in Numbers

1005



Tall Buildings in Numbers

The Economics of High-rise (as per 2nd Quarter 2010)

By Steve Watts, Davis Langdon, UK

High vs Low: An Elemental Comparison

(1) GIA = gross internal area (m²)

(2) The most important of the key cost drivers is shape, not least because it has a profound effect upon the structural solution and the cost of the façades.

(3) Tall buildings are less efficient than low-rise schemes because:

- Structural frames and core walls are larger and thicker
- More area is taken by plant and risers
- Smaller floor plates result in relatively high space taken by lifts, stairs, circulation, etc.

(4) Typical floor area efficiencies (NIA : GIA percentage) for low-rise is between 68%–75%, whilst for high-rise is between 60%–70% only.

(5) Whilst the progression from low/medium-rise offices (up to 20 stories) to high-rise projects (over 35 stories) is generally marked by a significant premium, within each range there are more important cost drivers than height alone. These are shown below:

Key High-rise Cost Drivers

Note: Irrespective of building use/ownership

- Shape & geometry – height, iconicity, slenderness
- Size and regularity of floor plate – floor area efficiency
- Structural Solution (including core location) – construction methodology
- Façade specification – articulation, repetition, detailing
- Environmental strategy/sustainability enhancements – life cycle value
- Site constraints (including seismic considerations) – location
- Market conditions/procurement route – procurement strategy, risk transfer, market appetite
- Vertical transportation strategy – number/speed/arrangement of elevators

The biggest cost items in high-rise office buildings are typically superstructure, facades and MEP services.

Given that façades can constitute 20% of the total shell & core cost of a tower, doubling the wall : floor ratio would add 10% to total construction costs.

The wall : floor ratio of the tallest Asia Pacific towers ranges between 0.30 – 0.36 with an average of 0.34. While for the tallest Central London towers, this ranges between 0.32 – 0.60 with an average of 0.51.

Financial Ratios

(1) Two key determinants of the bottom line on the cost and value sides of the development equation, are respectively:

- Wall : Floor ratio
- Net : Gross ratio

(2) Wall : Floor ratio is one of the principle implications of shape. It represents the amount of wall area that has to be constructed for every unit of floor area, so from a cost perspective, the lower the better.

(3) Net : Gross floor area ratio is a measure of how much tenant space is provided in proportion to the total area constructed, so the higher the better.

(4) Buildings with smaller floorplates and complex urban forms are less economic than buildings with larger floorplates and regular functional forms (generally possessing higher wall : floor ratios and lower net : gross ratios).

Location, Location, Location

(1) The basic principles of cost and height apply wherever the project is located – including the key cost drivers and particularly the impact of shape (in both the vertical and horizontal planes).

(7) High-rise costs vary considerably across the globe (for a variety of reasons) and the relative build up of construction costs can also be quite different (see graph top left).

Office vs Residential

(1) Tall building uses have changed over time and continue to develop. Whilst mixed-use towers become more popular, the most common single-use variants remain the office and residential towers.

(3) The differences in cost are largely driven by differences in the following key criteria for UK schemes:

	Office	Residential
Average floor plate size	1,500 – 3,000m²	560 – 790m²
Wall : floor ratio	0.35 – 0.60	0.40 – 0.65
Floor : floor heights	3.65 – 4.2m	2.90 – 3.20m
Façade strategy	Ventilated double wall façade	Unitised curtain walling, 60:40 solid : glass
Superstructure material	Frame usually steel; core steel or concrete	All concrete

The construction costs of high-rise office buildings in Central London can be over double that of New York and 3 times that of Shanghai.

Shell and core construction costs for iconic high-rise office buildings are approximately 160% of the construction costs for high-rise residential.

Tall Buildings | The Implications of Increasing Height

Appendix B | Green Walls in High Rise Buildings

Tall Buildings in Numbers

Green Walls in High-Rise Buildings

For centuries, green walls have been used to shade building walls and atriums, to shield buildings from wind, and to cultivate agricultural plants. Now, as the world population urbanizes, green walls have become a significant tool in the quest for greater sustainability in the tall-building field. The latest CTBUH technical guide, *Green Walls in High-Rise Buildings*, provices a thorough investigation of the methods used around the world for implementation cf vertical vegetation at height. In commemoration of the release of this important guide, Tall Buildings in Numbers profiles the 18 case study buildings included.

To purchase your copy of *Green Walls in High-Rise Buildings* visit: https://store.ctbuh.org

Location of Case Studies and Size/Percentage of their Green Coverage

One PNC Plaza
Pittsburgh, 2009
Building Height: 129 meters
Stories: 30
Total surface area of green coverage: 221 m²
Largest green coverage on a single façade: 221 m² (5%)
Green coverage of total façade: 1%

Athenaeum Hotel
London, 2009
Building Height: 48 meters
Stories: 9
Total surface area of green coverage: 256 m²
Largest green coverage on a single façade: 159 m² (9%)
Green coverage of total façade: 9%

B3Hotel Virrey
Bogota, 2011
Building Height: 30 meters
Stories: 9
Total surface area of green coverage: 264 m²
Largest green coverage on a single façade: 264 m² (49%)
Green coverage of total façade: 15%

Consorcio Santiago
Santiago, 1993
Building Height: 58 meters
Stories: 17
Total surface area of green coverage: 2,293 m²
Largest green coverage on a single façade: 2,066 m² (43%)
Green coverage of total façade: 22%

Hotel Intercontinental
Santiago, 2011
Building Height: 52 meters
Stories: 16
Total surface area of green coverage: 1,590 m²
Largest green coverage on a single façade: 1,302 m² (60%)
Green coverage of total façade: 29%

Bosco Verticale
Milan, 2013
Building Height: 112 meters
Stories: 27
Total surface area of green coverage: 10,142 m²
Largest green coverage on a single façade: 1,735 m² (47%)
Green coverage of total façade: 42%

The floors with green walls at Consorcio, Santiago, Chile, use 35% less energy than the floors without green walls in the same building.

The agriculture and greenery in Pasona Headquarters, Tokyo, Japan, has been attributed to 12% productivity gains and a 23% reduction in employee absences due to ailments.

Singapore's Parkroyal on Pickering provides 215% of the greenery that existed on the site before the building was built.

52 | Tall Building in Numbers CTBUH Journal | 2014 Issue III

Solaris
Singapore, 2011
Building Height: 79 meters
Stories: 15
Total surface area of green coverage: 3,065 m²
Largest green coverage on a single façade: 1,449 m² (N/A)
Green coverage of total façade: 15%

The Met
Bangkok, 2009
Building Height: 231 meters
Stories: 69
Total surface area of green coverage: 7,170 m²
Largest green coverage on a single façade: 3,385 m² (18%)
Green coverage of total façade: 14%

IDEO Morph 38 Tower
Bangkok, 2013
Building Height: 134 meters
Stories: 32
Total surface area of green coverage: 5,850 m²
Largest green coverage on a single façade: 1,226 m² (66%)
Green coverage of total façade: 22%

ACROS Fukuoka
Fukuoka, 1995
Building Height: 60 meters
Stories: 14
Total surface area of green coverage: 5,326 m²
Largest green coverage on a single façade: 5,326 m² (84%)
Green coverage of total façade: 28%

Pasona Headquarters
Tokyo, 2010
Building Height: 34 meters
Stories: 9
Total surface area of green coverage: 1,224 m²
Largest green coverage on a single façade: 720 m² (37%)
Green coverage of total façade: 20%

Building Functions

Across the 18 case studies, there are four different types of building functions. Green walls are thus clearly applicable across multiple building types and functions.

Newton Suites
Singapore, 2007
Building Height: 120 meters
Stories: 36
Total surface area of green coverage: 1,274 m²
Largest green coverage on a single façade: 734 m² (21%)
Green coverage of total façade: 10%

Gramercy Skypark
Makati, 2013
Building Height: 244 meters
Stories: 73
Total surface area of green coverage: 189 m²
Largest green coverage on a single façade: 138 m² (1%)
Green coverage of total façade: 0.4%

PARKROYAL on Pickering
Singapore, 2012
Building Height: 89 meters
Stories: 15
Total surface area of green coverage: 4,027 m²
Largest green coverage on a single façade: 2,257 m² (16%)
Green coverage of total façade: 11%

School of the Arts
Singapore, 2010
Building Height: 56 meters
Stories: 10
Total surface area of green coverage: 6,446 m²
Largest green coverage on a single façade: 1,434 m² (53%)
Green coverage of total façade: 38%

Helios Residences
Singapore, 2011
Building Height: 94 meters
Stories: 20
Total surface area of green coverage: 1,652 m²
Largest green coverage on a single façade: 1,142 m² (15%)
Green coverage of total façade: 7%

CH2 Council House 2
Melbourne, 2006
Building Height: 42 meters
Stories: 10
Total surface area of green coverage: 420 m²
Largest green coverage on a single façade: 420 m² (19%)
Green coverage of total façade: 7%

Trio Apartments
Sydney, 2009
Building Height: 39 meters
Stories: 16
Total surface area of green coverage: 139 m²
Largest green coverage on a single façade: 139 m² (5%)
Green coverage of total façade: 0.7%

The Bosco Verticale, Milan, Italy, has the largest total percentage of green coverage in the guide, at 42%, and the largest total surface-area coverage at 10,142 m².

The tallest green wall in the guide is at The Met, Bangkok, Thailand, rising about 200 meters in a thin strip. The building's overall green wall coverage is about 14%.

One Central Park, Sydney (submitted too late to make the guide) won the CTBUH 2014 Best Tall Building: Asia & Australasia award for its innovative use of heliostats and vertical greenery.

