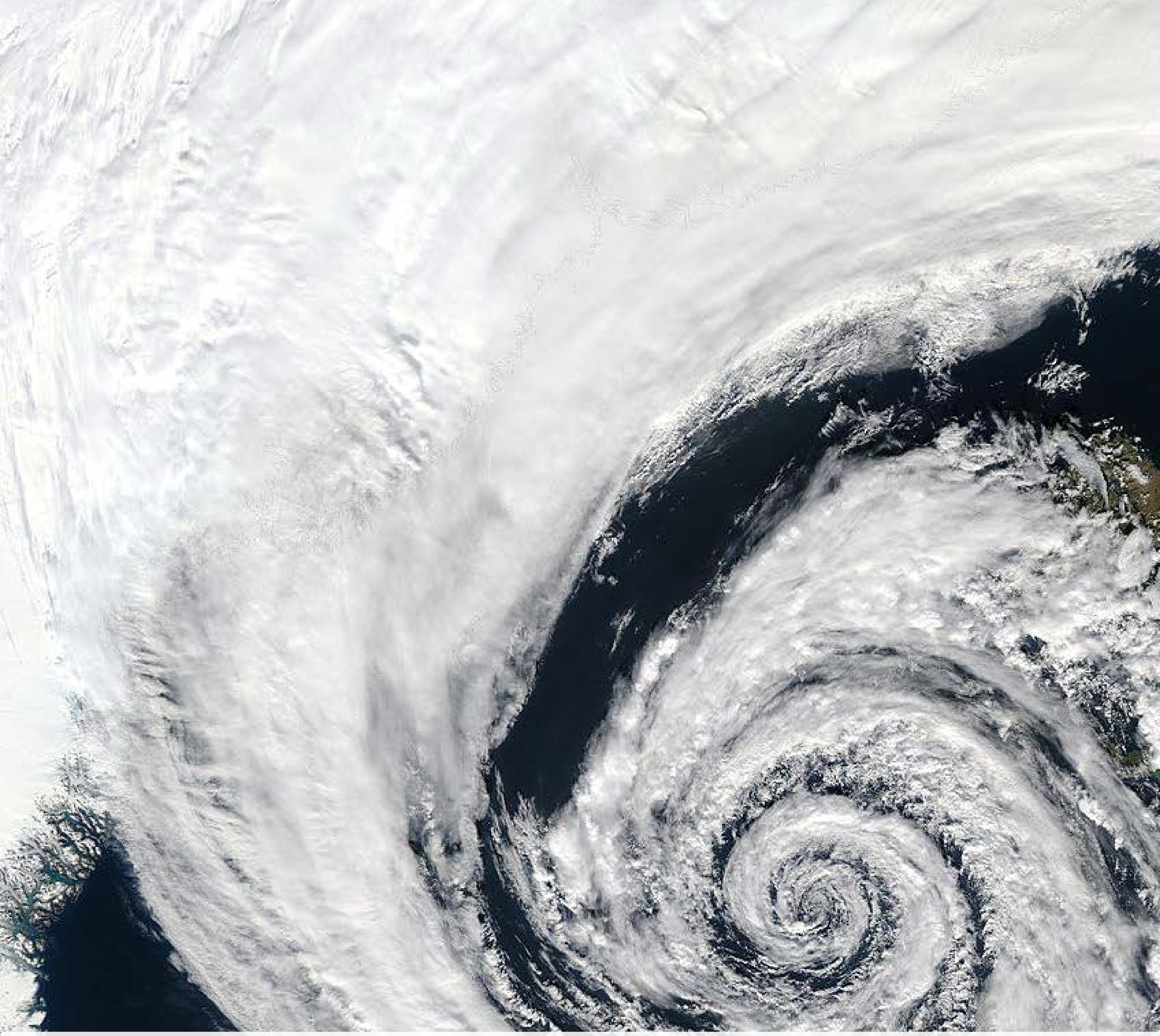

Cyclone-Glazing and Façade Resilience for the Asia Pacific Region

Market Study and Code Survey

Angela Mejorin, Dario Trabucco, Ingo Stelzer, Reisuke Nakada, Malvinder Singh Rooprai

Council on Tall Buildings and Urban Habitat

Council on Tall Buildings and Urban Habitat

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Contents

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The Council on Tall Buildings and Urban Habitat (CTBUH) is the world's leading resource for professionals focused on the inception, design, construction, and operation of tall buildings and future cities. Founded in 1969 and headquartered at Chicago's historic Monroe Building, the CTBUH is a not-for-profit organization with an Asia Headquarters office at Tongji University, Shanghai; a Research Office at Iuav University, Venice, Italy; and an Academic Office at the Illinois Institute of Technology, Chicago. CTBUH facilitates the exchange of the latest knowledge available on tall buildings around the world through publications, research, events, working groups, web resources, and its extensive network of international representatives. The Council's research department is spearheading the investigation of the next generation of tall buildings by aiding original research on sustainability and key development issues. The Council's free database on tall buildings, The Skyscraper Center, is updated daily with detailed information, images, data, and news. The CTBUH also developed the international standards for measuring tall building height and is recognized as the arbiter for bestowing such designations as "The World's Tallest Building."

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Introduction

The images shown in the newspapers of Hurricane Harvey and Hurricane Irma, which hit the US and the Caribbean between August and September 2017, are clear and recent in our mind. Climate change is increasing the strength of these natural disasters, which have different (but equally threatening) naming conventions, depending on the geographical area they occur in. Storms are called hurricanes in the Atlantic Ocean, Carribbean Sea, Gulf of Mexico and East of the International Date Line (Figure 2). These are named cyclones in the South-West Pacific Ocean. The third term adopted in the West side of the International Date Line in the Pacific area is typhoon. These events threaten the safety of one billion people every year, with violent precipitation and devastating wind.

The most affected geographic area of these events is the Asia Pacific region (World Bank Group, 2016). The Asia Pacific region has seen unprecedented growth over the past decade, both in terms of economy and urban population. As the growth in this area occurs, the demand for additional high density residential and office space has also increased, resulting in record numbers of high-rise buildings being constructed, concentrated mainly in urban areas (Safarik, D. et al., 2016). The development of the built environment in this region has largely occurred in coastal areas, which are increasingly vulnerable to disastrous storms, specifically tropical cyclones, also known as typhoons in Asia or as hurricanes in the US. These disaster events, due to climate change, are increasing both in frequency and intensity, as can been seen by their increased presence in newspapers and post-disaster assessments reports.

▲ Figure 1 - A sequence of satellite images depicting Hurricane Andrew (from right to left) on August 23–25, 1992

The bond between contemporary image of the skyscrapers and glazed construction is evident. The glass surfaces are rising with these buildings. The transparent, lightweight image that the building design aims to achieve has to adhere with safety regulations. This invisible appearance has to still guarantee resiliency of buildings and cities.

Curtain wall systems are not simply used to dictate what a building looks like, but they are a representation of their veritable skin. Like the skin on a living body, a building's curtain wall is the barrier between the indoor environment and the exterior. A building's façade is designed to control the indoor climate, allow natural light in, and, to some extent, allow the building to take advantage of natural ventilation. That being said, in many circumstances, the curtain wall becomes a barrier to protect the building and its occupants from external threats, such as rough climates and wind-borne objects. Glazed enclosures failure, caused by windborne debris during a typhoon, represents a potential threat for occupants and a significant contributor to the post-event recovery costs.

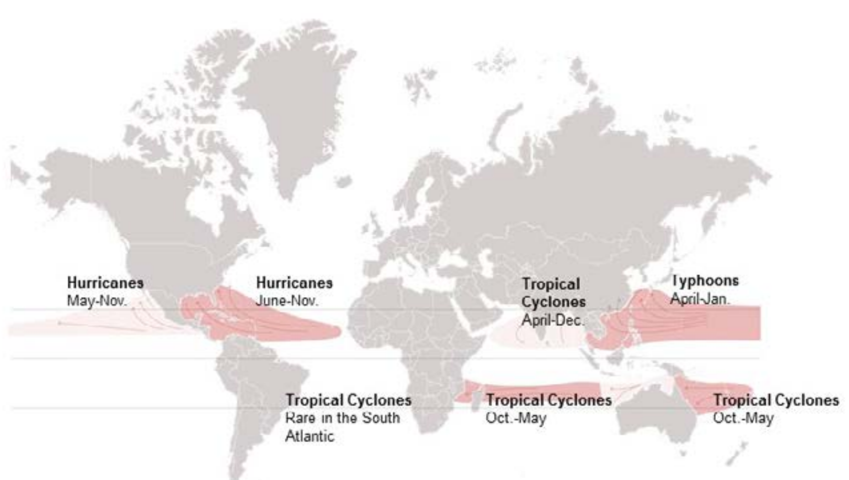
The Asia Pacific region is the most disaster prone in the world, and since 1980, these climate-change-induced disasters have been consistently increasing both in frequency and in severity. These events can be of such magnitude that the economic stability and growth of highly-populated areas can be threatened. In recent years, we often hear and read about Asia Pacific cities that are destroyed by typhoon events, related flood events, and the problems these areas have in reacting to these natural disasters.

The research presented in this document examined, through geographic information system (GIS) modeling, the buildings that have been affected by tropical cyclone events (cyclones), buildings that are currently at risk, and the steps that have already been taken to combat these threats within the Asia Pacific Region. The core objective of this study was to overview existing standards and best practices for the design, construction, and installation of cyclone-proof curtain walls in cyclone-prone areas. Furthermore, a code and standard comparison has been carried out, in order to present, with a brief summary, the key differences between the various standards and codes analyzed.

The background of cyclone-resistant glazing system requirements has been presented and an overview of the international and the US requirements for cyclone resistant façades is offered. The panel of experts involved in the research activities agrees the US has the "best practice" for the performance of glazed building systems during a cyclone event. Gaps in standard requirements have been identified and are presented in the specific chapter of the document.

The study focused on the following 12 Asian jurisdictions: Australia, Bangladesh, China, Hong Kong, India, Japan, New Zealand, the Philippines, South Korea, Taiwan, Thailand, and Vietnam. In addition to standard requirements, information is presented on urban population data, economic growth data, tall building trend data, and past cyclone events data. The effectiveness of cyclone-resistant façades has been proved in the US during past cyclone events and these goals are presented in this document.

The research project "Cyclone-Glazing and Façade Resilience for the Asia Pacific Region" has been conducted by the Council on Tall Buildings and Urban Habitat, thanks to a research grant received from Trosifol World of Interlayers – Kuraray group.
The aim of this research project is to give an overview on the available and used requirements for cyclone – resistant glazing building envelops. Moreover, the research project identify a second step in the cyclone-resistant curtain wall topic. Through the examination of specific building case-studies within the Asia Pacific Region, a technical publication according to the international best practices that have been adopted, will lay the foundation for creating a new, internationally adaptable guidaline on the specific topic. This technical publication could be used as a preliminary guide for industries and professionals in the design and renovation of curtain walls.



▲ Figure 2 - Cyclones, Hurricanes, Typhoons. Areas and time periods of activity

1.0 Research Objectives

1.0 Research Objectives

In 1974 Cyclone Tracy hit the city of Darwin in Australia. It heavily damaged the city and the major consequences of this natural disaster event were identified. It was clear that there was a need for better performance of building envelopes in order to prevent future damage, making building places of refuge, and instilling a sense of security and safety.

Hurricane Andrew (Figure 1), which hit Florida in 1992, became the costliest natural disaster in the history of the United States of America, at that time. In the following years, the Florida Building Code developed curtain wall provisions, which include cyclone resistant glazing to limit wind-borne debris damage caused by high velocity winds (Florida Building code, 1994).

In the US, the first steps in the development of requirements for hurricane resistance was based on the Australian studies and standard requirements that were developed after Cyclone Tracy.

The Florida Building Code, and the revisions introduced since, still represents the most demanding building codes in the US when it comes to impact-resistant facade systems.

On the other side of the Pacific, the South East region of Asia is affected by storms of the same strength, which are referred to as typhoons or cyclones in this region. Highly-populated areas, including the Philippines, Vietnam, South and East China, Korea and Japan, have been affected by these storms, which are of such magnitude they are threatening the economic stability and growth of these regions. Additionally, the megacities that are forming in these areas demand additional residential and office space, which calls for the construction of high-rise buildings.

The CTBUH research project presented in this document studied the current code and standards requirements for the construction of typhoon-resistant curtain wall assemblies in the Asia Pacific region. At the same time, the highest concentration of tall buildings in different Asia Pacific jurisdictions has been identified and projection of the future building concentration in nearby areas has been developed.

The geographic information system (GIS) modeling and the CTBUH database of tall buildings (The Skyscraper Center) were used together in order to give a scale to the problem of tall building construction in typhoon-prone area.

The main focus of the research was the identification of existing code and standard requirements in the Asia Pacific jurisdictions for typhoon resistant façades. This research determined which documents provide sufficient information to ensure safety measures for building glazing systems components in this area. At the same time, the development of the most developed requirements on this topic was studied. This study looked for international codes and standards and how their adoption in different jurisdictions has spread globally. The aim was to analyze the effectiveness (or lack thereof) of these glazing systems, of the differences between the codes.

Finally, some gaps in actual codes and standard requirements have been identified by the technicians operating in the curtain wall industry, by insurance companies and by building managers that have encountered cyclone disaster event on their projects. This scientific community and CTBUH agreed that additional requirements have to be introduced for typhoon resistant glazing systems, especially for tall building construction. This building typology is different from the others and has to face to a highest concentration of problems to solve, related with typhoon resilience.