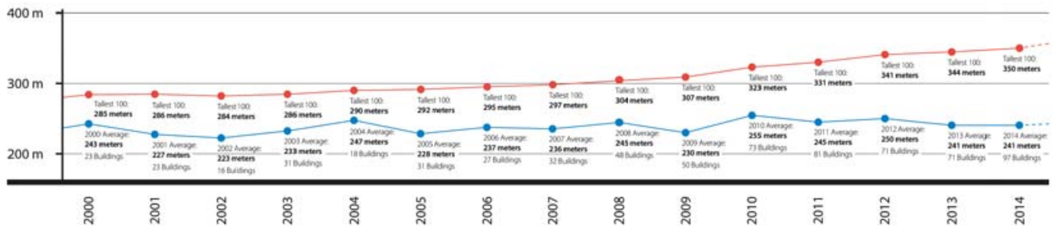
CTBUH Journal | 2014 Issue III Tall Building in Numbers | 53

Tall Buildings | The Implications of Increasing Height

Appendix C | Average Height of World Tall Buildings

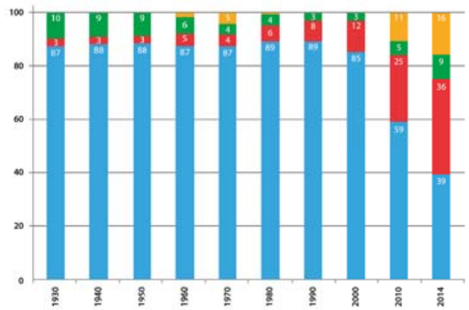
The Average Height of the Tallest Buildings

- The average height of the 100 tallest buildings in existence around the world that year
- The average height of all 200m+ buildings completed that year



Note: One tall building 200 m+ in height was also completed during 2014 in these cities: Brisbane, Busan, Changsha, Foshan, Haikou, Hanoi, Harbin, Istanbul, Izmir, Jeddah, Jinan, Kuala Lumpur, Kunming, Kuwait City, Liuzhou, London, Manila, Melbourne, Nanjing, Nanning, Nantong, Osaka, Riyadh, Santiago, Shenzhen, Singapore, Taipei, Taiyuan, Zhengzhou

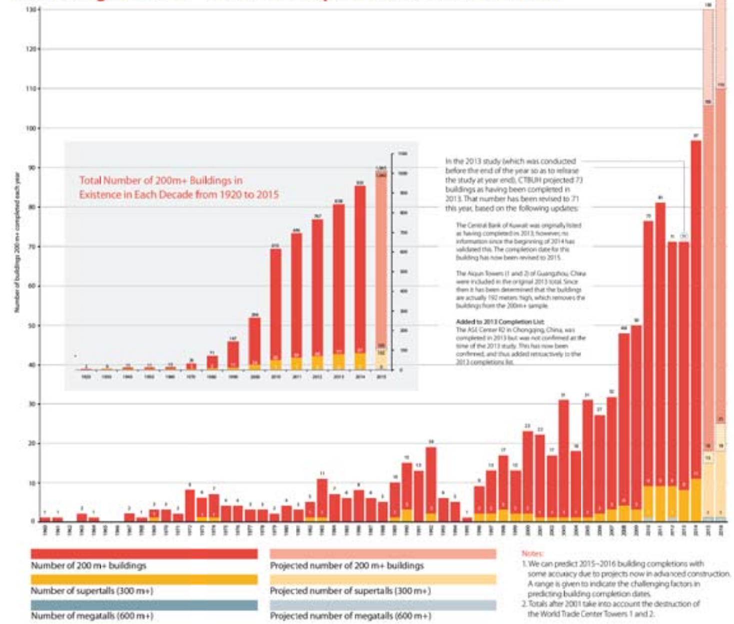
2014 Completions: 200m+ Buildings by City



100 tallest buildings by function

Office | Mixed-use | Hotel | Residential

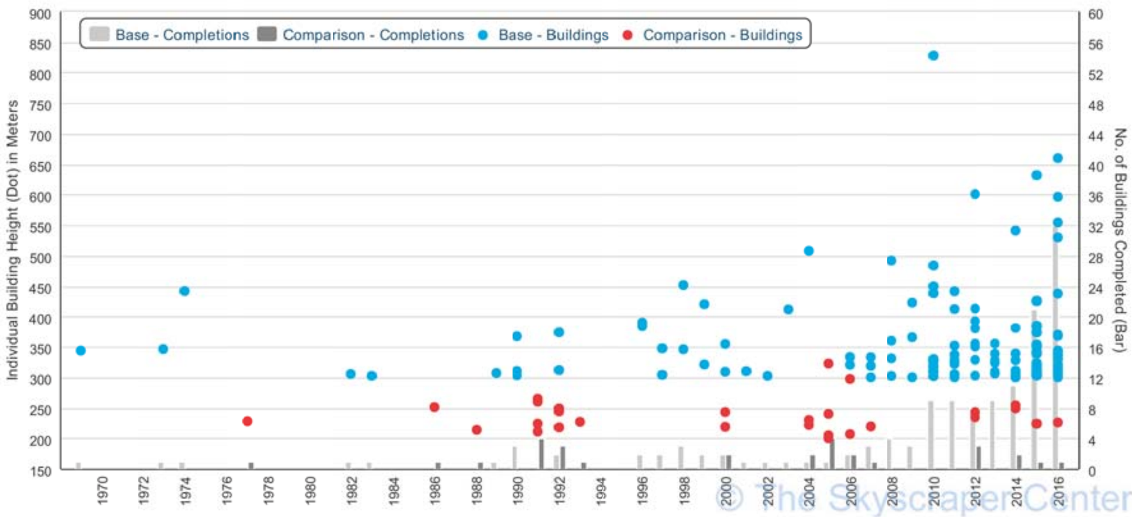
Tall Buildings 200 Meters or Taller Completed Each Year from 1960 to 2016



Tall buildings 200 meters or taller completed each year from 1960 to 2016, Inset: Total Number of 200m+ Buildings in Existence © CTBUH

Tall Buildings | The Implications of Increasing Height

Appendix C | Average Height of World Tall Buildings



The Skyscraper Center

The Global Tall Building Database of the CTBUH

This PDF was downloaded from The Skyscraper Center on 2015/07/22
For the most up to date version, please visit http://skyscrapercenter.com

Building/Tower List

Completed | Architecturally Topped Out | Structurally Topped Out | Under Construction | On Hold | Never Completed | Proposed | Vision | Demolished

Base Data
All Regions, All Companies, 300m+, 1960-2016

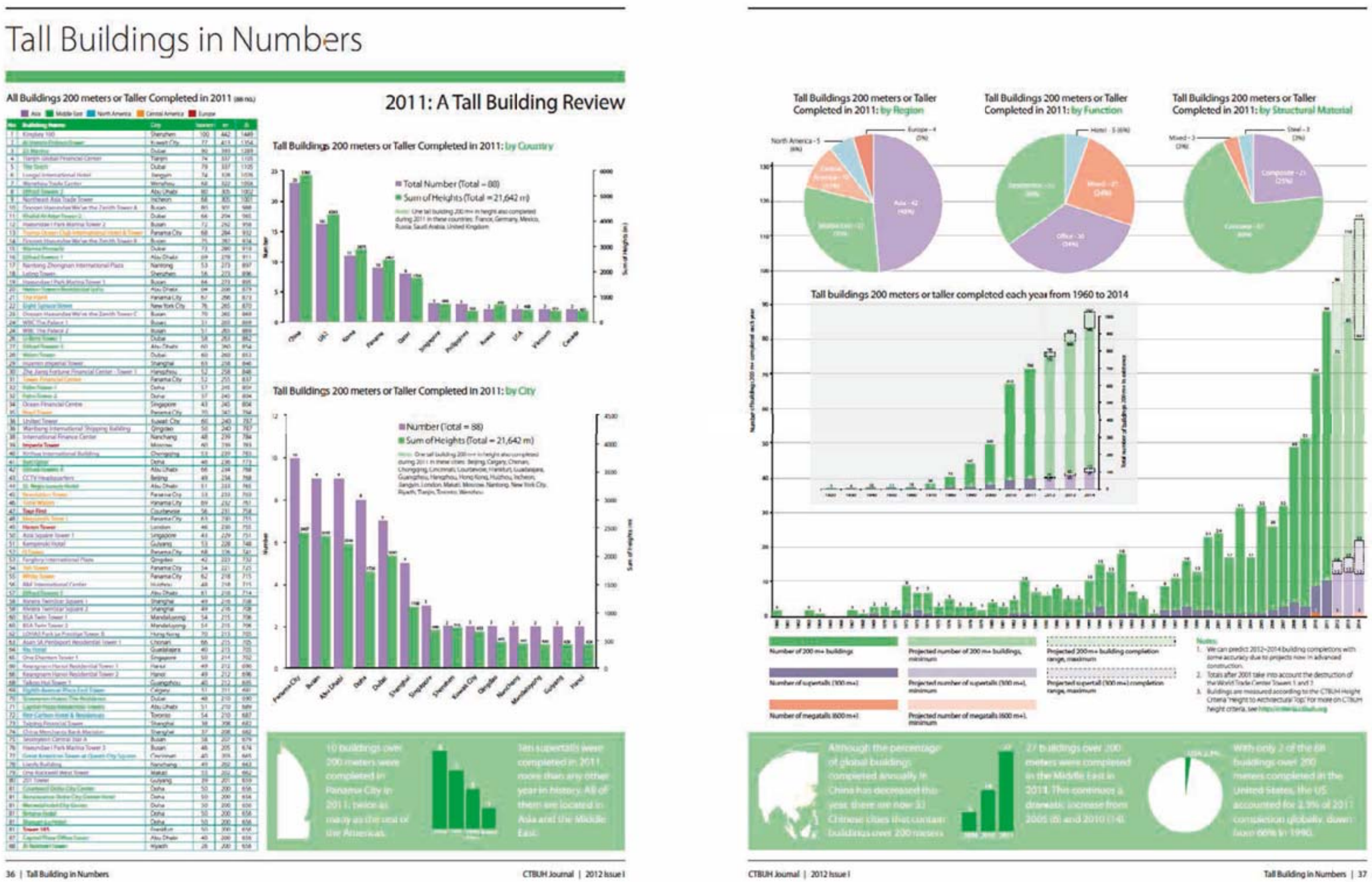
#	Building Name	Meters	Floors	Year	Material
1	Burj Khalifa	828	163	2010	steel/concrete
2	Ping An Finance Center	660	115	2016	composite
3	Shanghai Tower	632	128	2015	composite
4	Makkah Royal Clock Tower Hotel	601	120	2012	steel/concrete
5	Goldin Finance 117	596.5	128	2016	composite
6	Lotte World Tower	554.5	123	2016	composite
7	One World Trade Center	541.3	94	2014	composite
8	Guangzhou CTF Finance Centre	530	111	2016	composite
9	TAIPEI 101	508	101	2004	composite
10	Shanghai World Financial Center	492	101	2008	composite
11	International Commerce Centre	484	108	2010	composite
12	Petronas Twin Tower 1	451.9	88	1998	composite
12	Petronas Twin Tower 2	451.9	88	1998	composite
14	Zifeng Tower	450	66	2010	composite
15	Willis Tower	442.1	108	1974	steel
16	KK100	441.8	100	2011	composite
17	Guangzhou International Finance Center	438.6	103	2010	composite
18	Wuhan Center Tower	438	88	2016	composite
19	Marina 101	426.5	101	2015	concrete
20	432 Park Avenue	425.5	88	2015	concrete
21	Trump International Hotel & Tower	423.2	98	2009	concrete
22	Jin Mao Tower	420.5	88	1999	composite
23	Princess Tower	413.4	101	2012	steel/concrete
24	Al Hamra Tower	412.6	80	2011	concrete
25	Two International Finance Centre	412	88	2003	composite
26	23 Marina	392.4	88	2012	concrete
27	CITIC Plaza	390.2	80	1996	concrete
28	Capital Market Authority Tower	385	76	2015	composite
29	Shun Hing Square	384	69	1996	composite
30	Eton Place Dalian Tower 1	383.1	80	2015	composite
31	Burj Mohammed Bin Rashid Tower	381.2	88	2014	concrete
32	Elite Residence	380.5	87	2012	concrete
33	Central Plaza	373.9	78	1992	concrete
34	Federation Towers - Vostok Tower	373.7	95	2015	concrete
35	Dalian International Trade Center	370.1	86	2016	composite
36	The Address The BLVD	368	72	2016	concrete
37	Bank of China Tower	367.4	72	1990	composite
38	Bank of America Tower	365.8	55	2009	composite
39	Almas Tower	360	68	2008	concrete
40	JW Marriott Marquis Hotel Dubai Tower 1	355.4	82	2012	concrete
40	JW Marriott Marquis Hotel Dubai Tower 2	355.4	82	2013	concrete
42	Emirates Tower One	354.6	54	2000	composite
43	OKO - Residential Tower	353.6	85	2015	concrete