1.1 Methodology

The following research actions have been conducted:

1.1.1 Geographic Information System Analysis: Asia-Pacific Jurisdictions, Tall Buildings, Past Tropical Cyclone Events

The risk to tall buildings in the Asia Pacific region due to typhoon events has been examined in detail jurisdiction-by- jurisdiction. CTBUH manages and implements the Skyscraper Center, the world's largest database on tall buildings with entries on more than 13,000 buildings above 100 meters in height (and more than 25,000 tall buildings in total). Using GIS modeling, the location of such buildings have been compared with the geographic data of past typhoon events to identify how many tall buildings have suffered from typhoon events in the region and how many are located in an area that has been struck by a typhoon in the past, and therefore, are likely to experience extreme winds in the future.

Utilizing the GIS modeling of past typhoon events and tall building locations, the following information was extracted for the selected Asia Pacific analyzed jurisdictions:

- Amount of tall buildings affected by typhoon events before 2016;
- Amount of tall buildings in prone areas that could currently be affected;
- Amount of tall buildings in prone areas that could be affected in the near future.

1.1.2 Asia Pacific Jurisdictions: The Developing Economies

Data about the local economies of the Asia Pacific jurisdictions examined in this research project have been collected. This was conducted in order to understand the economic possibilities of these counties and the potential economic threat that major storm events could have.

1.1.3 Asia Pacific Jurisdictions: Urban Population Growth

Data about the total and urban populations of the Asia Pacific jurisdictions examined in this research project have been collected. This, along with the economic analysis, can help identify where there has been recent growth in megacities. These are the areas in which the majour Asia-Pacific number of tall buildings is concentrated. Moreover, at the same time, the curtain wall building envelope is adopted for considerable amount of surfaces.

1.1.4 Identification and Selection of Documents for Cyclone-Resistant Building Envelopes

The selection of documents was decided through research conducted by the research team and suggestions from peer review experts in the façade industry.

All of the documents suggested by the peer reviewers were included and analyzed in this research. Although some of the topics discussed in the suggested documents were outside of the scope of this research, the documents did contribute to enriching the overall knowledge of the topics and identified areas where new considerations should be taken, specifically the integration of requirements for cyclone resistant façades into standards and building codes.

1.1.5 Code and Standard Analysis

Each document has been analyzed and the summarized with the following contents:

a) Identification of the document
(author, title, year of publication)

b) A brief description of the document

c) Identification of the availability of information regarding the following seven topics
I. Testing apparatus
II. Wind loads
III. Wind-borne debris impact testing
IV. Pressure cycling testing
V. Testing procedures
VI. Technical reports
VII. Wind speed maps

d) Strengths and limitations of the document

e) Extraction of document contents about the previously identified seven topics (Testing apparatus; Wind loads; Wind-borne debris impact testing; Pressure cycling testing; Testing procedure; Technical report; Wind speed maps)

f) Structure of the Document
(number and name of sections, chapters, appendixes, etc.)

g) Referenced Documents

1.1.6 Document Comparison

The selected documents were compared for the following topics:

- Small missile impact testing
- Large missile impact testing
- Pressure cycles
- Acceptance criteria

The creation of a summary table was performed to share the research findings with the peer reviewers and the readers of the research report in a clear and concise manner.

1.1.7 Asia Pacific Jurisdictions Tabs

Every jurisdiction analyzed in the research project (Australia, Bangladesh, China, Hong Kong, India, Japan, New Zealand, Philippines, South Korea, Taiwan, Thailand, Vietnam), have its own summary tab, in which the following information can be found:

- **GIS Analysis**

TALL BUILDINGS and CYCLONE EVENTS
Tall buildings in 1995
Tall buildings in 2005
Tall buildings in 2017
Tall building in cyclone prone area
Tall building affected by cyclone event before 2016
Taller than 150m in 1995
Taller than 150m in 2005
Taller than 150m in 2017
Taller than 150m in cyclone prone area
Taller than 150m affected by cyclone event before 2016

- **Economic data collection**

ECONOMIC DATA
GDP (2016, million US$)
GDP per capita (2016, US$)
GDP, PPP per capita (2016, US$)
GDP, PPP per capita (2016, world ranking)

- **Population data collection**

POPULATION DATA
Population 2016
Urban population 1960
Urban population 2016
Urban population increase (from 1960 to 2016)

- **Code and standard requirements**

CODE/STANDARD REQUIREMENTS

- **Megacities**

Rank by population
Megacity
Combined population
Area (sq. km)
Density (ppl/sq. km)
Number of 200 m+ buildings
Cities & administrative areas within

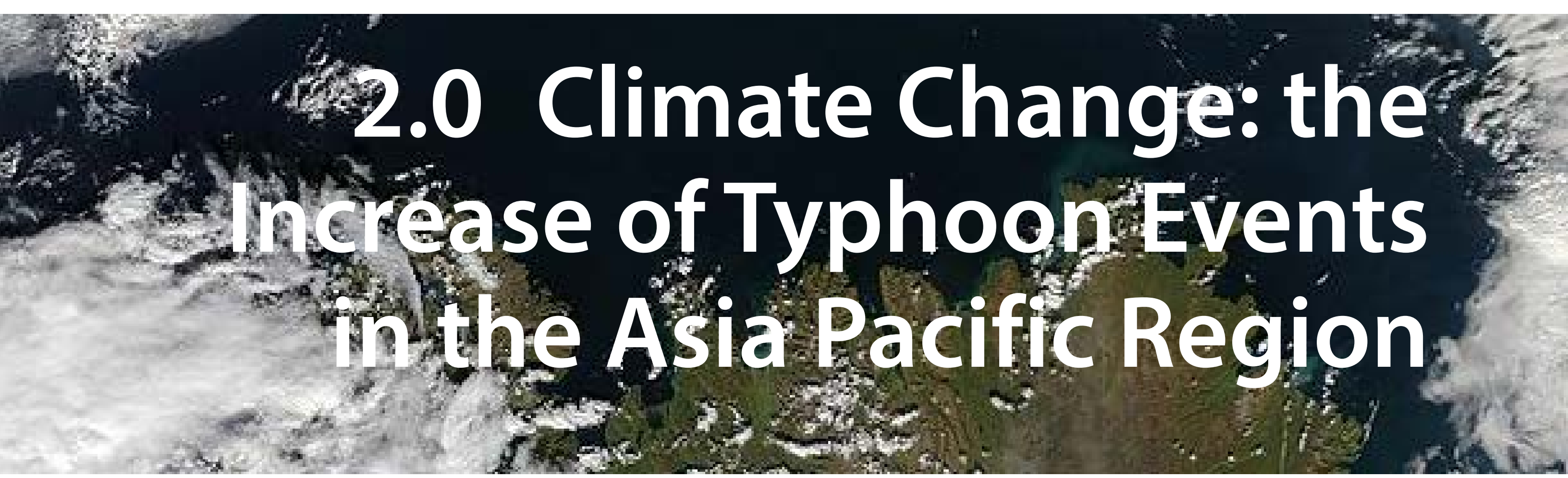
1.1.8 Identification of Gaps in Codes and Standards Requirements

Through communications with the peer review panel of experts, the gaps in international and local requirements for typhoon resistant façades have been identified. The aim of the process is to sensitize the local authorities on typhoon resistant façades topics.

1.1.9 Conclusion

Presentation of the final remarks on the research project activities.

2.0 Climate Change: the Increase of Typhoon Events in the Asia Pacific Region



2.0 Climate Change: the Increase of Typhoon Events in the Asia Pacific Region

Worldwide, climate-change induced disasters have been consistently increasing in both frequency and severity over the past 30 years.

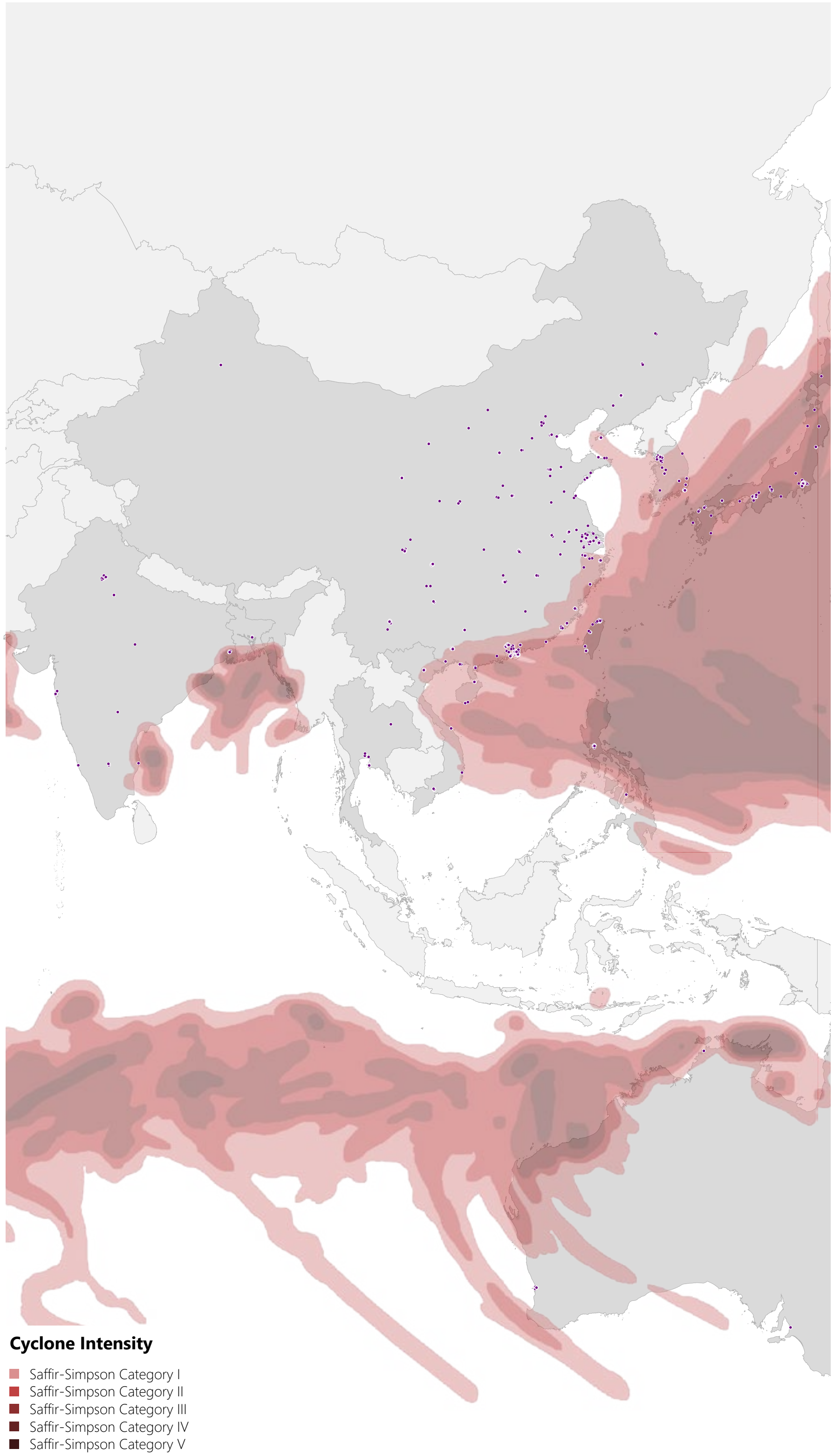
This has become especially evident following the publicity of the Hurricane Harvey, Irma and Maria disasters, which destroyed major, highly populated areadin the US and Carribbean between August and September 2017. These areas are still recovering from the damage.

The World Bank Group in its October 2016 "Reducing Vulnerabilities" East Asia and Pacific Economic Update (World Bank Group, 2016a) has shown that both the frequency and severity of disasters in East-Asia Pacific region have been rising since 1980. Over this period, more than 3.5 billion people have been affected by natural disasters, and the region has sustained some US$525 billion in losses (nearly a quarter of total global losses from natural disasters). Although the number of fatalities has not followed a linear trend, the total number of disasters and the amount of people affected in the EAP region between 1980 and 2015 have been constantly rising. The data also shows a growth in the frequency and intensity of atmospheric events.

This data means that there is a need to preemptively develop codes and standards in this Region, in order to avoid Asia Pacific people and economies suffering because of building failure during these destructive natural hazards.