Comparison Data
Oceania, All Companies, 200m+, 1960-2016

#	Building Name	Meters	Floors	Year	Material
1	Q1 Tower	322.5	78	2005	concrete
2	Eureka Tower	297.3	91	2006	concrete
3	120 Collins Street	264.9	52	1991	concrete
4	101 Collins Street	260	50	1991	composite
5	Prima Pearl Apartments	254	72	2014	concrete
6	Rialto Towers	251.1	63	1986	concrete
7	Central Park Tower	249	52	1992	concrete
8	Infinity	249	81	2014	concrete
9	Chifley Tower	244	50	1992	steel
10	Soleil	243	79	2012	concrete
11	Citigroup Centre	243	50	2000	concrete
12	Soul	242.6	76	2012	concrete
13	Deutsche Bank Place	240	39	2005	composite
14	Brookfield Place	234.4	45	2012	composite
15	World Tower	230	73	2004	concrete
16	MLC Centre	228	60	1977	concrete
17	Governor Phillip Tower	227	54	1993	composite
18	Vision Apartments	226	69	2016	concrete
19	568 Collins Street	224	68	2015	composite
20	Bourke Place	224	49	1991	concrete
21	Ernst & Young Tower at Latitude	222	45	2004	concrete
22	Circle on Cavill North Tower	219.5	70	2007	concrete
23	Aurora Place	218.9	41	2000	concrete
24	Telstra Corporate Building	218	47	1992	concrete
25	BankWest Tower	214	52	1988	concrete
26	Melbourne Central	211	53	1991	composite
27	Aurora	207	69	2006	concrete
28	Freshwater Place Residential Tower	205	63	2005	concrete
29	Riparian Plaza	200	53	2005	concrete

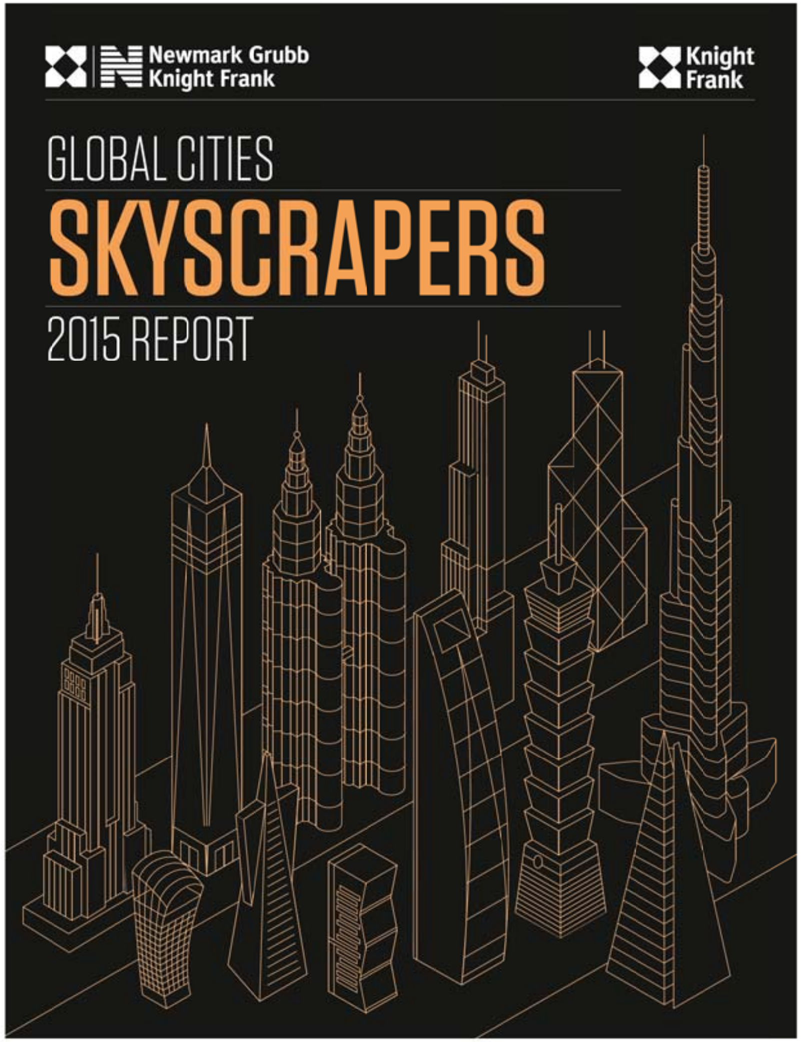
Tall Buildings | The Implications of Increasing Height

Appendix C | Average Height of World Tall Buildings



Tall Buildings | The Implications of Increasing Height

Appendix D | Knight Frank



1066

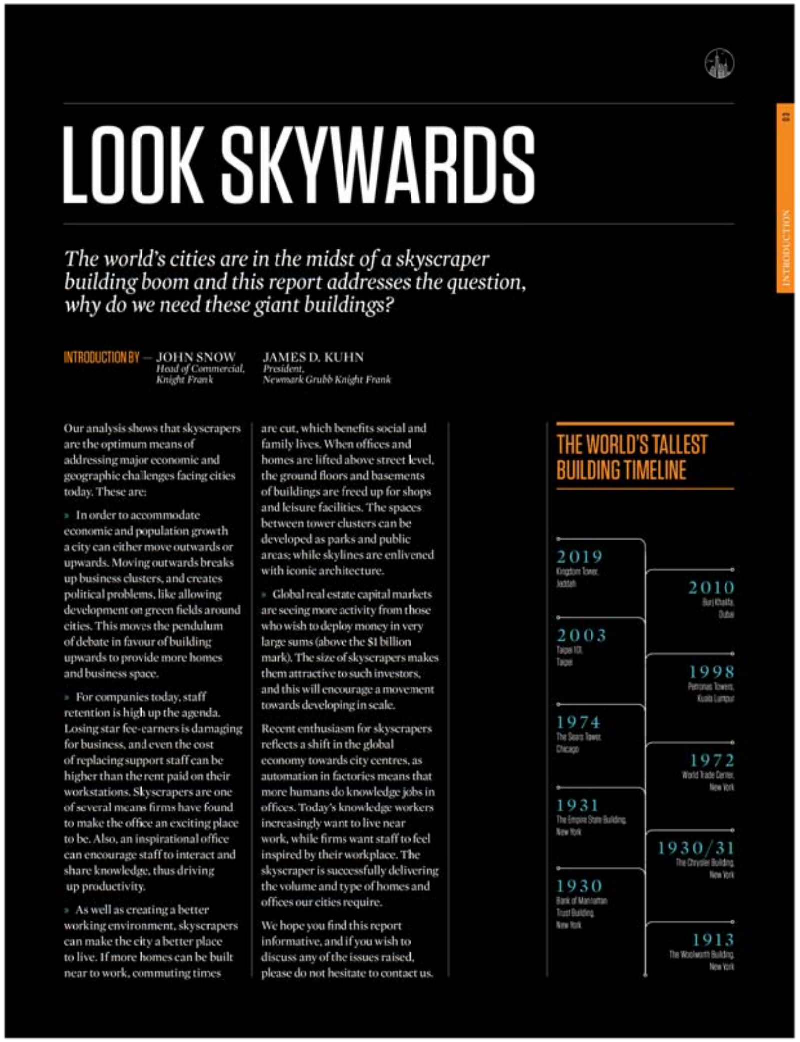
Tall Buildings | The Implications of Increasing Height

Appendix D | Knight Frank

1061

GLOBAL CITIES | SKYSCRAPERS 2015 REPORT

TABLE OF CONTENTS



LOOK SKYWARDS

The world's cities are in the midst of a skyscraper building boom and this report addresses the question, why do we need these giant buildings?

INTRODUCTION BY — JOHN SNOW, *Head of Commercial, Knight Frank* | JAMES D. KUHN, *President, Newmark Grubb Knight Frank*

Our analysis shows that skyscrapers are the optimum means of addressing major economic and geographic challenges facing cities today. These are:

» In order to accommodate economic and population growth a city can either move outwards or upwards. Moving outwards breaks up business clusters, and creates political problems, like allowing development on green fields around cities. This moves the pendulum of debate in favour of building upwards to provide more homes and business space.

» For companies today, staff retention is high up the agenda. Losing star fee-earners is damaging for business, and even the cost of replacing support staff can be higher than the rent paid on their workstations. Skyscrapers are one of several means firms have found to make the office an exciting place to be. Also, an inspirational office can encourage staff to interact and share knowledge, thus driving up productivity.

» As well as creating a better working environment, skyscrapers can make the city a better place to live. If more homes can be built near to work, commuting times are cut, which benefits social and family lives. When offices and homes are lifted above street level, the ground floors and basements of buildings are freed up for shops and leisure facilities. The spaces between tower clusters can be developed as parks and public areas; while skylines are enlivened with iconic architecture.

» Global real estate capital markets are seeing more activity from those who wish to deploy money in very large sums (above the $1 billion mark). The size of skyscrapers makes them attractive to such investors, and this will encourage a movement towards developing in scale.

Recent enthusiasm for skyscrapers reflects a shift in the global economy towards city centres, as automation in factories means that more humans do knowledge jobs in offices. Today's knowledge workers increasingly want to live near work, while firms want staff to feel inspired by their workplace. The skyscraper is successfully delivering the volume and type of homes and offices our cities require.

We hope you find this report informative, and if you wish to discuss any of the issues raised, please do not hesitate to contact us.

THE WORLD'S TALLEST BUILDING TIMELINE

INTRODUCTION 03

Tall Buildings | The Implications of Increasing Height

Appendix D | Knight Frank

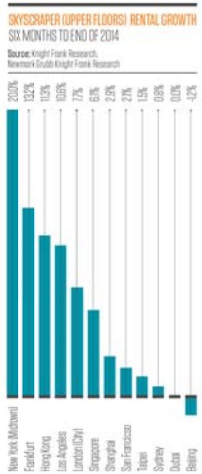
GLOBAL CITIES | SKYSCRAPERS 2015 REPORT

TOWERING ABOVE THE REST

From New York to Shanghai, companies want exciting new work places to inspire staff, while more people want to live near work. The skyscraper is seen as the best way to achieve these goals.

WRITTEN BY – JAMES ROBERTS
Chief Economist, Knight Frank

Dubai: The city has added almost 190 skyscrapers since 2000



Skyscrapers are a rising tide in the modern global city. London has added 23 new skyscrapers (a building over 350 feet high) since the turn of the millennium, compared to 17 in the preceding forty years. While New York added four new towers in 2014 alone, including the iconic One World Trade Center. This sounds impressive until one considers that Dubai has built nearly 190 skyscrapers since 2000, and Shanghai over 90.