The World Risk Report has created a World Risk Index, which characterizes the disaster risk for 173 jurisdictions. The risk index takes into account natural hazards and the social sphere. This is calculated on:

- The exposure to natural hazards;



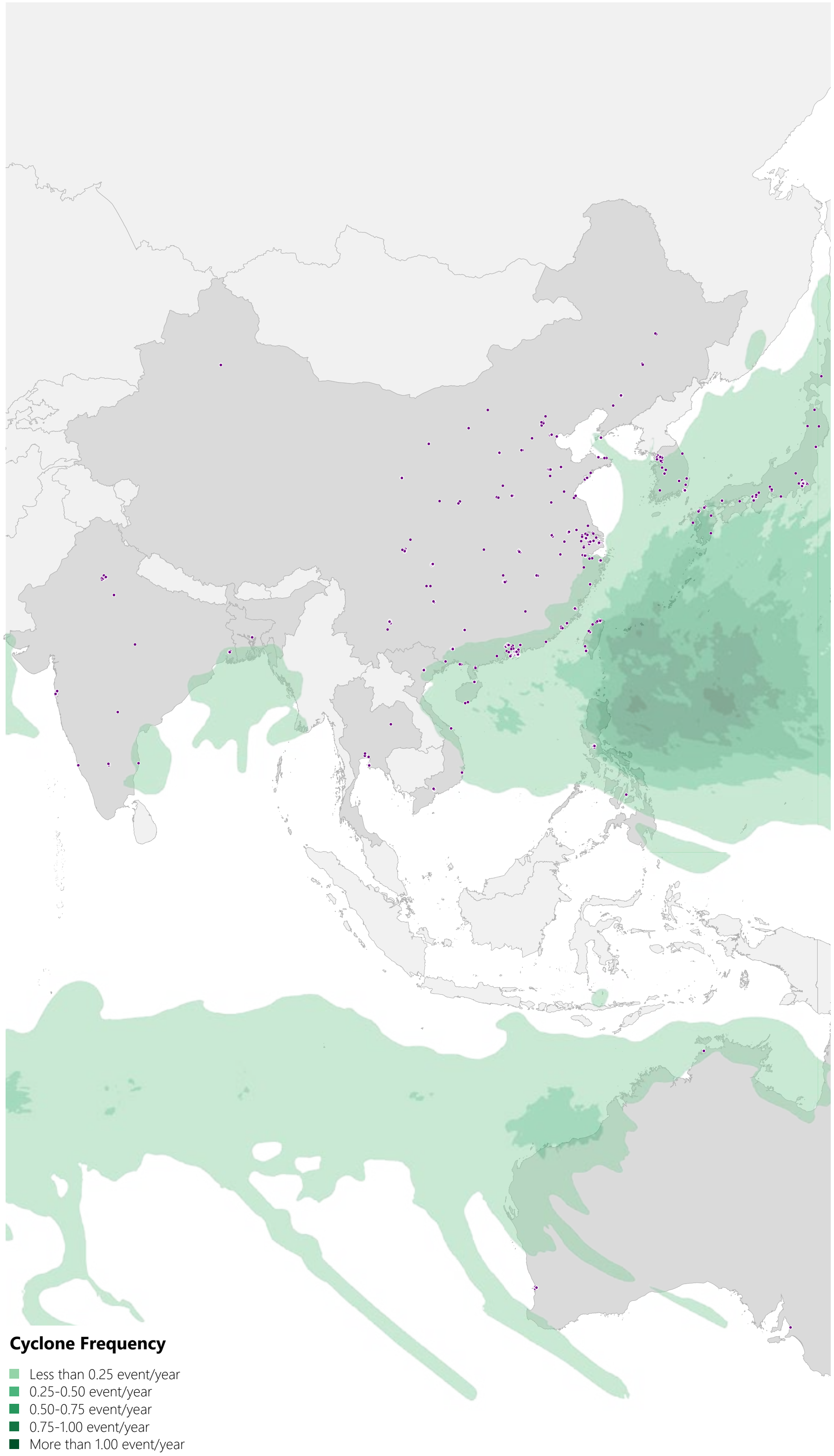
▲ Figure 3 – Cyclone intensities in the Asia-Pacific Region

- Susceptibility: likelihood of suffering harm;
- Coping capacities: the capacity for a jurisdiction to reduce negative consequences;
- Adaptive capacities: the capacity for a jurisdiction to develop long-term strategies for societal change.

The research community has to increase the amount of proposed technical and societal improvements for the Asia Pacific jurisdictions, in order to reduce the negative consequences of natural disasters. Currently, 7 of the 10 most at-risk jurisdictions in the world are located in the Asia Pacific region (11 in the top 20) and the East Asia and Pacific region is the most disaster prone in the world.

Furthermore, "Sustaining Resilience" East Asia and Pacific Economic Update of April 2017 (World Bank Group, 2017) indicates that most of the small Pacific Island Countries are experiencing moderate to strong growth but they are at the same time vulnerable to natural disasters and climate change. More or less every year, these jurisdictions are hit by natural disasters. In the "Pacific Possible" program of research on long-term economic opportunities, vulnerability will remain high even with an increase in policy focused on disaster risk management. This high level of vulnerability could undermine the development of these jurisdictions.

Almost all of the standards developed for wind speed and wind pressure for cyclone events are based on a predictive model. This model does not take into account the strongest event in a deterministic manner but in a statistical one. The development of the model has sped up in recent years, taking into account the increasing number of these natural events due to climate changes.



▲ Figure 4 – Cyclone frequencies in the Asia-Pacific Region

3.0 Asia Pacific Region Economic Growth

3.0 Asia Pacific Region Economic Growth

From 1990 to 2016, the GDP of each of the analyzed twelve Asia Pacific jurisdictions have experienced an incredible increase (Table 1).

In 2016 Australia, Hong Kong, Japan and South Korea are some of the jurisdictions that have the highest GDP PPP (gross domestic product based on purchasing power parity) globally.

This economic power effects the local requirements the research identified in the local governments or building departments – Hong Kong, for example, have a very stringent approval procedure for the new construction.

	GDP (2016, million US$)	GDP per capita (1990, US$)	GDP per capita (2016, US$)	GDP, PPP per capita (2016, US$)	GDP, PPP per capita (2016, world ranking)
Australia	$ 1,204,616.44	$18,249.00	$49,927.00	$46,789.90	17
Bangladesh	$ 221,415.28	$297.00	$1,358.00	$3,580.70	137
China	$ 11,199,145.16	$317.00	$8,123.00	$15,534.70	70
Hong Kong	$ 320,912.24	$16,485.00	$43,681.00	$58,552.70	8/9
India	$ 2,263,522.52	$363.96	$1,709.00	$6,572.30	113
Japan	$ 4,939,383.91	$25,417.00	$38,894.00	$41,469.90	22
New Zealand	$ 185,017.32	$13,663.00	$39,426.00	$39,058.70	24
Philippines	$ 304,905.41	$715.00	$2,951.00	$7,806.20	111
South Korea	$ 1,411,345.59	$6,516.00	$27,538.00	$35,750.80	29
Thailand	$ 406,839.68	$1,508.00	$5,907.00	$16,916.50	64
Vietnam	$ 202,615.89	$98.00	$2,185.00	$6,424.10	117

▲ Table 1 – Gross domestic product (GDP) of the analyzed jurisdictions. Source: World Bank Group

4.0 Asia Pacific Urban Population Growth

4.0 Asia Pacific Urban Population Growth

The Asia Pacific region has seen unprecedented growth over the past decade, both in terms of economy and population, specifically urban population. As the growth in this area occurs, the demand for additional high density residential and office space has also increased, resulting in record numbers of high-rise buildings being constructed (Table 2).

Another typology of city developed in these jurisdictions: the Megacity (Table 3). The human urbanization phenomenon, in fact, is changing the environment and the city morphology, letting megacities rise up. "A megacity is an urban agglomeration with a total population of 10 million people or greater, consisting of a continuous built-up area that encompasses one or more city centers and suburban areas, economically and functionally linked to those centers."

The 2016 CTBUH Conference focused on the megacities and one of the primary benchmarks for the megacity definition could be the Pearl River Delta region of southern China, which is currently the largest. Furthermore, this is one of the most typhoon prone areas, studied in the presented research project.

A list of the already existing megacities follows. The cities highlighted are in jurisdictions in which the research project focused: there is more than half billion people currently living in these cities and there are more than 600 buildings taller than 200 meters.

	Total Population (1960)	Urban Population (1960)	Total Population (2016)	Urban Population (2016)	Increase in Urban Population (from 1960 to 2016)	Average of Increase of Urban Population (from 1960 to 2016)
Australia	10,276.48	8,378.31	24,127.16	21,606.84	13,228.53	8.03%
Bangladesh	48,199.75	2,475.06	162,951.56	57,090.08	54,615.02	29.90%
China	667,070.00	108,085.35	1,378,665.00	782,778.41	674,693.06	40.58%
Hong Kong	3,075.61	2,620.41	7,346.70	7,346.70	4,726.29	14.80%
India	449,480.61	80,564.90	1,324,171.35	438,777.42	358,212.52	15.21%
Japan	92,500.57	58,526.96	126,994.51	119,283.40	60,756.44	30.66%
New Zealand	2,371.80	1,802.52	4,692.70	4,050.83	2,248.31	10.32%
Philippines	26,273.03	7,959.94	103,320.22	45,759.49	37,799.55	13.99%
South Korea	25,012.37	6,930.93	51,245.71	42,324.85	35,393.92	54.88%
Thailand	27,397.17	5,389.57	68,863.51	35,492.25	30,102.68	31.87%
Vietnam	34,743.00	5,107.22	92,701.10	31,737.15	26,629.93	19.54%

▲ Table 2 – Total and urban population data. Comparison 1960 – 2016. Source: World Bank Group

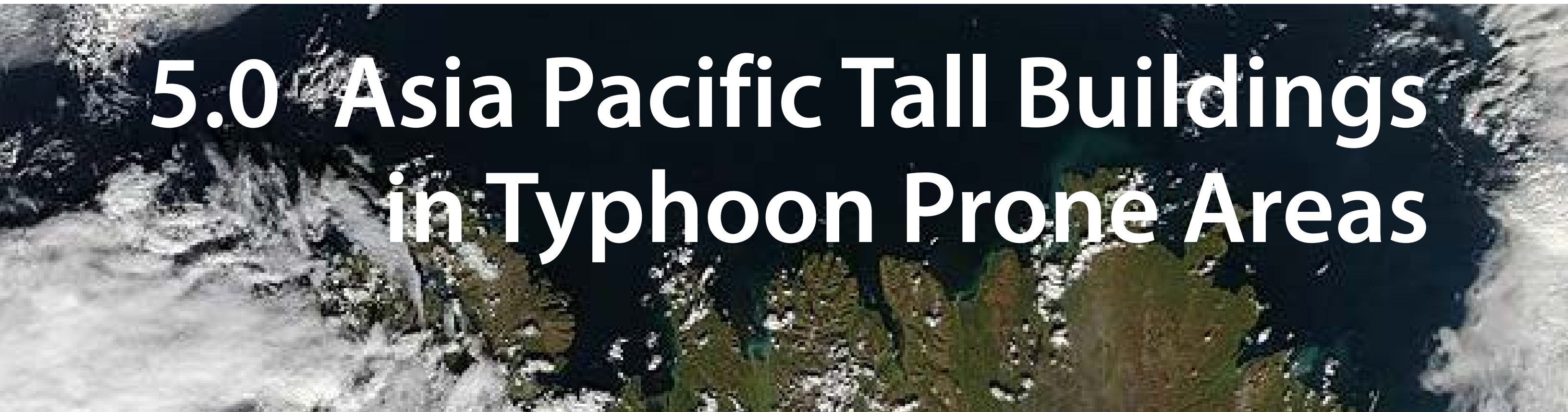
Rank by pop.	Megacity	Country	Combined Population	Area (sq. km)	Density (ppl/sq. km)	# of 200 m+ Buildings	Cities & Administrative Areas Within
1	Pearl River Delta	China	64,899,778	56,217	1,154	220	Dongguan, Foshan, Guangzhou, Hong Kong, Huizhou, Jiangmen, Macau, Shenzhen, Zhaoqing, Zhongshan, and Zuhai
2	Shanghai-Changzhou	China	50,302,212	28,010	1,796	90	Changzhou, Jiaxing, Shanghai, Suzhou, and Wuxi
3	Tokyo (Kanto Region)	Japan	42,797,000	32,424	1,320	29	Prefectures of Chiba, Gunma, Ibaraki, Kanagawa, Saitama, Tochigi and Tokyo
4	Beijing-Tianjin	China	40,594,839	34,588	1,174	50	Beijing, Langfang, and Tianjin
5	Delhi	India	34,397,873	15,562	2,210	3	Delhi, Nodia, Gurgaon, Ghaziabad, Rohtak, and Meerut
6	New York-Philadelphia	USA	30,907,175	54,880	563	96	Atlantic City, Jersey City, New Haven, New York, Philadelphia, Trenton, and Wilmington
7	Chongqing	China	30,165,500	82,403	366	46	Chongqing Province
8	Sao Paulo	Brazil	29,740,692	23,556	1,263	0	Baixada Santista, Campinas, Santos, Sao Jose dos Campos, Sao Paulo, and Sorocaba
9	Jakarta	Indonesia	28,424,717	6,438	4,415	46	Bekasi, Bogor, Depak, Jakarta, and Tangerang
10	Mumbai	India	26,136,721	17,313	1,510	38	Districts of Mumbai, Mumbai Suburban, Pulghar & Raigad, Thane
11	Seoul-Incheon	South Korea	25,524,572	11,807	2,162	39	Gyeonggi Province, Incheon, and Seoul
12	Manila	Philippines	25,169,197	8,113	3,102	30	Provinces of Bulacan, Cavite, Leguna, Rizal, and the National Capitol Region
13	Dhaka	Bangladesh	24,952,038	9,353	2,668	0	Districts of Dhaka, Gazipur, Munshiganj, Mymensingh, and Narayanganj within Dhaka Division
14	Karachi	Pakistan	23,500,000	3,527	6,663	1	Karachi Administrative District
15	Mexico City	Mexico	23,492,352	11,317	2,076	6	Metropolitain areas of Mexico City, Tianguistenco, Toluca, Tula, and the municipality of Tepeji del Río de Ocampo
16	Cairo	Egypt	21,455,656	6,649	3,227	0	Al Qalyubia, Cairo, and Giza Governorate
17	Hangzhou-Ningbo	China	21,218,301	34,936	607	24	Hangzhou, Ningbo, Shaoxing
18	Osaka	Japan	20,750,000	27,351	759	6	Prefectures of Hyogo, Kyoto, Osaka, Nara, Shiga, and Wakayama; including the cities of Hemeji, Izumisano, and Kobe

19	Kolkata	India	20,608,327	18,885	1,091	1	Districts of Hooghly, Howrah, Kolkata, North 24 Parganas, Parganas and South 24
20	Lahore	Pakistan	20,530,000	12,631	1,625	0	Districts of Gujranwala, Kasur, Lahore, and Sheikhupura
21	Moscow	Russia	19,002,220	33,262	571	19	Moscow City and the more urbanized portions of the Moscow Oblast
22	Los Angeles	USA	18,679,763	87,944	212	13	Long Beach, Los Angeles, Oxnard, and Riverside
23	Ho Chi Minh	Vietnam	18,051,200	23,724	761	7	Ho Chi Minh City and Provinces of Ba Ria-Vung Tau, Binh Duong, Dong Nai, Long An, Tay Ninh, and Tien Giang
24	Bangkok	Thailand	17,718,258	21,028	843	20	Provinces of Bangkok, Chachoengsao, Chon Buri, Nakhon Patham, Nonthaburi, Pathum Thani, Rayong, Samout Prakan, and Samut Sakhon
25	Chengdu	China	17,663,383	18,115	975	24	Chengdu, Deyang
26	Xiamen	China	16,469,863	25,792	639	20	Quanzhou, Xiamen, Zhangzhou
27	Istanbul	Turkey	16,437,489	8,808	1,866	7	Istanbul and Kocaeli provinces, including the districts of Gebze and Izmit
28	Tehran	Iran	15,450,000	18,814	821	0	Provinces of Alborz and Tehran, including the cities of Eslamshahr, Karaj, and Varamin
29	Buenos Aires	Argentina	15,333,035	11,134	1,377	1	Greater Buenos Aires and La Plata Metropolitan Areas
30	London	United Kingdom	14,031,830	12,091	1,161	8	London and the districts of Essex, Hertfordshire, Kent, and Surrey
31	Shantou	China	13,943,141	10,660	1,308	0	Chaozhou, Jieyang, and Shantou

32	Johannesburg -Pretoria	South Africa	13,937,500	22,017	633	1	Gautang Province (including Johannesburg, Midrand, and Pretoria) and the municipality of Madibeng
33	Bangalore	India	13,093,168	13,139	1,297	0	Districts of Bangalore, Krishnagiri Districts, and Ramanagara
34	Kinshasa-Brazzaville	Democratic Republic of Congo-Republic of Congo	13,271,392	10,229	997	0	Brazzaville and Kinshasa
35	Rhine-Ruhr	Germany	12,695,656	14,160	640	0	Bonn, Colonge, Duisburg, Dusseldorf, Essen, Mönchengladbach and Wuppertal
36	Chicago-Milwaukee	USA	11,970,050	37,324	1,154	31	Chicago, Kankakee, Michigan City, Milwuakee, Naperville, and Shaumburg
37	Lagos	Nigeria	12,864,745	20,107	1,749	0	Lagos State, Ogun State
38	Rio de Janeiro	Brazil	12,678,779	7,249	1,537	0	Belford Roxo, Dudue de Caxias, Nova Iguacu, Rio de Janeiro and San Goncalo
39	Chennai	India	12,373,088	8,052	705	0	Districts of Chennai, Kancheepuram Districts, and Thiruvallur
40	Hyderabad	India	12,273,352	17409	1,005	0	Districts of Hyderabad, Medak, and Rangareddy
41	Paris	France	12,073,914	12,011	321	2	Departments of Essonne, Paris, Seine-Saint-Denis, Seine-et-Marne, Val-de-Marne, Val-d'Oise, and Yvelines

▲ Table 3 – Megacities - underlined the regions located in the jurisdictions focus of the research project. Source: Megacities: Setting the Scene, 2016. CTBUH Research Paper.

5.0 Asia Pacific Tall Buildings in Typhoon Prone Areas



5.0 Asia Pacific Tall Buildings in Typhoon Prone Areas

	Tall buildings affected by typhoon events before 2016	Tall buildings in typhoon prone areas - existing	Tall buildings in typhoon prone areas - under construction	Tall buildings in typhoon prone areas - total number	Tall buildings - total number in the analyzed Asia Pacific jurisdictions
Asia Pacific analyzed jurisdictions	1,778	3,987	582	4,569	7,086

▲ Table 4 - There are 4,569 tall buildings in Asia Pacific's typhoon-prone areas. Sources: Global Risk Data Platform and the CTBUH Skyscraper Center

The risk to tall buildings in the Asia Pacific region due to typhoon events has been examined in detail jurisdiction-by-jurisdiction. CTBUH manages and implements the Skyscraper Center (Skyscraper Center, 2017), the world's largest database on tall buildings with entries on more than 13,000 buildings above 100 meters in height (and more than 25,000 tall buildings in total). Using GIS modeling, the location of such buildings have been compared with the geographic data of past typhoon event to identify how many tall buildings have suffered from typhoon events in the region and how many are located in an area that has been struck by a typhoon in the past, and therefore, are likely to experience extreme winds in the future.

Utilizing the GIS modeling of past typhoon events and tall building locations, the following information was extracted for the selected Asia Pacific analyzed jurisdictions:

- Amount of tall buildings affected by typhoon events before 2016;
- Amount of tall buildings in prone areas that could currently be affected;
- Amount of tall buildings in prone areas that could be affected in the near future.

1,778 buildings have experienced at least one typhoon event (Table 4), resulting in 14,617 total instances that buildings have been affected by 240 unique typhoon events in the past 45 years (293 of the 1,778 buildings have experienced a severe typhoon event with wind speeds greater than 150 km/h).

More than double that amount of buildings (3,987) are currently built in areas that have experienced a typhoon event in the past, and there are even more (4,569) if buildings that are currently under construction are included. This shows that the magnitude of the problem is increasing as there are now an increased number of tall buildings susceptible to typhoon events that are increasing in frequency and severity.

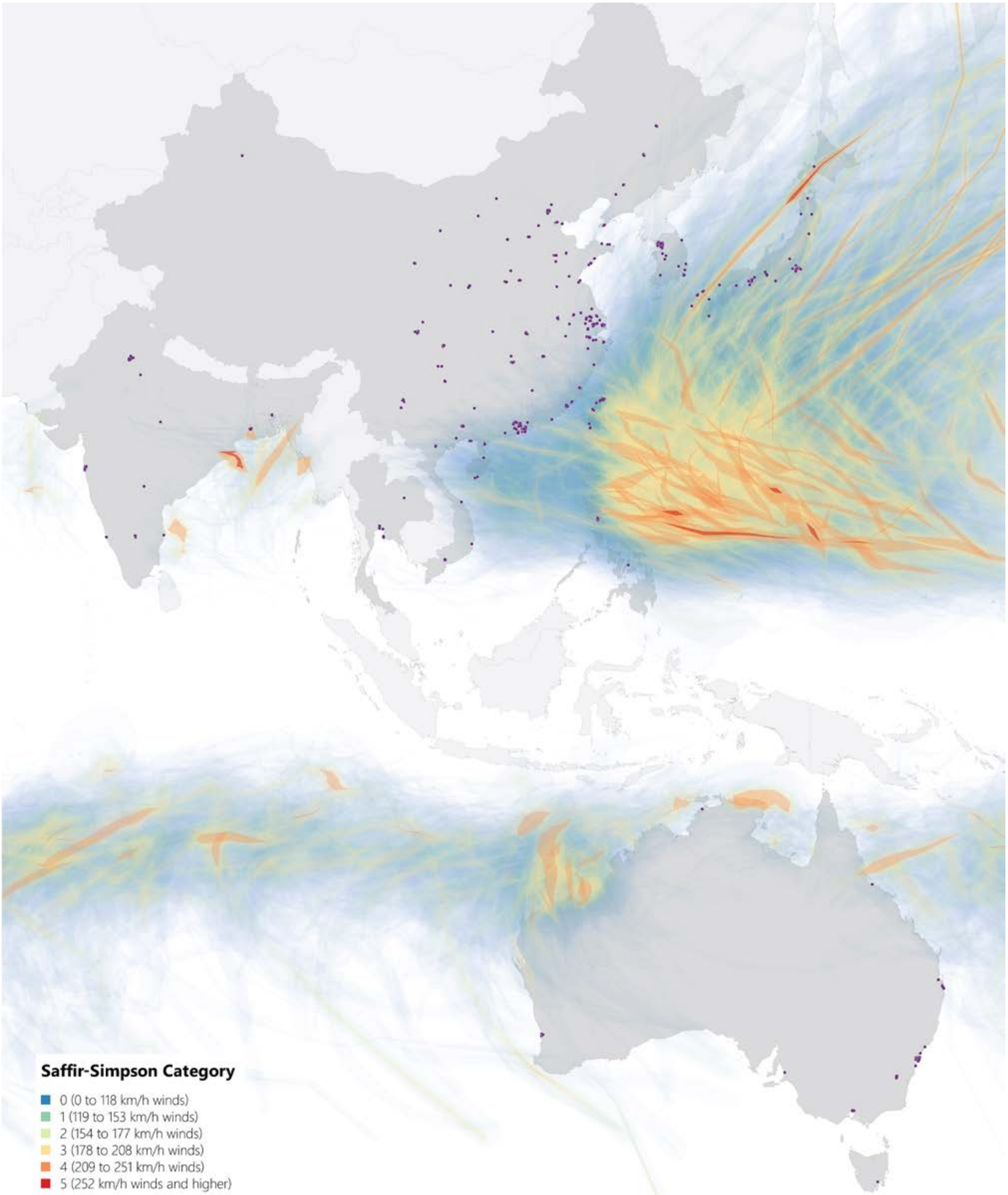
The summarized output of the GIS analysis for the Asia Pacific jurisdictions is displayed in Table 4. The total amount of Asia Pacific tall buildings analyzed was 7,086, and more than a half of those are located in typhoon-prone areas (4,569).

The list of jurisdictions analyzed in the research is shown in Tables 5, 2 and 1. These report data about: local population; total and urban population data comparison (1960 – 2016); economy; GDP of the analyzed jurisdictions; tall building development; amount of tall buildings in typhoon prone areas by each jurisdiction; average typhoon occurrences.

Data presented in Table 5 shows that there are no complete or under-construction tall buildings that are in areas that have experienced a typhoon event in the past 30 years in Thailand. That being said, the data analyzed by CTBUH does not take into account climate change, which is shown to cause storms to affect areas that may not have previously experienced any in the past. Thus, the buildings that are in these areas that have not experienced past events could very well experience a typhoon in the future. In Thailand the total amount of tall buildings currently complete or under-construction is 168.

	10-year moving average 2005-2014 Number of natural disaster events, Frequency of cyclones (%)	Tall buildings affected by typhoon event before 2016	Tall buildings in typhoon prone area - existing	Tall buildings in typhoon prone area - under construction
Australia	4, 43.5%	68	170	27
Bangladesh	6, 52.8%	1	5	4
China	29, 33.2%	300	1,675	387
Hong Kong	1, 78.3%	575	819	12
India	16, 22.7%	6	25	5
Japan	6, 55.4%	470	564	10
New Zealand	1, 32.3%	5	10	0
Philippines	18, 51.3%	74	144	47
South Korea	2, 51.6%	192	371	21
Taiwan	3, 81.3%	78	102	12
Thailand	4, 25.7%	0	0	0
Vietnam	7, 48.7%	9	102	57

▲ Table 5 - Asia Pacific jurisdictions' tall building development in typhoon-prone area and frequencies of typhoon events (10-year moving avarage). Sources: Prevention Web; Global Risk Data Platform; the CTBUH Skyscraper Center



▲ Figure 6 – Locations of buildings taller than 150 m, cross-referenced with past typhoon events. One purple dot represents the location of a city with at least one 150m+ building

6.0 Cyclone Resistant Façades

6.0 Cyclone Resistant Façades

6.1 First Steps

Australia (1975, following Cyclone Tracy) followed by the US (1994, following Hurricane Andrew) were the first developers of codes and standards requirements for typhoon prone regions.

In Christmas 1974, the Darwin Area, in the Northern Territory Australia, suffered huge losses due to Cyclone Tracy and resulted in the request for cyclone resilience for glazing building components to be introduced. This disaster event reached 240 km/h of wind speed and caused 71 fatalities: it was the strongest cyclone in the Southern Hemisphere. It represented the second major disaster event that Australia experienced in five years. Before Cyclone Tracy, Cyclone Althea hit Townsville in December 1971.

The main hazards during these disaster events were identified in the strong winds and in the flying wind-borne debris. In the following months, the Darwin Area, and specifically the Darwin Reconstruction Commission, aimed to reconstruct the city within five years starting from the houses, began working on building safety guidelines in order to avoid extreme losses due to cyclone events in the future. Here, the Darwin Area Building Manual in 1975 introduced the requirement for all houses to be engineered and presented tests to perform on building components. The openings had to be capable of resisting a 4 kg mass with a geometry of 100x50 mm impacting cross section striking any angle at a velocity of 20 m/s without affecting internal design pressure, as specified in clause 30.1 (VI) of the Darwin Area Building Manual (Darwin reconstruction Commission, 1975). The glass could be fractured but had to withstand this impact test, which represents an impact energy of 800 J without penetration.

This requirement follows the loss of the 80 percent of houses that were destroyed by Cyclone Tracy. In 1975, for the first time, "cyclone resistant glass" was introduced as part of an envelope capable of withstanding a defined stress without affecting the building's internal condition and preserving it.