The new enthusiasm for skyscrapers is partly one of city status. Less mentioned are recent changes in how firms perceive offices, particularly in relation to their workers.

In the past, offices were typically viewed as a cost that companies wanted to minimise, with little thought given to how they could boost productivity. Consequently, in the 1970s and 1980s, offices that were out-of-town and low rise, and thus cheaper, were growing in popularity with companies. Skyscrapers like the city centres they occupied were viewed as expensive and in decline.

However, firms today increasingly view real estate as a means of controlling a much bigger cost, namely staff retention. This has coincided with a movement of people back into cities, reversing the preceding exodus to the suburbs – New York City's population has increased by 19% since 1980.

SKYSCRAPERS: IT'S ALL ABOUT PEOPLE

For private sector services firms (the mainstay of city office occupation) salaries typically account for around half of operating expenses. However, an unquantifiable cost is the loss of value when successful staff leave, and the additional expense of replacing them.

Chicago's Willis Tower (formerly Sears Tower) was the world's tallest building from 1974 to 1998

20 Fenchurch Street, one of London's new wave of towers

For a worker earning over £35,000 p.a. in London's The City financial district, should they leave, the fee paid to a recruitment consultant to replace them is greater than the annual rent on their office work station; and that head-hunter charge is just a small part of the overall staff turnover cost. This means that even for staff in support roles the expense of replacement overshadows property costs, and this is before considering the effect an enhanced working environment can have on productivity.

As a consequence firms when approaching property now strive for:

1. **The office as the place to be:** Firms aim to create offices that staff want to spend time in. This is partly achieved by innovative fit-out, ranging from games rooms, to buffets and cafés, to private work areas. Being in a skyscraper is another way to give the office wow factor in the eyes of staff.

2. **The office as a catalyst of integration:** This is where firms use the office to bring about changes in working habits, so people mix and interact to create a greater sense of community. Staff are encouraged to leave desks and move around the office and speak face-to-face. Moving to a new tower can offer a sense of a new beginning that will encourage staff to embrace change.

3. **The office which is close to home:** This final point in particular has brought offices back into city centres from out-of-town locations, which makes skyscrapers important to re-introduce more business space into crowded CBDs.

Many firms now want to support the work/life balance, and try to fit the office around lifestyles. For instance, locker-rooms and showers for staff who wish to jog or cycle to work are becoming common, as is replacing car parking spaces with bike racks. A gym in the building, and eating establishments are also now increasingly valued by tenants. Extensive basement areas and retail concourses that are typical among skyscrapers can help on these issues.

> "MOVING TO A NEW TOWER CAN OFFER A SENSE OF A NEW BEGINNING THAT WILL ENCOURAGE STAFF TO EMBRACE THE CHANGES."

To this backdrop, skyscrapers are flourishing. They are seen as a way to give staff a workplace that feels special, and promotes esprit-de-corps – an office you want to tell people about at a dinner party.

EVERYONE GETS LIGHT

Insurance firm, Markel, has recently moved their London office into 20 Fenchurch Street, a Rafael Viñoly designed tower. Andy Davies, the COO and CFO, sees being in a skyscraper as a way of improving the workplace experience.

Markel found a tower floor plate has an advantage over a conventional building as there are no desks remote from a window. According to Davies: "Wherever you go in the new office, everyone gets natural light, even at their desk; and the views are spectacular."

Markel installed internal staircases that pass through the floors to encourage staff to circulate in the office rather than remain tied to desks. This increased the incidence of chance encounters where knowledge can be shared. Again, the open environment and natural light facilitate this cultural change – according to Davies, "in the new office, you can't hide".

CONTINUED ON —— 06-07

Tall Buildings | The Implications of Increasing Height

Appendix D | Knight Frank

GLOBAL CITIES | SKYSCRAPERS 2015 REPORT

CONTINUED FROM — 04-05

ICONIC IS NOT ENOUGH

Martin Jepson, President & COO for Brookfield's UK division, believes that the best means of achieving the staff-friendly skyscraper is via a very efficient floor plate. "Building iconic for the sake of it is not sustainable. Offering efficiency of floor occupation and flexibility is what tenants are seeking first and foremost." This creates a blank canvas on which the occupier can set out a bespoke office that matches their business practices.

> "BUILDING ICONIC FOR THE SAKE OF IT IS NOT SUSTAINABLE."

Another important factor, according to Jepson, is offering an entrance to the building that suits the tenant's needs. "At 100 Bishopsgate we have the luxury of almost 17,000 sq ft of reception at ground level, so we can offer some tenants their own identity. We don't scrimp on the ground floor space". This brings out the importance of an appropriate public realm for skyscrapers, where impressions are often shaped before the front door is even reached.

Particularly in London's EC3 insurance district, utilising towers to raise a firm's profile has played a role in generating office demand. Swiss Re famously chose The Gherkin (aka 30 St Mary Axe) in order to leverage the publicity value of being in such an iconic building. This set in motion a domino effect of innovative towers in EC3 signing up insurance tenants, such as The Leadenhall Building, with its tapering design,

SKYSCRAPER PRIME YIELD SPREAD OVER 10 YEAR BONDS (BASIS POINTS)

Source: Knight Frank Research, Newmark Grubb Knight Frank Research, Thomson Reuters

A	Paris	492
B	Frankfurt	421
C	Chicago	381
D	Sydney	265
E	London	246
F	Shanghai	245
G	Hong Kong	190
H	New York	181
I	San Francisco	181
J	Singapore	114

SHANGHAI'S SUPER TOWER

The Shanghai Tower, which is now the tallest building in China, is part of this movement towards skyscrapers that allow staff to interact, according to the building's Marketing Director, Wendy Yu. "The office floors connect with the 21 sky lobbies and courtyard gardens, providing people with spaces to interact. Amenities like cafés, convenience stores, ATMs, and entertainment facilities are also distributed throughout the The Shanghai Tower." A super-tall building of 6.2 million sq ft, the sense of community is facilitated by breaking the tower into several vertical communities, each with its own atrium.

Shanghai's skyscraper cluster is found in the Lujiazui CBD, part of the city's Pudong district whose futuristic skyline has become symbolic of China's economic success. In 1993, Pudong was largely warehouses and farmland. By 2000 the population had mushroomed to over 3 million, before rising above 5 million at the time of the 2010 census. Around 40% of people living there originate from elsewhere in China. This makes Pudong a case study in the urgent need for emerging market cities to go skywards to cope with rapid economic change.

TOWERING AMBITIONS

Inevitably other cities have ambitions to replace the Pudong towers as the Chinese skyline photo that appears in foreign newspapers. In Shenzen, the Ping An International Financial Centre overtake The Shanghai Tower in height in 2016. Its design includes a three storey 'retail bridge' that will connect the tower to future neighbouring developments. Guangzhou has constructed a purpose built CBD, the Zhujiang New Town, which incorporates skyscrapers like the Guangzhou Twin Towers (the second of which completes next year).

Other Asian towers completing this year include Jakarta's Cemindo Tower (which will be the tallest building in Indonesia), and the IB Tower, and the Naza Tower in Kuala Lumpur (these will be the city's third and fourth highest skyscrapers, respectively).

Over the next two years, Sydney will add to its skyline the triple skyscraper International Towers cluster at Barangaroo, a major dockside redevelopment. Anchor tenants include HSBC, KPMG, PwC and Westpac. The complex will include more than 800 apartments, a hotel, and shops, while Renzo Piano has been commissioned to design three new residential towers at Barangaroo South.

Manhattan is seeing two new tower clusters developed

Hong Kong has the highest skyscraper office rents in the world

The Shanghai Tower is currently China's tallest building

REINVENTING THE CITY

Barangaroo, much like London's Canary Wharf, is an example of former-industrial land in a dense city centre being wholesale redeveloped to match economic changes.

Where there is a large swathe of industrial land, regenerating piecemeal is often not an option. A small office building constructed in the midst of redundant warehouses will struggle to sign a tenant, and the local transport authority is unlikely to add it to their routes. Redevelopment has to be en-masse to get the buy-in from municipal authorities to add infrastructure, and with architecture of a quality that will draw big name tenants as anchor pre-lets; which in turn persuades other firms to move to the new district.

Skyscrapers have the gravitas and quality of offices that attract Fortune 500-type firms, which gives the confidence to other potential stakeholders (such as the local government, retail and leisure tenants, and investors) to back a major regeneration scheme. That a growing number of large companies are willing to be that pre-let anchor tenant, even if it means moving to another part of the city, is behind a new wave construction around the world. New York City has several examples of this.

NYC'S NEW TOWER CLUSTERS

New York is benefiting from the arrival of two new skyscraper clusters, found in Downtown and western Midtown.

In Downtown, there is the new World Trade Center complex, where 5.3 m sq ft of office space has already completed, with a

CONTINUED ON — 08-10

1069

Tall Buildings | The Implications of Increasing Height

Appendix D | Knight Frank

1050

GLOBAL CITIES | SKYSCRAPERS 2015 REPORT

CONTINUED FROM — 06-07

further 5.3 m sq ft to follow. This is complemented by 565,000 sq ft of retail at Brookfield Place, and Westfield's World Trade Retail.

The new office stock is coinciding with a transformation of the Downtown market, with more technology and creative firms moving in. Conde Nast, the publisher of Vogue, is the anchor tenant for One World Trade Center. Other firms signed up include ad agency KiDS Creative, and tech companies High 5 Games, Tinypass, and xAd, demonstrating the changing tenant profile of a district once associated with finance.

Turning to Midtown, near Penn Station we are seeing a new cluster of skyscrapers being developed. This includes the 28 acre Hudson Yards district, which is being developed by Oxford Properties and Related Companies. This consists of four commercial towers and two residential towers. It is complimented by Brookfield's neighbouring Manhattan West project of 5.8 m sq ft, which includes two skyscrapers of 67 storeys each.

As with the new World Trade Center, the tenants already signed up for Hudson Yards are not from the financial and professional industries who previously dominated Manhattan skyscrapers. Future occupiers will include, CNN, L'Oreal, Time Warner, and Coach (a luxury goods firm).

This transition of skyscrapers away from finance and towards creative industry occupiers is seen elsewhere in the world. In San Francisco towers are under construction to house technology jobs moving into the city from low-rise Silicon Valley. Cloud computing firm, Salesforce has pre-let a new skyscraper as its headquarters in San Francisco, and in London they also occupy space in The Heron Tower. Similarly, Al-Jazeera are a tenant in London's The Shard, further demonstrating the media/creative interest in towers.

MIXED-USE MOVING UP THE AGENDA

Increasingly, mixed-use is moving up the tower agenda – indeed the majority of skyscrapers in both Manhattan and London's future development pipeline are residential. For instance, in London a residential tower cluster is being developed at Nine Elms, thanks to a new underground rail line which will terminate at the mixed-use redevelopment of the Battersea Power Station site.

> "BEYOND THE LOCAL POPULATION AND WORKFORCE, AN ESTIMATED SIX MILLION PEOPLE EACH YEAR VISIT LA DÉFENSE."