This innovative use of glass was developed in the testing labs of Pilkington (Australia) in 1975. A 4 kg timber plank with 100x50 mm impacting cross section was used striking the glass a velocity of 20 m/s and this cracked the glass without penetrating the glass. The cracked glass was then subjected to the full design wind pressure applicable to the cyclonic region. The cracked glass was able to resist the pressure without any air leakage provided the edges of the glass were properly held to the frame using adhesive glazing compound. That is, the critical part of the design was not only the glass being adequate but also the cracked glass needed to be adhered to the frames in order to prevent the entire glass panel being forced out of the frame. This testing procedure was modified and served as a basis for the following years guidelines.

Furthermore, in Australia, in 1978, the Experimental Building Station Department of Construction issued Technical Record 440 "Guidelines for the Testing and Evaluation of Products for Cyclone-Prone Areas" in which the impact test requirements indicated a different impact speed for the 4-kg mass timber missile impacting building glazing systems (TR 440, 1978). This procedure derived from the research activities carried out after Cyclone Tracy, that focused on two main areas: "the nature of winds and the response of buildings and building components to them; and the development of valid methods of performance testing". The impact speed to be applied for testing the building envelope was agreed as 15 m/s for the 4-kg mass timber missile (100x50 mm section).

Also, in Technical Record 440, the requirement for metal roof cladding in cyclone prone regions to withstand dynamic wind loading effects was agreed, but there was no pressure cycling requirement for cyclone-resistant windows.

In mid-August 1992, Hurricane Andrew hit the coasts of Florida, Bahamas and Louisiana. This was the most destructive and costliest disaster event at the time, and maintained that title until Katrina occurred in 2005. The highest winds were recorded in the Miami-Dade County between August 23rd and August 24th 1992 and they reached a 270 km/h wind speed. Hurricane Andrew was a Category Four Hurricane on the Saffir-Simpson Scale and caused $25.3 billion in damage to local buildings, especially to their envelopes and 44 fatalities just in Florida.

The South Florida landscape changed completely. In South Florida, around 150,000 to 250,000 people were left homeless and communication and transportation infrastructure were significantly impaired while there was tremendous loss of water, power and utilities. 1.4-million people were left without power and the residential buildings remained without it for up to six months after Andrew occurred.

Hurricane Andrew was the most powerful hurricane to hit South Florida in almost 30 years and there was about one generation who had not experienced any hurricane. For these residents the psychological impact was shocking. That was the reason why many people decided to move to other cities and states instead of repairing their homes and businesses. For people who decided to re-build their own buildings, the reconstruction process took years to complete.

Following the hurricane, there was a revision process for the building code in South Florida, in order to prevent future hurricanes from causing comparable destruction in the future. Curtain wall provisions were added to Florida Building Code, which included the strengthening of building openings and glass surfaces to limit damage caused by high velocity windborne debris.

The Australian Technical Record 440 (1978) represented the basis for the introduction of impact test requirements for building façades and windows. The Florida impact test procedure improved upon Australia's; it differed from the Australian one because of well identified points in which the missile had to impact the glazing building component and the request for the specimen to withstand a cycling of positive and negative pressure after the impact test.

Another test procedure was used as the basis for the development of the Florida Building Code requirement: the non-mandatory reference standard SSTD 12-94 "Standards for Determining Impact Resistance from Windborne Debris" (SBCCI, 1994) by the Alabama-based Southern Building Code Congress International (SBCCI, 1994). This document was edited with the purpose to strengthen window glazing in order to make them withstand wind-borne debris (which can act as missiles to penetrate a building during a hurricane) and to the push/pull force of the eye of a hurricane. The glazing system building component, in order to pass the test for the voluntary product approval process, has to withstand both the missile impact and, next, the pressure cycling.

The Florida Building Code was the toughest in the US and here it was the first building code in which wind-borne debris requirements were introduced in order to improve the impact-resistance of façade systems from cyclone events. In 1994, the Florida Building Code began to introduce façade performance requirements and the Florida Building Commission, regulating the High Velocity Hurricane Zone (Wind Zone 4) introduced the Testing Application Standard procedures (TAS 201-94, TAS 202-94, TAS 203-94 specified in the Florida Building Code, 1994).

From 1996, the Miami-Dade County best practice includes the product approval program with the Notice of Acceptance (NOA). These are set forth by Miami-Dade County for all construction trades and the Florida Product Approval organizes the owner's product acceptance.

The design of a cyclone resistant façade to withstand the requested tests for the product approval process does not consist in the changing of the glazing system. It is a complex process, in which many factors have to work together in order to reach the resilience needed by the window system. All the elements have to co-operate to resist first the impact test, than the cycling pressure test, that are associated with extreme winds and flying wind-borne debris. The design choice of the glass characteristics, the interlayer for glass lamination, and the fastening method all affect the performance of the building glazing system. By focusing on the window or façade's size, geometry, and design pressure, it is possible to proceed with the design of: glass thickness and strength characteristics, and the interlayer material properties and thickness specifications.

Looking at extreme wind events, different kind of damages on the glazing systems building components have been noticed. On the basis of this damage, the test requirements for cyclone resistant façades and windows have been improved. In the test, the large wooden missile is well representative of the tree branches, of the garbage cans, and of other objects that typically impact buildings close to the ground level. These objects, during a cyclone event, normally build up enough energy to break windows and to penetrate inside the building.

Also, it has been noticed that all building elevations could be impacted by small wind-borne debris during a cyclone event. This small debris could reach high velocity and break the glass of the façade.

From this, testing procedures for small and large missile impact tests have been developed.

Then, the investigation pointed out that, during a cyclone event, alternation of positive and negative pressure act on the building envelope and that positive internal pressure develops if the envelope of the building is broken due to the impact of wind-borne debris.

The aim of the impact-resistant building codes is to guarantee that new building constructions preserve their integrity without breaking during a cyclone event.

6.2 Typhoon Resistant Façades – Main Characteristics

Façade resilience is needed to provide adequate safety during a typhoon event. This characteristic aims to primarily avoid broken glass. When the break occurs, the glass could injury people and, in order to avoid this kind of problem, requirements for tempered glass should be introduced and the whole system needs to be designed properly. The success of the system can be significantly impacted by the characteristics of the glass, the interlayer for glass lamination, and the fastening method. In the US, the product approval process asks for the entire curtain wall system to be tested. This entire system must pass the impact tests, and the subsequent application of pressure cycle tests, before it can be approved and used in a construction project.

The laminated glass composition used in typhoon resistant glass must resist both the design wind load and the missile impact specified by codes. The thickness of the glass lites in the laminated glass is determined by the wind load and the interlayer type. However, the resistance to penetration by missile impact is almost entirely reliant on the interlayer type and its thickness.

Laminated systems utilize two or more lites of glass, merged toghether with one or more interlayer elements, which can ensure glass retention and post glass breakage strenght if breakage occurs. The primary types of interlayers used are polyvinyl butyral (PVB) and Ionoplast.

PVB is a soft interlayer and it is commonly used for low design pressures and missile speeds. The laminate risks to pull out with high wind pressures during the final pressure cycling testing (for ASTM E1996, 2014). Thus, normally using PVB, better frame design or thicker interlayer will be needed.

Ionoplast interlayers were introduced in 1998 in South Florida and they can meet the highest performances requested for impact resistance (large missiles D and E). Being a stiff interlayer, it provides added strength and rigidity and could down gauge the glass used. The laminate remains intact after the pressure cycling test. Another advantage of the Ionoplast interlayer is the possibility it gives to the glazing system to be dry glazed, reducing installation costs and the time needed for the traditional wet glaze system installation.

It is not possible to design a dry glaze system with laminated glass which uses PVB interlayers because it is too flexible.

However, in the testing for the product approval process the aim is not just the components to be tested, but the whole system. In this way, the glass can be pre-dimensioned based on the size of the specimen and the impact velocity of the missile, but it is necessary to verify that the system can withstand testing requirements. Impact testing and then subsequent application of pressure cycles and depression must present positive results for window approval to be used.

Polyvinyl butyral

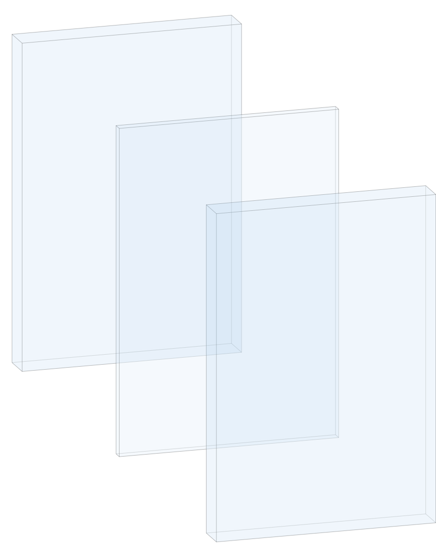
- Typically used for relatively small glass panel sizes & low pressures in large missile impact resistance applications in 2.28 mm thickness;
- Small missile impact resistance uses 1.52 mm thickness;
- Available in clear or colors;
- UV-filtering.

Ionoplast

- Typically used for high design pressures, large windows, large missile impact;
- Can be used in dry glaze systems - lower cost and easier installation;
- High modulus interlayer used to bond two lites of glass together;
- 100x stiffer than PVB, 5x more tear resistant;
- Thicknesses include 0.89 mm, 1.52 mm, & 2.28 mm, and greater thicknesses;
- UV-filtering;
- UV-transparency available;
- Available in clear or translucent white;
- Less sensitive to moisture intrusion at the laminate edge than PVB.

Typical Construction

- 6 mm HS Glass/ 2.28 mm interlayer/ 6 mm HS Glass for large missile impact;
- 6 mm HS Glass/1.52 mm or 0.89 mm interlayer/ 6 mm HS Glass for small missile impact.



▲ Figure 7 – Laminated glass: two glass lites and one interlayer

6.3 Best Codes and Standards Requirements for Cyclone Resistant Façades

In the US there are the standards that provide the most developed testing requirements on the research topic. The Florida Building Code requirements were the first in the US for building protection from wind-borne debris. These were the more stringent testing requirements since the ASTM standards were developed and the most representative of a real storm event, thanks to the pressure cycling test after the missile impact test. Hurricane resistant building components began to follow a strict product approval process and to withstand to impact and pressure cycling testing.

In the ASCE 7-16 (ASCE, 2016), the main US Building Code, the wind zone map is shown to identify the windborne debris regions and the boundary for hurricane-prone regions. ASTM E1886 (ASTM, 2013) and ASTM E1996 (ASTM, 2014) requirements, or local standards requirements when more stringent, have to be follow by buildings constructed in US areas affected by hurricanes. ASTM standards dictate the glass composition for the building envelope, as well as, the air infiltration control during a disaster event.

- ASTM E1996, 2014. Standard Specification of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Wind-borne Debris in Hurricanes;
- ASTM E1886, 2013. Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors and Impact Protective Systems Impacted by Missile(s) and Exposed to Cyclic Pressure Differentials.

The ASTM E1996 (ASTM, 2014) defines the small and the large missile impact test and the pressure cycling phase of the testing procedure. It introduces other parameters for testing, not mentioned in the Testing Application Standards TAS 201, TAS 202, TAS 203 (Florida Building Code, 1994), such as the test temperatures. This is a very important parameter to control, which often causes the failure of the test. This standard creates protection zones and additional missile types for users. The ASTM E1996 (ASTM, 2014)identifies the design wind speed for the location as well as the risk category of the building from ASCE 7: the enhanced protection refers to essential facilities as fire rescue stations, emergency centers, hospitals.

There are some differences between the wind zone map represented in the previous editions of the ASCE 7 (ASCE 7-05, 2005; ASCE 7-10, 2010). The wind maps are used to determine the wind zone and performance level needed for a building depending on its location. In ASCE 7-05 the wind speed is lower than that shown in the ASCE 7-10. This reflected the definition of a safer wind speed map based on climate change, but in the last edition of ASCE 7-16 (ASCE, 2016), the wind speed maps represent reduced wind speeds for much of the jurisdiction and clarify the special wind study zones, including new maps for Hawaii.

The International Code Council regulates areas in 130 mph (209 km/h) wind zones and higher, which are identified as wind borne debris regions and the required debris missile resistance is defined (International Code Council, 2015). International Building Code references the ASTM E1886 and the ASTM E1996 standards for these requirements.

The International Standard ISO 16932 (ISO, 2015) defines the destructive-windstorm resistant security glazing requirements and it references the ASTM standards and Australian technical requisites developed in the last decades, which are well rooted as best practices for the Asia Pacific jurisdictions, even if in recent years they have changed significantly.

6.3.1 The ASTM Standard Requirements for Hurricane Resistant Façades

6.3.1.1 Classification of Hurricanes in the US

ATLANTIC, EASTERN AND CENTRAL PACIFIC	
National Hurricane Center / Central Pacific Hurricane Center	
SAFFIR-SIMPSON SCALE	
Category	**Wind speed**
Five	≥70 m/s, ≥137 knots, ≥157 mph, ≥252 km/h
Four	58–70 m/s, 113–136 knots, 130–156 mph, 209–251 km/h
Three	50–58 m/s, 96–112 knots, 111–129 mph, 178–208 km/h
Two	43–49 m/s, 83–95 knots, 96–110 mph, 154–177 km/h
One	33–42 m/s, 64–82 knots, 74–95 mph, 119–153 km/h
Tropical storm	18–32 m/s, 34–63 knots, 39–73 mph, 63–118 km/h
Tropical depression	≤17 m/s, ≤33 knots, ≤38 mph, ≤62 km/h

▲ Table 6 Tropical cyclone classification - Saffir Simpson Scale, National Hurricane Center/Central Pacific Curricane Center

6.3.1.2 Occupance Category of Buildings in the US

AUTHOR	American Society of Civil Engineers
TITLE	ASCE 7-16 Minimum Design Loads and Associated Criteria for Buildings and Other Structures
YEAR	2016
RISK CATEGORY OF BUILDINGS AND OTHER STRUCTURES	
RISK CATEGORY	NATURE OF OCCUPANCY
I	Buildings and other structures that represent low risk to human life in the event of failure.
II	All buildings and other structures except those listed in Risk Categories I, III, and IV.
III	Buildings and other structures, the failure of which could pose a substantial risk to human life. Buildings and other structures, not included in Risk Category IV, with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure. Buildings and other structures not included in Risk Category IV (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives) containing toxic or explosive substances where the quantity of the material exceeds a threshold quantity established by the Authority Having Jurisdiction and is sufficient to pose a threat to the public if released.
IV	Buildings and other structures designated as essential facilities. Buildings and other structures, the failure of which could pose a substantial hazard to the community Buildings and other structures (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, or hazardous waste) containing sufficient quantities of highly toxic substances where the quantity of the material exceeds a threshold quantity established by the Authority Having Jurisdiction and is sufficient to pose a threat to the public if released. Buildings and other structures required to maintain the functionality of other Risk Category IV structures.

▲ Table 7 - Risk Category of Buildings, ASCE 7-16

AUTHOR	ICC International Code Council
TITLE	Florida Building Code, Building
YEAR	2015 - 5th edition
RISK CATEGORY OF BUILDINGS AND OTHER STRUCTURES	
RISK CATEGORY	NATURE OF OCCUPANCY
I	Buildings and other structures that represent a low hazard to human life in the event of failure, including but not limited to: • Agricultural facilities. • Certain temporary facilities. • Minor storage facilities.
II	Buildings and other structures except those listed in Risk Categories I, III and IV.

III	Buildings and other structures that represent a substantial hazard to human life in the event of failure, including but not limited to: • Buildings and other structures whose primary occupancy is public assembly with an occupant load greater than 300. • Buildings and other structures containing Group E occupancies with an occupant load greater than 250. • Buildings and other structures containing educational occupancies for students above the 12th grade with an occupant load greater than 500. • Group I-2 occupancies with an occupant load of 50 or more resident care recipients but not having surgery or emergency treatment facilities. • Group I-3 occupancies. • Any other occupancy with an occupant load greater than 5,000. • Power-generating stations, water treatment facilities for potable water, wastewater treatment facilities and other public utility facilities not included in Risk Category IV. • Buildings and other structures not included in Risk Category IV containing quantities of toxic or explosive materials that: Exceed maximum allowable quantities per control area as given in Table 307.1(1) or 307.1(2) (ICC, 2015) or per outdoor control area in accordance with the International Fire Code; and Are sufficient to pose a threat to the public if released.
IV	Buildings and other structures designated as essential facilities, including but not limited to: • Group I-2 occupancies having surgery or emergency treatment facilities. • Fire, rescue, ambulance and police stations and emergency vehicle garages. • Designated earthquake, hurricane or other emergency shelters. • Designated emergency preparedness, communications and operations centers and other facilities required for emergency response. • Power-generating stations and other public utility facilities required as emergency backup facilities for Risk Category IV structures. • Buildings and other structures containing quantities of highly toxic materials that: Exceed maximum allowable quantities per control area as given in Table 307.1(2) (ICC, 2015) or per outdoor control area in accordance with the International Fire Code; and Are sufficient to pose a threat to the public if released. • Aviation control towers, air traffic control centers and emergency aircraft hangars. • Buildings and other structures having critical national defense functions. • Water storage facilities and pump structures required to maintain water pressure for fire suppression.
a. For purposes of occupant load calculation, occupancies required by Table 1004.1.2 (ICC, 2015) to use gross floor area calculations shall be permitted to use net floor areas to determine the total occupant load.	
b. Where approved by the building official, the classification of buildings and other structures as Risk Category III or IV based on their quantities of toxic, highly toxic or explosive materials is permitted to be reduced to Risk Category II, provided it can be demonstrated by a hazard assessment in accordance with §1.5.3 of ASCE 7 (ASCE, 2016) that a release of the toxic, highly toxic or explosive materials is not sufficient to pose a threat to the public.	

▲ Table 8 - Risk Category of Buildings, Florida Building Code

6.3.1.3 Testing procedure – ASTM E 1996

From 'ASTM E 1996 - 14a, 2014. Standard Specification for Performance of Exterior Windows, Curtain Walls and Storm Shutters Impacted by Windborne Debris in Hurricanes':

4. Test Specimens

4.1 Number of Test Specimens:

4.1.1 Fenestration Assemblies:

4.1.1.1 Three test specimens shall be submitted for the large missile test.

4.1.1.2 Three test specimens shall be submitted for the small missile test.

4.1.1.3 One additional test specimen may be submitted for each of the tests should no more than one of the original three specimens fail any portion of the testing.

4.1.2 Impact Protective Systems:

4.1.2.1 A minimum of three test specimens shall be submitted for the large missile test for the largest span to be qualified.

4.1.2.2 A minimum of three test specimens shall be submitted for the small missile test.

4.1.2.3 One additional test specimen may be submitted for each of the tests should no more than one of the original specimens fail any portion of the testing.

4.2 Test specimens shall be prepared as specified in Test Method E 1886.

4.3 The size of the test specimen shall be determined by the specifying authority. All components of each test specimen shall be full size.

4.4 Where it is impractical to test the entire fenestration assembly such as curtain wall and heavy commercial assemblies, test the largest size of each type of panel as required by the specifying authority to qualify the entire assembly.

4.5 Fenestration assemblies and impact protective systems intended to be mulled together shall be tested separately or tested by combining three specimens into one mounting frame separated only by the mullions.

5.1 Test specimens shall be tested according to Test Method E 1886.

5.2 Determine the missile based upon building classification, wind speed, and assembly elevation according to Section 6.

5.3 Location of Impact

5.3.1 Large Missile Test—Impact each impact protective system specimen and each fenestration assembly infill type once as shown in Fig. 8, except for additional impacts specified in 5.3.2.

5.3.1.1 Impact one specimen with the center of the missile within a 65-mm (21/2-in.) radius circle and with the center of the circle located at the center of each type of infill.

5.3.1.2 Impact a different specimen with the center of the missile within a 65-mm (21/2-in.) radius circle and with the center of the circle located 150 mm (6 in.) from supporting members at a corner.

5.3.1.3 Impact the remaining specimen with the center of the missile within a 65-mm (21/2-in.) radius circle and with the center of the circle located 150 mm (6 in.) from supporting members at a diagonally opposite corner.

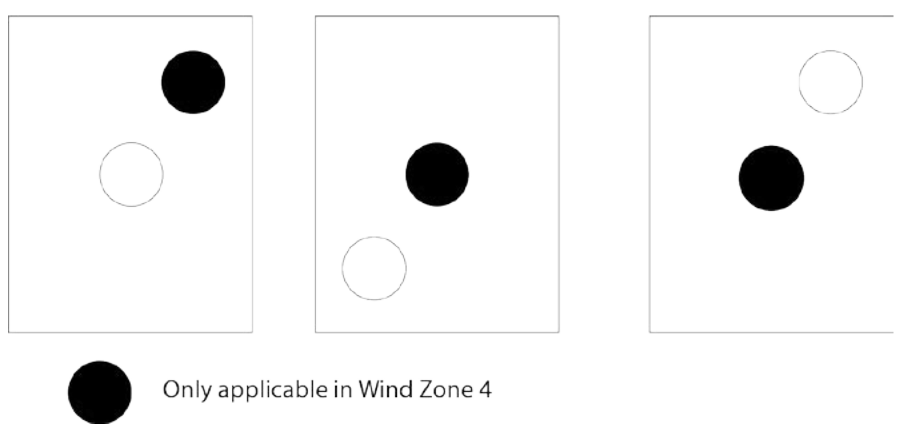
5.3.2 Additional Impact Locations in Wind Zone 4 (See Fig. 8):

5.3.2.1 Impact the same specimen specified in 5.3.1.1 a second time with the center of the second missile within a 65-mm (21/2-in.) radius circle and with the center of the circle located 150 mm (6 in.) from supporting member at a corner.

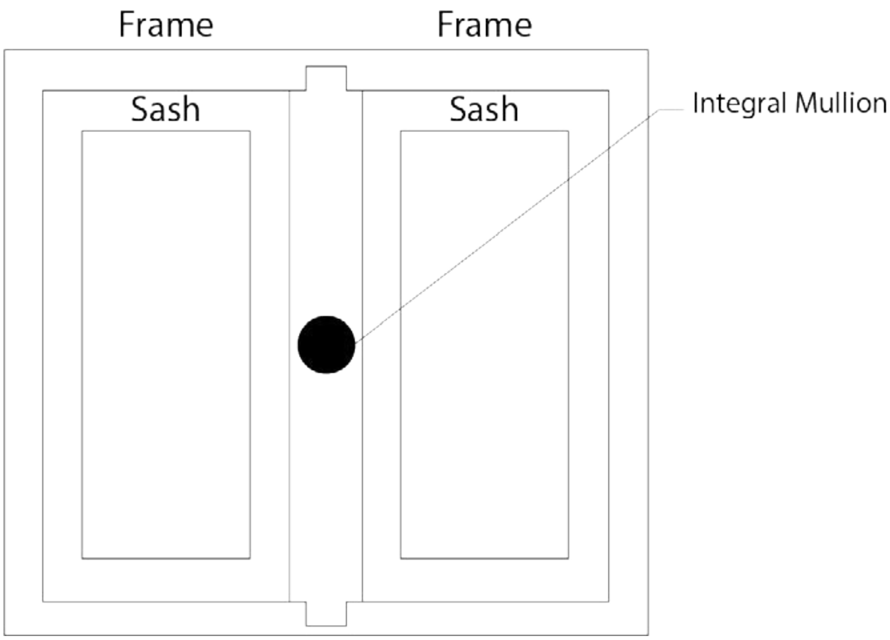
5.3.2.2 Impact the same specimen specified in 5.3.1.2 a second time with the center of the second missile within a 65-mm (21/2-in.) radius circle and with the center of the circle located at the center of each type of infill.

5.3.2.3 Impact the same specimen specified in 5.3.1.3 a second time with the center of the second missile within a 65-mm (21/2-in.) radius circle and with the center of the circle located at the center of each type of infill except as specified in 5.3.3.6.

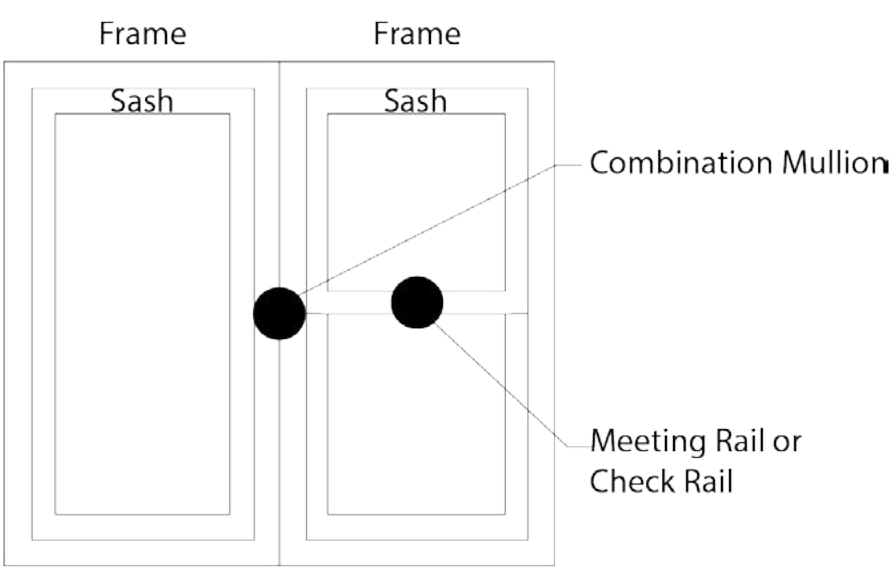
5.3.2.4 For test specimens with bracing at the specified impact location(s), the impact location(s) shall be relocated to the nearest area with no bracing.



▲ Figure 8 – Impact Location for large Missile Test (Each Type of Infill). The white circles denote first impact and the black circles denote second impact.



▲ Figure 9 – Integral Mullion



▲ Figure 10 – Combination Mullion with Meeting or Check Rail

5.3.3 Special Considerations:

5.3.3.1 For test specimens containing multiple panels, impact the exterior glazing surface innermost from the exterior plane of the fenestration assembly or impact protective system panel innermost from the exterior.

5.3.3.2 For test specimens containing fixed and operable panels of the same type of infill, impact the operable portion.

5.3.3.3 For operable test specimens, a corner impact location shall be nearest a locking device and the other corner impact location shall be at a corner diagonally opposite.

5.3.3.4 For test specimens with bracing at the specified impact location(s), the impact location(s) shall be relocated to the nearest area with no bracing.

5.3.3.5 The impacts on accordion impact protective systems shall be at the valleys located closest to the impact locations shown in Fig. 8.

5.3.3.6 In Wind Zone 4, impact the integral mullion and other intermediate members such as a meeting rail, check rail, or meeting stile mid-span in lieu of the impact specified in 5.3.2.3 if applicable. (See Fig. 9, Fig. 10, and Fig. 11).