La Défense in Paris shows how skyscrapers when set in a well-designed public realm can create a destination in its own right. Beyond the local population and workforce, an estimated six million people each year visit La Défense for non-business reasons. A survey of visitors by the local tourist board found that half of all non-business visitors were there to shop, and a third were tourists from outside Paris.

La Défense is a successful example of mixing living with work, with its 25,000 local residents. The proposed Foster and Partners designed Hermitage Plaza is characteristic of this mixed-use approach. The 3.4 m sq ft project (including twin towers of 85 and 86 floors) will incorporate offices, luxury homes, a five star hotel, conference centre, and high-end retail.

The resounding message from our study of the global skyscrapers market is that they are associated with exclusivity, whether it be for commercial or residential use. This can be more of a psychological perception than reality, as it tends to be the upper floors, above the skyline that command the premium office rents – the lower floors tend to let on standard prime rents. The premium for views can vary from 15-20% in the City of London and Hong Kong island, to nearly double average prime rents in Midtown Manhattan.

The Shard, London Bridge Quarter

La Défense in Paris combines offices, homes, hotels, shopping and culture in an iconic skyscraper district

NEW WAVE OF INVESTORS

Skyscrapers are not just popular with tenants, as they are also in vogue with real estate investors. This is the result of more mega-funds targeting property in recent years, sometimes sovereign wealth funds, but also national pension schemes and global private equity funds. Recent examples include Blackstone purchasing 1740 Broadway and the Park Avenue Tower in New York for a combined $1.1 bn, while in London the Qatari Investment Authority recently combined with Brookfield to buy the majority shareholding in developer Canary Wharf Group.

For funds which have very large amounts of money to deploy sub-$100 m deals can be too granular, however skyscrapers allow sums over the billion dollar mark to be invested in a single deal.

Changes in global capital markets are shaping the new trend, as the mega-funds have traditionally been major investors in sovereign bonds. Years of Quantitative Easing (QE) have pushed bond yields to record lows for some of the most popular triple A and double A sovereigns, making real estate yields comparatively attractive. QE has also encouraged many funds to diversify their investment portfolios, increasing interest in real estate as an alternative to bonds and equities.

Another attraction of skyscrapers relates to the diversity of the tenancy schedule found in many towers. Multiple tenants with leases expiring at different times increases exposure to the rental cycle, creating plenty of opportunity to asset manage a tower to exploit changes in the leasing market.

Particularly for pension funds, who must match income streams with

As an island city, skyscrapers have proved ideal for accommodating Singapore's rapid economic growth

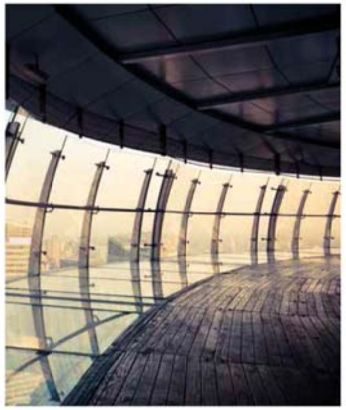
The skyline of Pudong in Shanghai has become symbolic of China's emergence as an economic giant

Tall Buildings | The Implications of Increasing Height

Appendix D | Knight Frank

Burj Khalifa will pass the title of the world's tallest building to Kingdom Tower in Jeddah in 2019

With a population of 15 million, Shenzen is embracing tall buildings



long-term obligations, the longevity of skyscrapers is also an attraction. In New York, art deco towers from the 1930s still operate as modern office buildings. The prospect of a building that gains almost timeless appeal is of interest to an investor who must think very long-term.

As well as the mega funds mentioned above, we are even seeing interest in skyscrapers from private investors; as shown by Brazil's Safra family buying 30 St Mary Axe. This could suggest a new club of skyscraper investors is emerging where the status factors found in leasing tower space are similarly applied to owning one.

SKYSCRAPERS AND THE FUTURE

Turning to the future, skyscrapers offer many opportunities for crowded inner cities to address problems of how to accommodate growth. This includes delivering more homes and additional business space. Particularly, in emerging markets this has led to a drive to build towers that are ever bigger. However, this could change as these cities reach maturity.

In western cities when skyscrapers are developed it is common practice to pre-let a large share of the commercial space either before construction starts, or early on in the development process. This is because towers in the west, which are unlikely to be backed by government money, are shaped principally by commercial decisions. This has been less of a factor in emerging markets cities, where governments have often wanted to encourage large amounts of modern business space to be developed to accelerate the modernisation of their cities.

With economic maturity we could see more cities in Asia choosing not to build very big towers in the future, but adopting the western model as the need to modernise recedes. The drive for super tall buildings may give way to a world where towers are less concerned with height and more with the financial bottom line.

GLOBAL CITIES | SKYSCRAPERS 2015 REPORT

IN 2009 THERE WERE

NINETEEN

SKYSCRAPERS IN THE WORLD WITH HEIGHTS OF OVER ONE THOUSAND FEET

TODAY THERE ARE

SEVENTY NINE

40%

OF WHICH ARE IN CHINA

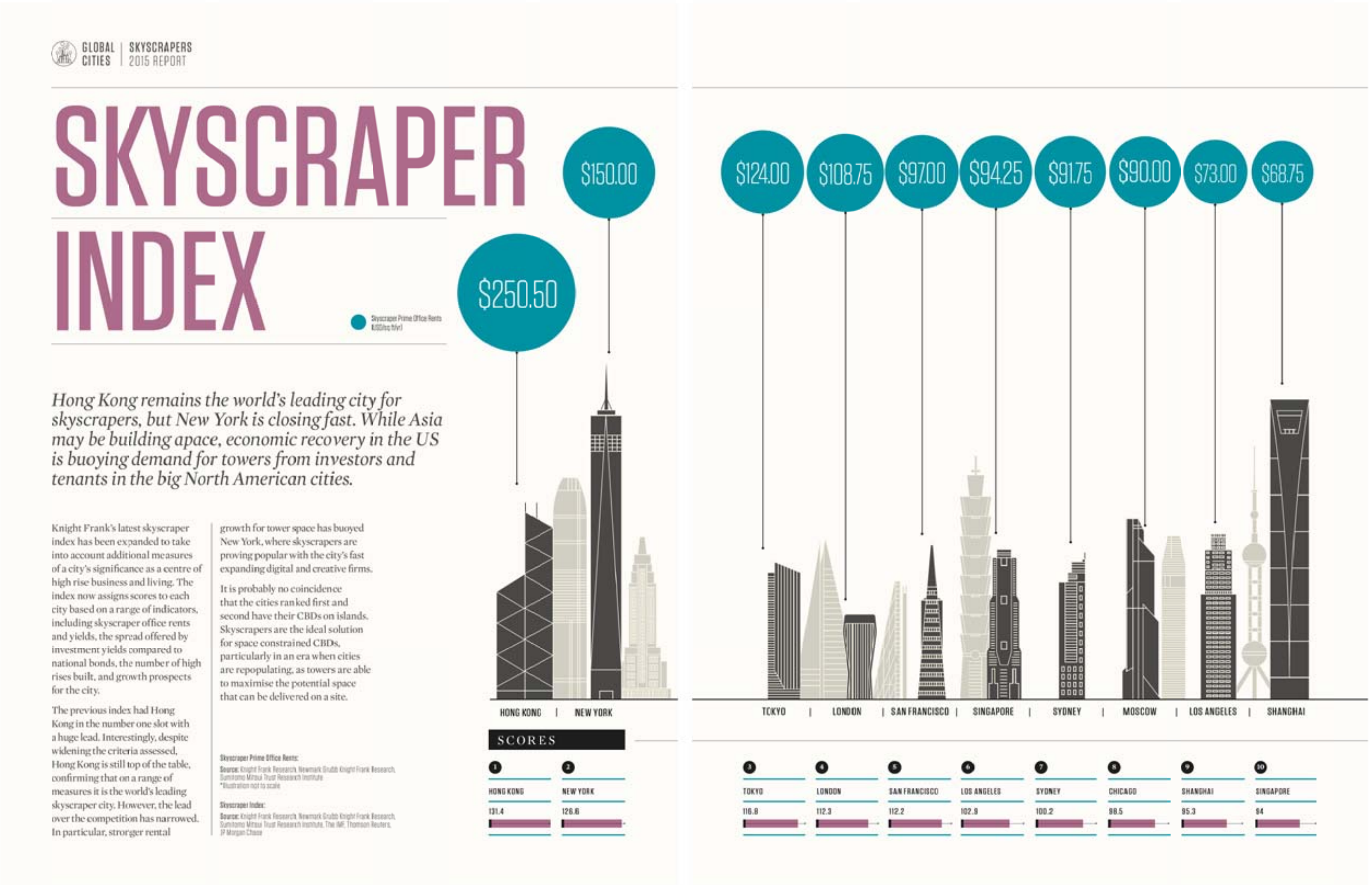
28%

OF WHICH ARE IN THE UAE

Source:
Emporis, Knight Frank Research,
Newmark Grubb Knight Frank Research
Note: based on completed buildings

Tall Buildings | The Implications of Increasing Height

Appendix D | Knight Frank



GLOBAL CITIES | SKYSCRAPERS 2015 REPORT

SKYSCRAPER INDEX

Hong Kong remains the world's leading city for skyscrapers, but New York is closing fast. While Asia may be building apace, economic recovery in the US is buoying demand for towers from investors and tenants in the big North American cities.

Knight Frank's latest skyscraper index has been expanded to take into account additional measures of a city's significance as a centre of high rise business and living. The index now assigns scores to each city based on a range of indicators, including skyscraper office rents and yields, the spread offered by investment yields compared to national bonds, the number of high rises built, and growth prospects for the city.

The previous index had Hong Kong in the number one slot with a huge lead. Interestingly, despite widening the criteria assessed, Hong Kong is still top of the table, confirming that on a range of measures it is the world's leading skyscraper city. However, the lead over the competition has narrowed. In particular, stronger rental growth for tower space has buoyed New York, where skyscrapers are proving popular with the city's fast expanding digital and creative firms.

It is probably no coincidence that the cities ranked first and second have their CBDs on islands. Skyscrapers are the ideal solution for space constrained CBDs, particularly in an era when cities are repopulating, as towers are able to maximise the potential space that can be delivered on a site.

SCORES

1	HONG KONG	131.4
2	NEW YORK	126.6
3	TOKYO	116.8
4	LONDON	112.3
5	SAN FRANCISCO	112.2
6	LOS ANGELES	102.9
7	SYDNEY	100.2
8	CHICAGO	98.5
9	SHANGHAI	95.3
10	SINGAPORE	94

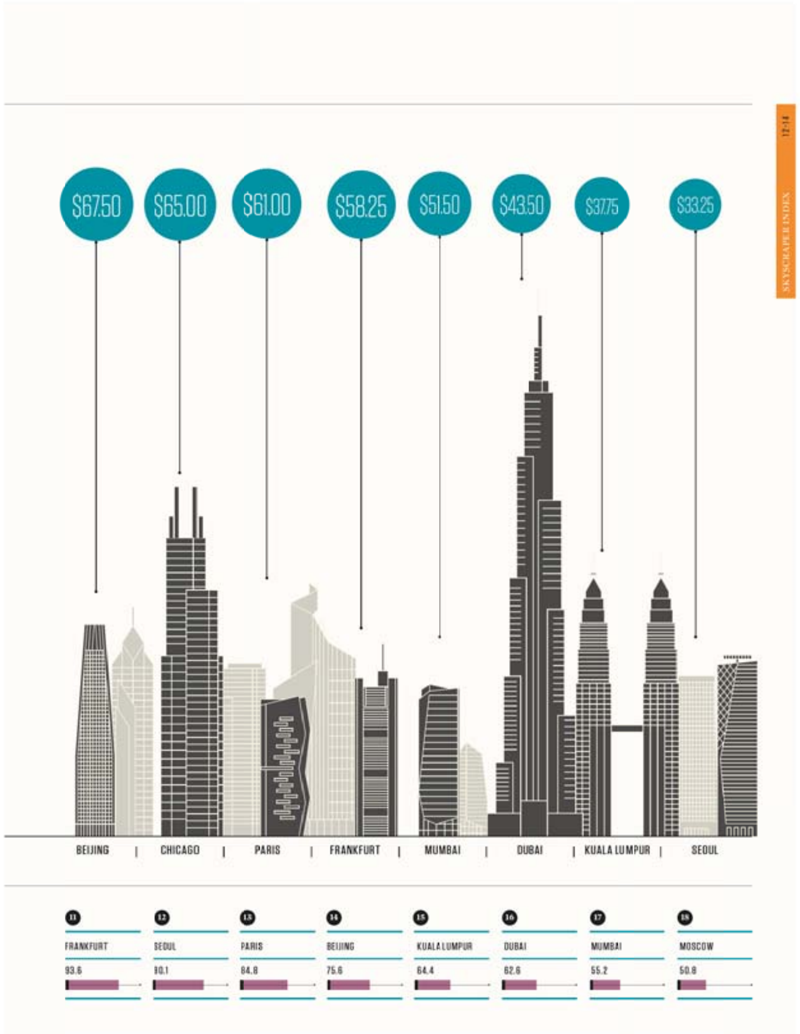
Skyscraper Prime Office Rents:
Source: Knight Frank Research, Newmark Grubb Knight Frank Research, Sumitomo Mitsui Trust Research Institute
*Illustration not to scale

Skyscraper Index:
Source: Knight Frank Research, Newmark Grubb Knight Frank Research, Sumitomo Mitsui Trust Research Institute, The IMF, Thomson Reuters, JP Morgan Chase

Tall Buildings | The Implications of Increasing Height

Appendix D | Knight Frank

1053



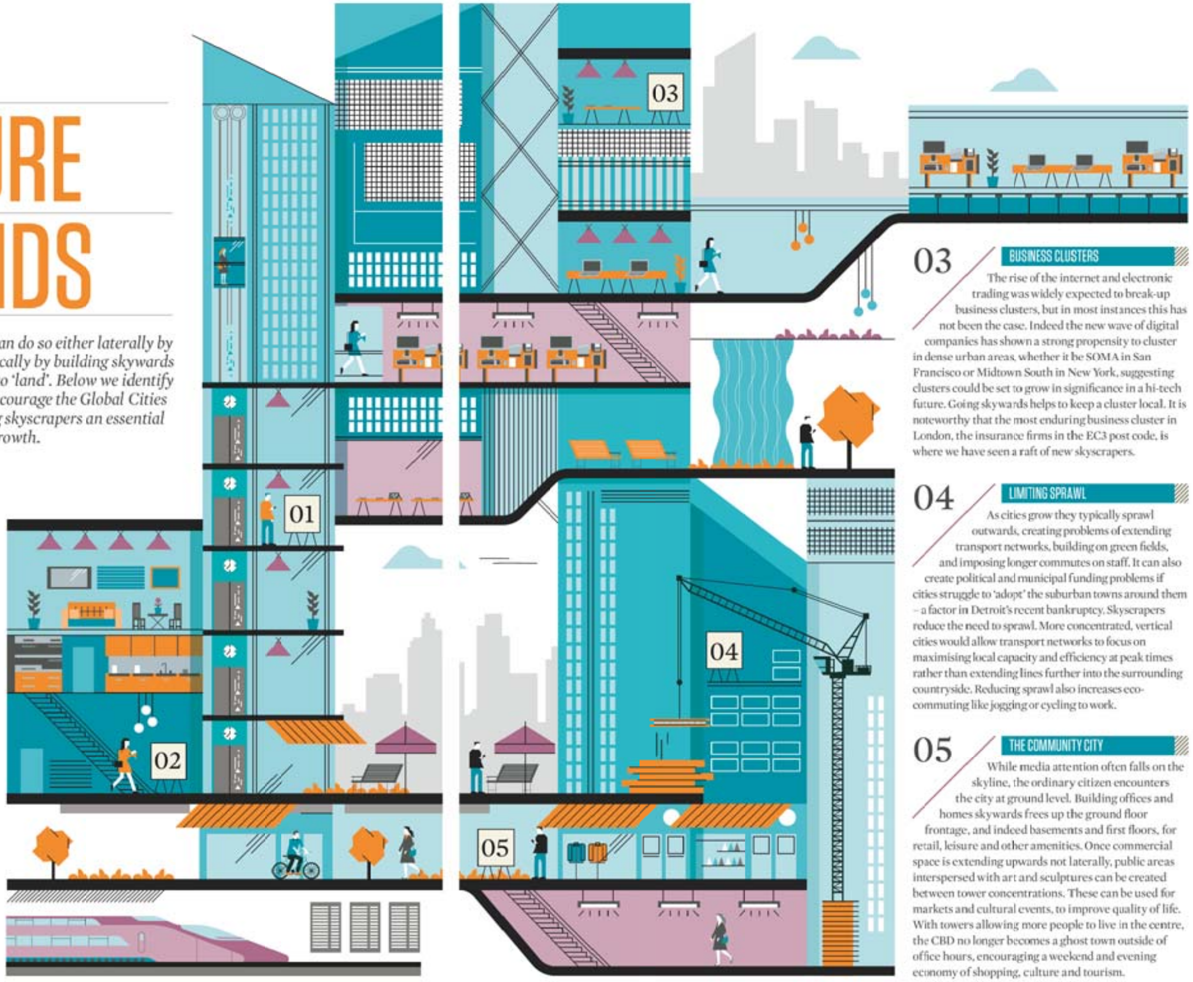
Tall Buildings | The Implications of Increasing Height

Appendix D | Knight Frank

GLOBAL CITIES | SKYSCRAPERS 2015 REPORT

5 FUTURE TRENDS

When a city grows it can do so either laterally by spreading out, or vertically by building skywards thus converting air into 'land'. Below we identify five trends that will encourage the Global Cities to go upwards, making skyscrapers an essential component of urban growth.



01 NEW TECHNOLOGY

As buildings rise higher, new technologies are emerging to make this both possible and cost effective. With steel elevator cables, going much above 500 metres becomes problematic as both weight and energy consumption increase. Finnish company, Kone, have developed a new carbon fibre cable which can be as long as one kilometre while using less energy to hoist elevators, as it is a fraction of the weight of steel. Thyssen-Krupp are looking into an elevator that has no cable. It is based on magnet technology which would eliminate the need for a counterweight, freeing up internal space for other uses.

02 LIVING IN THE CITY

Migration, gentrification, and growing economic opportunities have brought about rapid population growth in cities across the globe. The UN is predicting the number of mega cities (those with a population of over 10 million) to jump from 28 currently to 41 by 2030. India's urban population is forecast to nearly double to 814 million by 2050. For emerging markets cities, skyscrapers offer a means of delivering large swathes of homes and business space in response to rapid economic and population growth. For western cities towers offer a means of matching the popularity of living near work in densely developed inner cities.

03 BUSINESS CLUSTERS

The rise of the internet and electronic trading was widely expected to break-up business clusters, but in most instances this has not been the case. Indeed the new wave of digital companies has shown a strong propensity to cluster in dense urban areas, whether it be SOMA in San Francisco or Midtown South in New York, suggesting clusters could be set to grow in significance in a hi-tech future. Going skywards helps to keep a cluster local. It is noteworthy that the most enduring business cluster in London, the insurance firms in the EC3 post code, is where we have seen a raft of new skyscrapers.

04 LIMITING SPRAWL

As cities grow they typically sprawl outwards, creating problems of extending transport networks, building on green fields, and imposing longer commutes on staff. It can also create political and municipal funding problems if cities struggle to 'adopt' the suburban towns around them – a factor in Detroit's recent bankruptcy. Skyscrapers reduce the need to sprawl. More concentrated, vertical cities would allow transport networks to focus on maximising local capacity and efficiency at peak times rather than extending lines further into the surrounding countryside. Reducing sprawl also increases eco-commuting like jogging or cycling to work.

05 THE COMMUNITY CITY

While media attention often falls on the skyline, the ordinary citizen encounters the city at ground level. Building offices and homes skywards frees up the ground floor frontage, and indeed basements and first floors, for retail, leisure and other amenities. Once commercial space is extending upwards not laterally, public areas interspersed with art and sculptures can be created between tower concentrations. These can be used for markets and cultural events, to improve quality of life. With towers allowing more people to live in the centre, the CBD no longer becomes a ghost town outside of office hours, encouraging a weekend and evening economy of shopping, culture and tourism.

Tall Buildings | The Implications of Increasing Height

Appendix D | Knight Frank

1059

GLOBAL CITIES | SKYSCRAPERS 2015 REPORT

ABOUT THE GROUP

Knight Frank and Newmark Grubb Knight Frank, together, is a thoroughly integrated market-leading global real estate advisor.

The combined group have more than 12,500 property professionals, with more than 370 offices around the world; this global commercial and residential capability allows us unrivalled access to wealth, properties and occupiers in 55 countries.

Our integrated office network enables us to offer clients a dedicated service from our headquarters in London and New York City. Together, we are strengthened by the specialist desks we have created in these cities, devoted to further enhancing our global client relationships.

We have a highly developed Global Corporate Services business with hubs in London, New York and Hong Kong. Working with occupiers of commercial premises our teams are able to offer an outstanding level of service globally, regionally and at a country or city level. We excel at portfolio strategy, leasing, workplace consultancy, tenant representation and project management.

Our Global Capital Markets teams operate from five core regions, the UK, Europe, Asia, Middle-East and The Americas. We have unrivalled access to institutional, corporate, sovereign and private wealth.

Our Office Leasing teams are appointed on some of the most high profile buildings around the world, including The Shard in London, Gateway in Sydney, SRE Finance Centre in Shanghai and the Empire State Building in New York. The strength and depth of our Leasing and Tenant Representation business enables us to offer clients a truly global service.

To complement our Capital Markets, Tenant Representation and Leasing teams we have a highly developed and enviable Valuations business who can manage the valuation of a portfolio of global assets from a single location whilst working closely with our teams at a local level.