5.3.3.7 In Wind Zone 4, for each type of mullion impact one vertical or horizontal combination mullion with the longest span at mid span in addition to impacts specified in 5.3. (See Fig. 10)

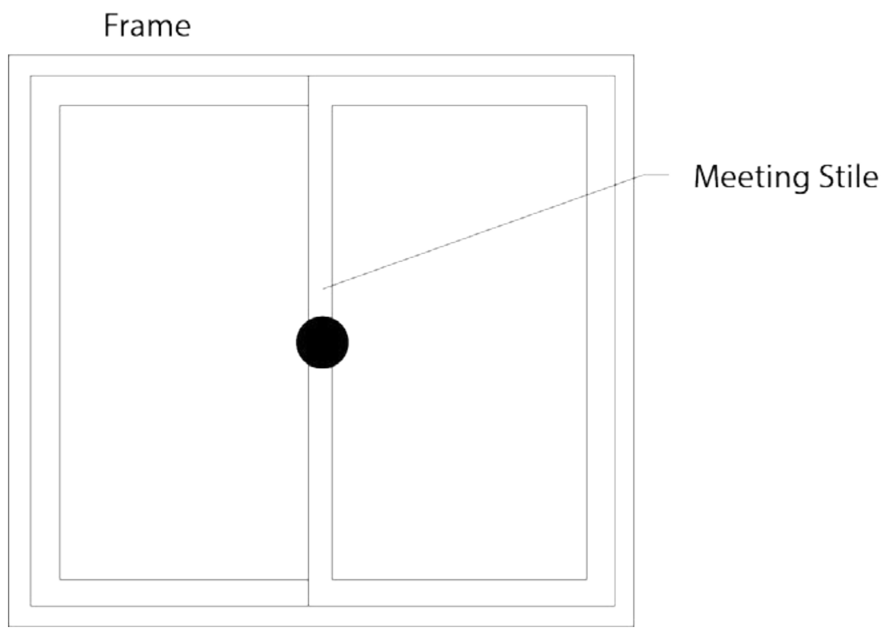
5.3.4 Small Missile Test - Impact each impact protective system specimen and each fenestration assembly infill type three times with ten steel balls each as shown in Fig. 12.

5.3.4.1 Each impact location shall receive distributed impacts simultaneously from ten steel balls. The impact shall be described in the test report.

5.3.4.2 The corner impact locations shall be entirely within a 250-mm (10-in.) radius circle having its center located at 275 mm (11 in.) from the edges.

5.3.4.3 The edge impact locations shall be entirely within a 250-mm (10-in.) radius circle at the centerline between two corners having its center located at 275 mm (11 in.) from the edge.

5.3.4.4 The center impact location shall be entirely within a 250-mm (10-in.) radius circle having its center located at the horizontal and vertical centerline of the infill.



▲ Figure 11 – Meeting Styles

5.4 Air Pressure Cycling

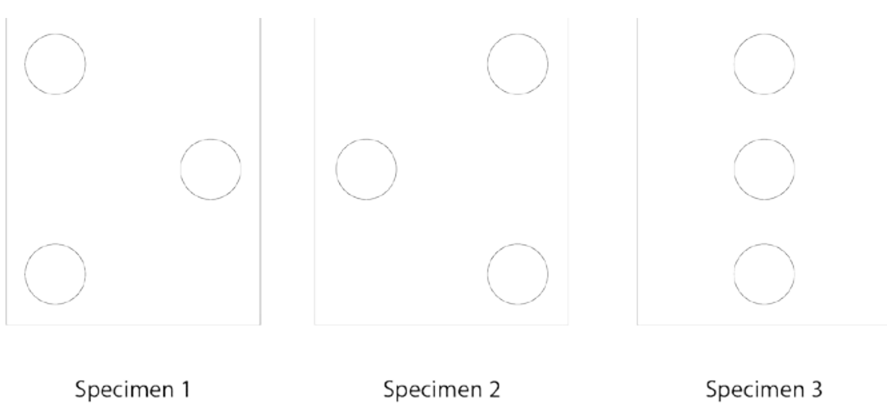
5.4.1 Air Pressure Differential:

5.4.1.1 The air pressure portion of the test shall use the test loading program in Table 9. Select Ppos and Pneg for the maximum inward (positive) and maximum outward (negative) air pressure differential for which qualification is sought.

5.4.1.2 The air pressure differential to be used for porous impact protective systems shall be F (the design wind force for other structures as specified in ASCE 7) divided by the horizontally projected area of the entire assembly.

5.4.2 Except in Wind Zone 4, porous impact protective systems whose aggregate open area exceeds 50% of their projected surface area that pass the small missile test and that are not subject to the large missile test need not be tested for the air pressure portion of the test described in this section.

5.5 For impact protective system specimens that are tested independently of the fenestration assemblies they are intended to protect, measure, and record both the maximum dynamic deflection and the residual deflection following the impact test and measure and record the maximum positive deflection in combination with the residual deflection during the air pressure cycling test. Measure all deflections to the nearest 2 mm (0.1 in.).



▲ Figure 12 – Impact Locations for Small Missile Test (Each Type of Infill)

6. Missiles

6.1 The specifying authority shall select an applicable missile by defining a level of protection, a wind zone, and an assembly elevation above the ground.

6.2 The applicable missile from Table 10 shall be chosen using Table 11 or Table 12, unless otherwise specified.

6.2.1 Unless otherwise specified, select the appropriate level of building protection from 6.2.1.1-6.2.1.3 and enter Table 3 or Table 4 at the appropriate column.

6.2.1.1 Enhanced Protection (Essential Facilities) - Buildings and other structures designated as essential facilities, including, but not limited to, hospitals; other health care facilities having emergency treatment facilities; jails and detention facilities; fire, rescue and police stations, and emergency vehicle garages; designated emergency shelters; communications centers and other facilities required for emergency response; power generating stations; other public utility facilities required in an emergency; and buildings and other structures having

Cyclic Static Pressure Differential Loading			
Loading Sequence	Loading Direction	Air Pressure Cycles	N. of Air Pressure Cycles
1	Positive	0.2 P - 0.5 Ppos	3500
2	Positive	0.0 P - 0.6 Ppos	300
3	Positive	0.5 P - 0.8 Ppos	600
4	Positive	0.3 P - 1.0 Ppos	100
5	Positive	0.3 P - 1.0 Pneg	50
6	Positive	0.5 P - 0.8 Pneg	1050
7	Positive	0. 0 P - 0.6 Pneg	50
8	Positive	0.2 P - 0.5 Pneg	3350
Cycling pressure used is determined by design pressure of the building for the maximum inward (Ppos) and maximum outward (Pneg) air pressure differential for which qualification is sought.			

▲ Table 9 – Cyclic Static Air Pressure Loading

critical national defense functions.

6.2.1.2 Basic Protection - All buildings and structures except those listed in 6.2.1.1 and 6.2.1.3.

6.2.1.3 Unprotected - Buildings and other structures that represent a low hazard to human life in a windstorm including, but not limited to: agricultural facilities, production greenhouses, certain temporary facilities, and storage facilities.

7. Pass/Fail Criteria

7.1 In Wind Zones 1, 2, 3, and 4, the specifying authority shall select an applicable pass/fail criterion based on 7.1.1 and 7.1.2.

7.1.1 Fenestration Assemblies and Non-Porous Impact Protective Systems:

7.1.1.1 The test specimen shall resist the large or small missile impacts, or both, with no tear formed longer than 130 mm (5 in.) and wider than 1 mm (1/16 in.) through which air can pass, or with no opening formed through which a 76 mm (3 in.) diameter solid sphere can freely pass when evaluated upon completion of missile impacts and test loading program.

7.1.1.2 All test specimens meeting the enhanced protection impact levels shall resist the large or small missile impacts, or both, without penetration of the inner plane of the infill or impact protective system, and resist the cyclic pressure loading specified in Table 1 with no tear formed longer than 130 mm (5 in.) and wider than 1 mm (1/16 in.) through which air can pass.

7.1.2 Porous Impact Protective Systems Tested Independently of the Fenestration Assemblies They are Protecting:

7.1.2.1 There shall be no penetration of the innermost plane of the test specimen by the applicable missile(s) during the impact test(s).

7.1.2.2 Upon completion of the missile impact(s) and test loading program, there shall be no horizontally projected opening formed through which a 76 mm (3 in.) diameter solid sphere can pass.

7.2 In Wind Zone 4, the specifying authority shall be permitted to select an optional applicable pass/fail criterion based on 7.2.1, 7.2.2, and 7.2.3.

Applicable Missiles		
Missile Level	Missile	Impact Speed
A	2 g (31 grains) ± 5 % steel ball	39.62 m/s (130 ft/s)
C	2050 g ± 100 g (4.5 lb ± 0.25 lb) 2 x 4 in.; 1.2 m ± 100 mm (4 ft. ± 4 in.) lumber	12.19 m/s (40 ft/s)
D	4100 g ± 100 g (9.0 lb ± 0.25 lb) 2 x 4 in.; 2.4 m ± 100 mm (8 ft. ± 4 in.) lumber	15.25 m/s (50 ft/s)
E	4100 g ± 100 g (9.0 lb ± 0.25 lb) 2 x 4 in.; 2.4 m ± 100 mm (8 ft. ± 4 in.) lumber	24.38 m/s (80 ft/s)

▲ Table 10 – Applicable Missiles

Levels of Protection and Impact Test Requirements				
Level of Protection	Basic Protection		Enhanced protection	
Assembly elevation	≤ 9.1 m (30 ft)	> 9.1 m (30 ft)	≤ 9.1 m (30 ft)	> 9.1 m (30 ft)
Wind Zone 1 49 m/s (110 mph) ≤ basic wind speed < 54 m/s (120 mph)	C	A	D	D
Wind Zone 2 54 m/s (120 mph) ≤ basic wind speed < 58 m/s (130 mph) at greater than 1.6 km (one mile) from the coastline	C	A	D	D
Wind Zone 3 58 m/s (130 mph) ≤ basic wind speed ≤ 63 m/s (140 mph), or 54 m/s (120 mph) ≤ basic wind speed ≤ 63 m/s (140 mph) and within 1.6 km (one mile) of the coastline	D	A	E	D
Wind Zone 4 basic wind speed > 63 m/s (140 mph)	D	A	E	D

▲ Table 11 – Levels of Protection and Impact Test Requirements

Description of Levels for Rooftop Skylights in One- and Two-Family Dwellings		
Assembly elevation	≤ 9.1 m (30 ft)	> 9.1 m (30 ft)
Wind Zone 1	A	A
Wind Zone 2	B	A
Wind Zone 3	C	A
Wind Zone 4	D	A
NOTE —The term "One- and Two-Family Dwellings" includes all buildings included under the scope of the International Residential Code 2000.		

▲ Table 12 – Description of Levels for Rooftop Skylights in One- and Two-Family Dwellings

7.2.1 All test specimens shall resist the large or small missile impacts, or both, without penetration of the inner plane of the infill or impact protective system, and resist the cyclic pressure loading specified in Table 1 with no tear formed longer than 130 mm (5 in.) and wider than 1 mm (1/16 in.) through which air can pass.

7.2.2 The overlap seams of an impact protective system shall not have a separation greater than 1/180 of the span or 13 mm (1/2 in), whichever is less, after impact. The length of the separation shall not be greater than 900 mm (36 in.) or 40 % of the span whichever is less.

7.2.3 Fasteners, when used, shall not become disengaged during the test procedure.

6.3.1.4 Cyclone-Resistant Curtain Walls – United States Resilience Tested

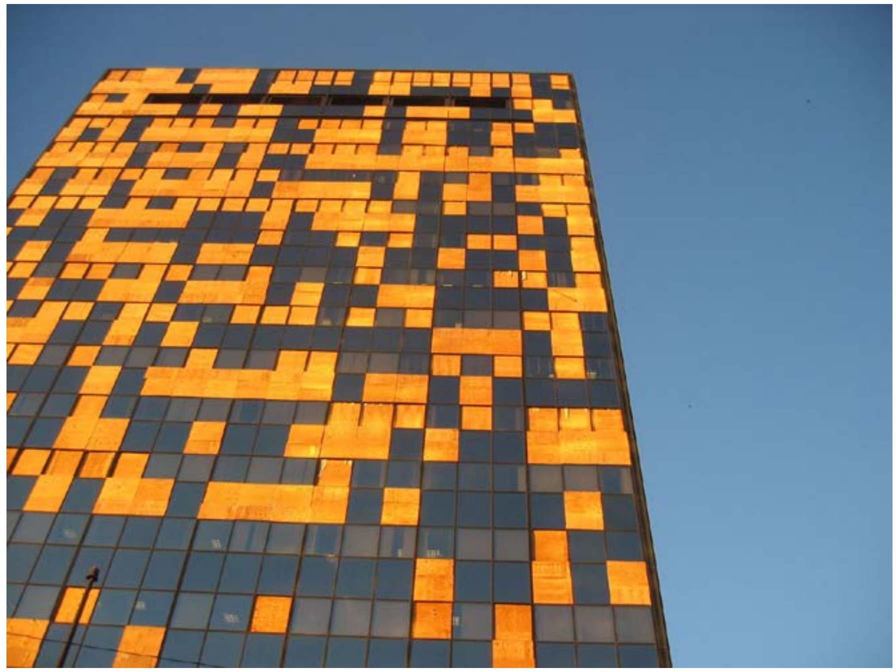
Florida, in 2005, was hit by Hurricane Wilma. It represented the first occasion in Florida to understand if the typhoon-prone buildings regulated by the Building Code systems worked appropriately.