Our track record of trust and integrity means we, together, are becoming increasingly recognised as the advisor of choice in the global real estate market. With our best-in-class advice, and ability to deliver seamlessly in collaboration, we set ourselves apart in the global market place.

The combination of our people, network, research and technology has helped us grow our enviable track record and, for that reason, clients come back to us time and time again.

Our objective is to deliver uncompromising standards, our clients deserve nothing less.

ABOUT THE GROUP 18-19

CONTACT

SKYSCRAPERS 2015 REPORT BY KNIGHT FRANK AND NEWMARK GRUBB KNIGHT FRANK

JOHN SNOW, HEAD OF COMMERCIAL
KNIGHT FRANK
+44 20 7861 1190
JOHN.SNOW@KNIGHTFRANK.COM

JAMES D. KUHN, PRESIDENT
NEWMARK GRUBB KNIGHT FRANK
+1 212 372 2200
JKUHN@NGKF.COM

JAMES ROBERTS, CHIEF ECONOMIST
KNIGHT FRANK
+44 20 7861 1239
JAMES.ROBERTS@KNIGHTFRANK.COM

LIAM BAILEY,
GLOBAL HEAD OF RESEARCH
KNIGHT FRANK
+44 20 7861 5133
LIAM.BAILEY@KNIGHTFRANK.COM

JONATHAN MAZUR,
MANAGING DIRECTOR OF RESEARCH
NEWMARK GRUBB KNIGHT FRANK
+1 212 372 2154
JMAZUR@NGKF.COM

NICHOLAS HOLT, HEAD OF RESEARCH
KNIGHT FRANK ASIA PACIFIC
+65 6429 3595
NICHOLAS.HOLT@ASIA.KNIGHTFRANK.COM

DAVID JI, HEAD OF RESEARCH
KNIGHT FRANK GREATER CHINA
+852 2846 9552
DAVID.JI@HK.KNIGHTFRANK.COM

MATT WHITBY, HEAD OF RESEARCH
KNIGHT FRANK AUSTRALIA
+61 2 9036 6616
MATTWHITBY@AU.KNIGHTFRANK.COM

CAVEATS

This report is published for general information only and not to be relied upon in any way. Although high standards have been used in the preparation of the information, analysis, views and projections presented in this report, no responsibility or liability whatsoever can be accepted by Knight Frank LLP for any loss or damage resultant from any use of, reliance on or reference to the contents of this document.

As a general report, this material does not necessarily represent the view of Knight Frank LLP in relation to particular properties or projects.

Within this report all figures quoted for 2014 are year-end.

This report was largely written in March 2015 based on available data and drawing from the business news and market sentiment at the time; then going to press in early April 2015.

Rent figures quoted for cities in the Americas are prime average asking rents. Rents elsewhere are quoted normal prime achieved.

Many external sources regarding Skyscrapers have been consulted for this report, but the information has been cross referenced against Knight Frank and Newmark Grubb Knight Frank's proprietary knowledge, and information kindly provided by several firms in the development sector regarding their specific skyscraper projects. This explains any disparities between data in the report and that quoted elsewhere.

FORECAST CAVEAT:

Forecasting is an inherently uncertain activity and subject to unforeseen changes in the external environment. Although high standards have been used in the preparation of the information, analysis, and projections presented in this forecast, no legal responsibility can be accepted by Knight Frank Research or Knight Frank for any loss or damage resultant from the contents of this forecast. As a general forecast, this material does not necessarily represent the view of Knight Frank in relation to particular properties or projects.

Tall Buildings | The Implications of Increasing Height

Appendix E | Let There Be Light

Introduction

This study considers daylight conditions on a generic office floor plate located in different cities around the world. It compares various facade configurations in these cities and the impact they have on internal daylight. The study is based on similar studies undertaken by Arup for the architectural firm Woods Bagot (Australia) over the past three years.

The daylight quality of perimeter office space should take into account the daylight intensity, glare and external views. All of these factors relate directly to occupant well-being and can affect work productivity. Studies[1] suggest that, if combined with higher levels of indoor environmental quality and individual comfort control, daylight and glare strategies can cause occupant's billable hours to improve by just over 1% for a one year period.

The present study focused its analysis on daylight penetration into the floor plate as an important part of a larger study that intends to analyse the other factors. It is crucial, however, to emphasize the importance of considering design issues such as glare minimisation, solar and view access in conjunction with daylight intensity when finding the right configuration of floor plate depth and façade configuration to achieve ideal conditions for occupant well-being within commercial office spaces.

The study compares the Useful Daylight Illuminance (UDI), explained later in this document, for a standard office floor plate with different facade configurations and different visible light transmittances (VLT) in various cities around the world. For each city the outcome of the study is represented on a separate page. In this way, when designing a building in a city that has been analysed, this page can be extracted and used during the early design stages. The preliminary design recommendations that are given relate to floor plate depth, preferred facade configuration and a recommended VLT range.

Method

The daylight penetration analysis involved the following procedures:

- Analysis of climatic data and sky type for each specific location;
- Modelling of a typical floor plate and with each façade configuration that is tested;
- Computer simulation with Radiance software for each façade configuration and different VLT properties; and
- Analysis of the results.

[1] **Incorporating Energy Efficiency and ESD into Australian Government Owned and Occupied Buildings: Guidelines for Briefing of Design Consultants** - Draft report by The Department of the Environment and Heritage, Australian Greenhouse Office Design, July 2005, p. 13.

Kats, Greg. 2003, The Cost and Financial benefits of Green Buildings: **A Report to California's Sustainable Building Task Force- October 2003**, p. 62.

Useful Daylight Illuminance

The Useful Daylight Illuminance (UDI) is described in study by Nabil and Mardaljevic (2005)[1]. It is designed to aid the interpretation of climate-based analysis of daylight illuminance and as an alternative to the Daylight Factor (DF) approach.

The UDI informs not only the minimum useful daylight levels but also the likelihood of exceeding daylight levels that may result in visible discomfort and unwanted solar gains. The UDI is capable of assessing the provision of daylight, as well as solar penetration and daylight levels below the minimum targeted requirements. Useful daylight illuminance, according to Nabil and Mardaljevic's studies, is defined as that illuminance that falls within the range 100-2000 lux. The range is based on a comprehensive review of the latest data from studies of occupant behaviour under daylight conditions. Arup's daylight study has adopted a UDI range of 250-2000 lux, as 250 lux is considered the minimum useful amount of daylight desired in an office space.

The colours on the images represent a daylight intensity of:

- 250 to 2000 lux, defined as useful daylight (green);
- Less than 250 lux, defined as dark areas or zones (blue); and
- More than 2000 lux, defined as excessive daylight with potential to cause visible and thermal discomfort (red).

Based on the approach described above it was possible to analyse the amount of useful daylight within the space and daylight penetration depending on the sky conditions and the façade configuration.

Superimposing the grid and the three different colours of illuminance ranges (excessive, useful and low) allowed us to define what areas are likely to achieve A grade office space with ideal daylight conditions and areas that may be used as office spaces with less ideal conditions in terms of occupant well-being and natural daylight. Office grades are based on the Property Council of Australia's terminology (Premium, A and B grades).

In simple terms, A grade daylight is the depth of the green zone. Areas of excessive brightness, in the red zones, may be dealt with by reducing the light transmission of the glass or deploying blinds. This will have the effect of bringing the green section closer to the façade and potentially increasing its size. Thus the area with A grade daylight can be read directly from the graphs.

The analysis can be used to inform initial selection of VLT, shading configuration, building form and internal planning and layout.

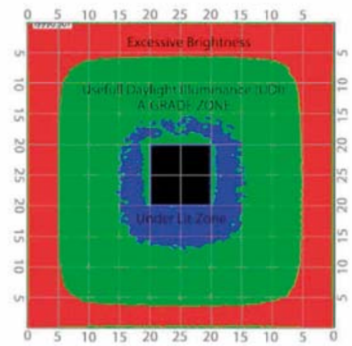
It is important to note that even though the useful daylight analysis gives a lot of insight into the classification of commercial spaces into various grades, other aspects such as blind use and access to views must be analysed in the future to determine useful daylight penetration. These results will allow an interpolation of all analysis to define the final distance from window depth criteria.

[2] Useful daylight illuminance: a new paradigm for assessing daylight in buildings, A Nabil, J. Mardaljevic, Ligthing Research and Technology, Vol.37, No. 1, pp. 41-57.

Purpose

This document can be used during the early design stages of a project. It will give insight to the typical daylight conditions in various cities around the world. It also gives preliminary design recommendations on the use of light shelves, floor plate depth and the VLT of the glazing. The study has focused on the design of office floors, but can be applied to various other building types.

Please note that the recommendations given are preliminary and need verification during later design stages.



1066

Tall Buildings | The Implications of Increasing Height

Appendix E | Let There Be Light

Let There Be Light

ARUP

Skies

The sun is our source of light and all daylight is light coming from the sun. The sky illuminance, which can also be called the 'sky brightness', is the light intensity of the sky. Light coming from the sky is called diffuse daylight. Technically this is light from the sun being reflected by the sky. Its intensity is mainly dependent on the properties of the atmosphere, the cloud distribution, the type of clouds and the location of the sun. Typically, diffuse daylight is considered to have a positive impact on the office environment as it lights the interior without creating too much contrast or light intensity, generally creating a pleasant environment. However, if the sky is really bright, sometimes it can create glare as a result of diffuse daylight. In addition to the diffuse daylight, there is direct sunlight that is coming directly from the sun and reaches its receiver without reflections. Direct sunlight is very intense and often causes glare or visual/thermal discomfort. Typically, direct sunlight does not have a positive effect on office interiors because of these issues. Illuminance should not be confused with luminance, which describes the amount of light coming from a point in a given direction in a given angle. Generally, luminance can be thought of as brightness.

The assessment for each city is based on the information in the weather files available at the EnergyPlus website for that city (http://www.eere.energy.gov/buildings/energyplus/). This information is collected from weather stations throughout the world and formatted by the United States Department of Energy for use in climate analysis. These files contain hourly information about the sky conditions and the illuminance levels at a certain location. This includes information about the horizontal and vertical sky brightness as well as the cloud distribution for every hour of a typical weather year.

The information in these files was used to generate an annual average sky model with a script developed by Arup. The sky files were generated based on an occupancy schedule from 8 am to 6 pm.

In the weather files, skies are classified as one of three types based on the amount of cloud cover (octas) information that was available for each individual hour of the year; this allows the creation of an annual sky distribution for each location as per the figures shown on the top right.

Overcast Sky – The Standard Overcast Sky [CIE, 1990] defines the luminance distribution for a fully and uniformly overcast sky with stratus type clouds. In this case the luminance peaks at the zenith. The relative luminance distribution has a 1 to 3 horizon to zenith ratio and only varies with the altitude of the part of the sky of which we are concerned.

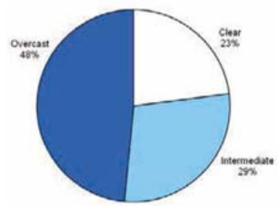
Clear Sky – The Standard Clear Sky [CIE, 1973] represents the luminance distribution for a perfectly clear (cloudless) sky. The model is based on the theoretical diffusion characteristics of the earth's atmosphere.

Intermediate Sky - This describes an intermediate sky condition between overcast and clear sky types where the sun is partially obscured by clouds.

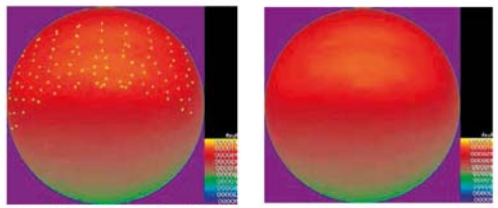
An annual average sky model was developed for each location taking into account sky type distribution. Both direct and diffuse components are accounted for based on hourly radiation data an sky type. This approach results in a final sky model for each locality that reflects daylight illuminance levels as an average condition through the year. This ensures that the design of the façade and floor plate is capable of responding to the most common sky conditions during the year.

The middle images on the right show the skies that are created. Two sky models are made; one that includes the direct sun component (cumulative direct + cumulative diffuse sky) and one with the diffuse component only (cumulative diffuse sky). The 'direct + diffuse' sky is used to assess the different facade configurations. The cumulative diffuse sky is used to determine the recommended floor plate depth and VLT of the glass.

Weather files can be retrieved from different sources. For the purpose of this study the *International Weather for Energy Calculations* data from the American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) is used where possible. The skies created for the same location with different weather files have proven to be quite different (see the sky files for Beijing on the lower part of the page.) The type of weather file that is used can therefore have a significant impact on the outcome of the study.

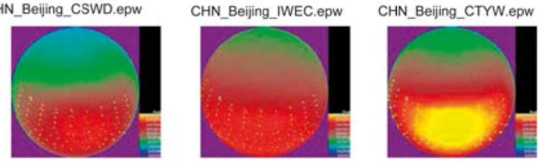


Sky distribution graph for Shanghai



Cumulative diffuse + direct sky **Cumulative diffuse sky**

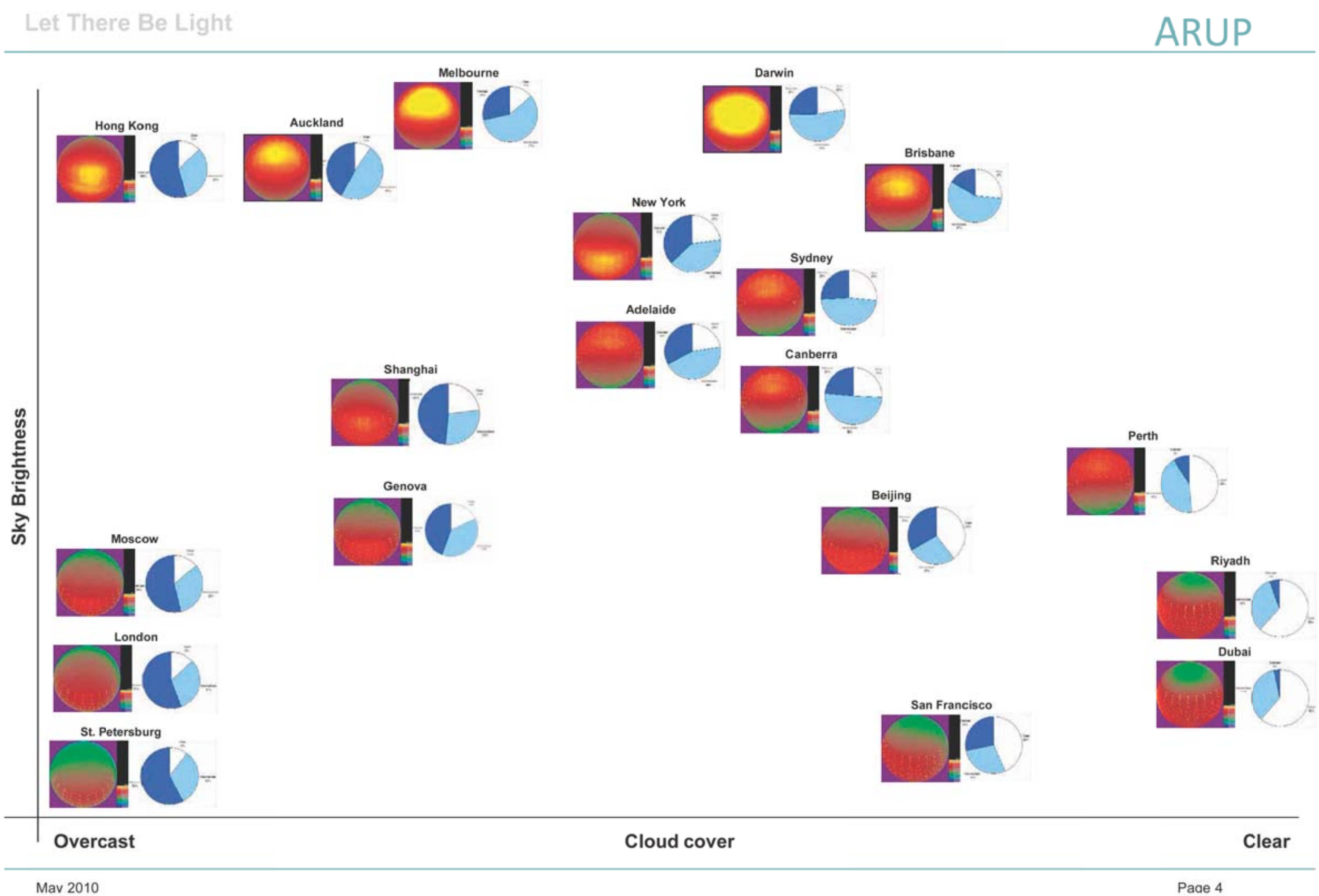
CHN_Beijing_CSWD.epw CHN_Beijing_IWEC.epw CHN_Beijing_CTYW.epw



Sky files generated with different types of weather files for Beijing

Tall Buildings | The Implications of Increasing Height

Appendix E | Let There Be Light



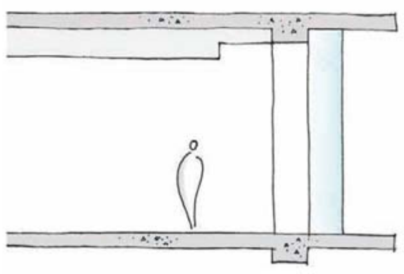
Tall Buildings | The Implications of Increasing Height

Appendix E | Let There Be Light

Let There Be Light

ARUP

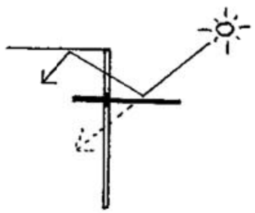
Recessed ceiling



With recessed ceilings, part of the sky will be visible further inwards and the amount of daylight that penetrates the floor plate will likely increase. Generally, daylight conditions will improve for zones deeper into the floor plate. It also means, however, that direct sun can penetrate further and the perimeter zone will get brighter. Therefore a balance should be struck. Ideally, shading devices should be used in combination with a higher ceiling.

As building costs are affected by the floor-to-floor height, there is a tendency to reduce ceiling heights to a minimum in commercial buildings. By recessing the ceiling along the perimeter the floor-to-floor height can be maintained while increasing the daylight penetration.

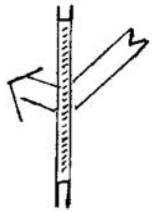
Light Shelves



Light shelves are an effective way of avoiding sunlight penetration along the perimeter zone while at the same time improving daylight conditions further into the floor plate. Sunlight is reflected off the shelf onto the ceiling and diffusely dispersed into the office. Light shelves can greatly improve daylight conditions by lighting up the ceiling and in this way the space will be perceived as brighter.

As the 'Let There Be Light' study only looks at the daylight intensity in the horizontal plane, the full benefit of a light shelf is not captured in the results presented here. However, the benefits of external shading devices are reflected in this study.

Daylight Redirectors



Daylight redirectors are an even more efficient way of reflecting sunlight onto the ceiling and walls, further into the floor plate. Like light shelves, daylight redirectors can greatly improve daylight conditions by lighting up the ceiling and walls.

As the 'Let There Be Light' study only considers the daylight intensity in the horizontal plane, the full benefit of using daylighting redirectors is not included.

1069

Tall Buildings | The Implications of Increasing Height

Appendix E | Let There Be Light

Let There Be Light

ARUP

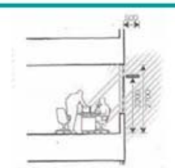
Façade configurations

Six different façade configurations are modelled with the cumulative skies created as described on page 2 and shown on page 3. The purpose of the analysis is to demonstrate that different façade options and floor plate configurations are capable of optimising daylight for different locations. The six façade types were modelled around a square floor plate of 50 by 50 meters with a 10 by 10 meter core in the centre.

The following façade options were modelled:

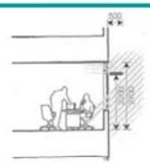
Type 1

- 2.7 m ceiling height;
- Glass (0.4 to 2.7 m) with a VLT of 0.5;



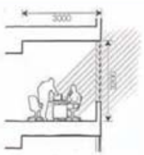
Type 2

- 2.7 m ceiling height;
- Glass (0.4 to 2.7 m) with a VLT of 0.5;
- A 500 mm wide light shelf at the cutside at 2.2 m height;



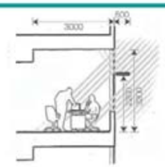
Type 3

- 2.7 m ceiling height;
- Glass (0.4 to 2.2 m) with a VLT of 0.44;
- A 500 mm wide light shelf at the outside at 2.2 m height;
- Light redirectors (2.2 to 2.7 m) in front of glass with a VLT of 0.70;



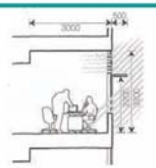
Type 4

- 3.2 m ceiling height;
- Glass (0.4 to 3.2m) with a VLT of 0.5;



Type 5

- 3.2 m ceiling height, three meters deep into the floor plate;
- Glass (0.4 to 3.2 m) with a VLT of 0.5;
- A 500 mm wide light shelf at the outside at 2.2 m height;



Type 6

- 2.7 m ceiling height
- Glass (0.4 to 2.2 m) with a VLT of 0.39
- A 500 mm wide light shelf at the outside at 2.2 m height
- Light redirectors (2.2 to 3.2 m) in front of glass with a VLT of 0.70

	Ceiling height	Light shelves	Daylight redirectors
Type 1	2.7		
Type 2	2.7	✓	
Type 3	2.7	✓	✓
Type 4	3.2		
Type 5	3.2	✓	
Type 6	3.2	✓	✓

The results are displayed in a graph showing the floor plate of model with the area that is considered to be too bright, the area with useful daylight and the area that is considered to be too dark (see the figure below). The northern façade is along the top. A grid of 5 by 5 meters is overlaid on the floor plate to allow the simulations to be interrogated in relation to façade option efficiency in delivering useful daylight based on local climate and orientation.