The post disaster event assessments - carried out both from the Government and from the façade associations - underlined the effectiveness of building component solution which followed the most updated code and standard requirements.

From 2006 we started seeing the difference between the building glazing systems realized with the most updated building code and the old ones, which were heavily damaged after Hurricane Wilma occurred. Currently, we are waiting for more recent surveys which have been submitted after Hurricane Irma and Harvey occurred in recent months.

From "Performance of Laminated Glass during Hurricane Wilma in South Florida, Glazing Consultants International LLC, September 2006":

- Aim to survey buildings utilizing laminated glass with SentryGlas® Plus or Butacite® PVB interlayer that were in the path of Hurricane Wilma in South Florida and to report the findings;
- 82 properties in the path of Hurricane Wilma were built with these interlayer products and were surveyed – 71% no damage; 18% broken glass but no glazed system failure; 11% of the interviews had no answer or vague responses.



▲ Figure 13 - Plywood repair panels were visible on the Colonial Bank building, Miami, after Hurricane Wilma (2005)

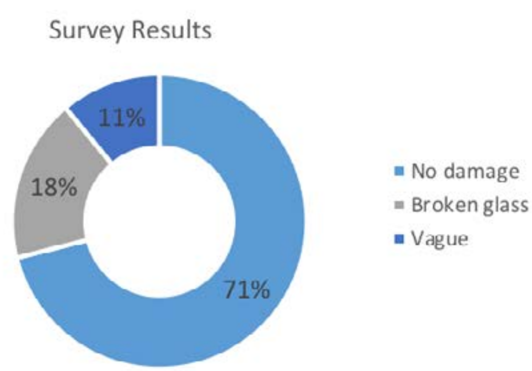
From "Post Hurricane Wilma Progress Assessment, Miami Dade County Building Code Compliance Office, April 2006":

Glass and Glazing

- High rise buildings in isolated areas of the county were affected;
- Loss of glazing in balcony railings, sliding glass doors, curtain walls and windows did occur;
- However, none of the damage was observed in buildings constructed under the most recent building code;
- In those isolated cases where the building envelope was breached, interior damage due to water intrusion and internal pressurization occurred, causing collateral damage.

Building Construction Successes

- Window, curtain wall and sliding glass door frames;
- Glass tested under the current impact tests.



6.4 Asia Pacific Jurisdictions Codes and Standards Requirements for Typhoon-Resistant Façades

Australia and New Zealand are the Asia Pacific's most advanced countries in terms of the existence of codes and standards requirements for typhoon resilient façade design and construction. While test and performance requirements in Australia and New Zealand are well identified, they differ from the best practices in the US. The 2011 edition of AS/NZS 1170.2 'Wind Actions' (AS/NZS, 2011 incorporating Amendment n.4, 2016) included significant increases to speeds for the large missile (4 kg mass of timber) tests, which are now higher than those specified in the US. However, cyclic pressure testing following missile impact testing, which has long been a requirement for roofing and façade panels in buildings in cyclone prone areas, is not a requirement for typhoon glazing certification.

The effect of cyclic pressures on the glazing construction component is well representative of the meteorological phenomenon of the typhoon event and has been identified in the US as a critical part of the testing protocol for missile impacted glazing.

In other Asia Pacific jurisdictions, different kinds of approaches have been identified for building codes and standard minimum design requirements.

References to international or US standards for typhoon resistant glazing systems is found in some Asia Pacific codes - i.e., the National Structural Code of the Philippines is based on the ASCE 7 and it refers to the ASTM E1886 and ASTM E1996 requirements.

That being said, many analyzed jurisdictions that are affected by

▲ Figure 14 –Porsche Design Tower, Miami (2017) extensively uses ionoplast interlayers in its façade typhoons every year still do not have any typhoon resilience construction safety requirements. If there are not specific codes for typhoon resistant façades it is commonly possible to use every more restrictive foreign code for wind, pressure cycling, debris resistance, in order to secure storm disaster façade resilience. From the various parties consulted by CTBUH, it is evident that a major problem faced by contractors operating in the Asia Pacific region is that bids for new projects can be over-exhaustive and contain a generic list of codes. It is up to the responsibility of the contractor to decide which one to comply with. Many foreign jurisdictions, the US, and international codes are frequently mentioned and, in most cases, no test requirements are needed for façade construction authorization process.

6.4.1 Asia Pacific Local Requirements

The Asia Pacific Region is the most prone area to natural disasters. This vulnerability also depends on the lack of infrastructure in place for most Asia Pacific jurisdictions to suddenly react in the case of a catastrophic event. Typhoons, in this region, could represent an inestimable danger in terms of interruption of public services and of the main facility activities. These are the territories where a large number of high rises are built in recent years, which are normally clad with curtain walls, but there are just few states that introduced requirements for typhoon resistant construction. There are just a couple of jurisdictions in which the glazed system components must be tested to withstand to impact and then pressure cycling testing of wind and debris.

Looking at Australia and New Zealand building codes, which are some of the most demanding jurisdictions in terms of typhoon resistant building component requirements and certification processcodes, we will see that their building codes changed in the past 6 years. Today, the missile speed impacting the façade mock-up, in order to make the building component classified as cyclone-proof, doubled. There is still no pressure cycling requirement after the impact test. Thus, in order to take into account the goals of other countries (US) product approval processes available, which were positively tested under natural conditions, a discussion to define a general guideline could begin in the near future.

Looking at the 12 Asia Pacific jurisdictions analyzed in the research, only two other ones introduce standard testing requirements for glazing building envelope in their building code new edition: Bangladesh and the Philippines (HBRI Housing and Building Research Institute, Bangladesh National Building Code, 2004; Association of Structural Engineers of the Philippines C101-10, NSCP National Structural Code of the Philippines, 2010). Their reference is in the ASTM standards, despite their geographic location being closer to Australia, which may have more regionally appropriate standards.

Another jurisdiction that will provide typhoon resistant glazing requirements in the near future is Japan. This jurisdiction decided to follow a different way: it will refer to the ISO 16932 (ISO, 2015. It is based on: the ASTM E1886, 2013; and ASTM E1996, 2014), but they are changing the standard thanks to their technician commission, in order to adapt the test to their own environment context. The impact testing will also use special missiles that will have the same shape of the tiles typical of traditional Japanese roof construction.

The above mentioned jurisdictions are the only ones in Asia Pacific region that have typhoon resistant curtain wall requirements. Although jurisdictions like China, Taiwan, Hong Kong, or India have been and continue to be affected by typhoons, they are not introducing any kind of requirements to ensure users and property safety.

	Code/Standard requirements
Australia	AS/NZS 1170.2
Bangladesh	ASTM E 1886, ASTM E 1996
China	No
Hong Kong	No
India	No
Japan	No
New Zealand	AS/NZS 1170.2
Philippines	ASTM E 1886, ASTM E 1996
South Korea	No
Taiwan	No
Thailand	No
Vietnam	No

▲ Table 13 – Asian jurisdictions' cyclone-glazing test requirements

6.4.2 Different Jurisdictions Classification of Hurricane / Cyclone / Typhoon

<table>
<tr><th colspan="9">TROPICAL CYCLONE CLASSIFICATION</th></tr>
<tr><th>Beaufort scale</th><th>1-minute sustained winds</th><th>10-minute sustained winds</th><th>NE Pacific & N Atlantic</th><th>NW Pacific</th><th>NW Pacific</th><th>N Indian Ocean</th><th>SW Indian Ocean</th><th>Australia & S Pacific</th></tr>
<tr><td></td><td></td><td></td><td>National Hurricane Center / Central Pacific Hurricane Center</td><td>Joint Typhoon Warning Center</td><td>Japan Meteorological Agency</td><td>India Meteorological Department</td><td>Meteo France's La Reunion tropical cyclone centre</td><td>Australian Bureau of Meteorology/ Fiji Meteorological Service</td></tr>
<tr><td>0–7</td><td><32 knots (37mph; 59 km/h)</td><td><28 knots (32mph; 52 km/h)</td><td rowspan="2">Tropical Depression</td><td rowspan="2">Tropical Depression</td><td rowspan="3">Tropical Depression</td><td>Depression</td><td>Zone of Disturbed Weather</td><td>Tropical Disturbance</td></tr>
<tr><td>7</td><td>33 knots (38 mph; 61 km/h)</td><td>28–29 knots (32–33 mph; 52–54 km/h)</td><td rowspan="2">Deep Depression</td><td>Tropical Disturbance</td><td>Tropical Depression</td></tr>
<tr><td>8</td><td>34–37 knots (39–43 mph; 63–69 km/h)</td><td>30–33 knots (35–38 mph; 56–61 km/h)</td><td rowspan="3">Tropical Storm</td><td rowspan="3">Tropical Storm</td><td>Tropical Depression</td><td>Tropical Low</td></tr>
<tr><td>9–10</td><td>38–54 knots (44–62 mph; 70–100 km/h)</td><td>34–47 knots (39–54 mph; 63–87 km/h)</td><td>Tropical Storm</td><td>Cyclonic Storm</td><td>Moderate Tropical Storm</td><td>Category 1 tropical cyclone</td></tr>
<tr><td>11</td><td>55–63 knots (63–72 mph; 102–117 km/h)</td><td>48–55 knots (55–63 mph; 89–102 km/h)</td><td rowspan="2">Severe Tropical Storm</td><td rowspan="2">Severe Cyclonic Storm</td><td rowspan="2">Severe Tropical Storm</td><td rowspan="2">Category 2 tropical cyclone</td></tr>
<tr><td rowspan="9">12+</td><td>64–71 knots (74–82 mph; 119–131 km/h)</td><td>56–63 knots (64–72 mph; 104–117 km/h)</td><td rowspan="2">Category 1 hurricane</td><td rowspan="7">Typhoon</td></tr>
<tr><td>72–82 knots (83–94 mph; 133–152 km/h)</td><td>64–72 knots (74–83 mph; 119–133 km/h)</td><td rowspan="8">Typhoon</td><td rowspan="3">Very Severe Cyclonic Storm</td><td rowspan="3">Tropical Cyclone</td><td rowspan="3">Category 3 severe tropical cyclone</td></tr>
<tr><td>83–95 knots (96–109 mph; 154–176 km/h)</td><td>73–83 knots (84–96 mph; 135–154 km/h)</td><td>Category 2 hurricane</td></tr>
<tr><td>96–97 knots (110–112 mph; 178–180 km/h)</td><td>84–85 knots (97–98 mph; 156–157 km/h)</td><td rowspan="2">Category 3 major hurricane</td></tr>
<tr><td>98–112 knots (113–129 mph; 181–207 km/h)</td><td>86–98 knots (99–113 mph; 159–181 km/h)</td><td rowspan="3">Extremely Severe Cyclonic Storm</td><td rowspan="3">Intense Tropical Cyclone</td><td rowspan="2">Category 4 severe tropical cyclone</td></tr>
<tr><td>113–122 knots (130–140 mph; 209–226 km/h)</td><td>99–107 knots (114–123 mph; 183–198 km/h)</td><td rowspan="3">Category 4 major hurricane</td></tr>
<tr><td>123–129 knots (142–148 mph; 228–239 km/h)</td><td>108–113 knots (124–130 mph; 200–209 km/h)</td><td rowspan="3">Category 5 severe tropical cyclone</td></tr>
<tr><td>130–136 knots (150–157 mph; 241–252 km/h)</td><td>114–119 knots (131–137 mph; 211–220 km/h)</td><td rowspan="2">Super Typhoon</td><td rowspan="2">Super Cyclonic Storm</td><td rowspan="2">Very Intense Tropical Cyclone</td></tr>
<tr><td>>137 knots (158 mph; 254 km/h)</td><td>>120 knots (140 mph; 220 km/h)</td><td>Category 5 major hurricane</td></tr>
</table>

▲ Table 14 - Tropical cyclone classifications, showing regional differences in scales

6.4.3 Occupance Category of Buildings in Different Asian Jurisdictions

6.4.3.1 Australia

AUTHOR	Australian Building Codes Board
TITLE	National Construction Code
YEAR	2016

TYPES OF CONSTRUCTION		
RISE IN STOREYS	CLASS OF BUILDING 2, 3, 9	CLASS OF BUILDING 5, 6, 7, 8
4 OR MORE	A	A
3	A	B
2	B	C
1	C	C

	CLASSES OF BUILDINGS	DESCRIPTION
1	1A	A single dwelling being a detached house, or one or more attached dwellings, each being a building, separated by a fire-resisting wall, including a row house, terrace house, town house or villa unit.
	1B	A boarding house, guest house, hostel or the like with a total area of all floors not exceeding 300m2, and where not more than 12 reside, and is not located above or below another dwelling or another Class of building other than a private garage.
2	A building containing 2 or more sole-occupancy units each being a separate dwelling.	
3	A residential building, other than a Class 1 or 2 building, which is a common place of long term or transient living for a number of unrelated persons. Example: boarding-house, hostel, backpackers accommodation or residential part of a hotel, motel, school or detention centre.	
4	A dwelling in a building that is Class 5, 6, 7, 8 or 9 if it is the only dwelling in the building.	
5	An office building used for professional or commercial purposes, excluding buildings of Class 6, 7, 8 or 9.	
6	A shop or other building for the sale of goods by retail or the supply of services direct to the public. Example: café, restaurant, kiosk, hairdressers, showroom or service station.	
7	7A	A building which is a car park.
	7B	A building which is for storage or display of goods or produce for sale by wholesale.
8	A laboratory, or a building in which a handicraft or process for the production, assembling, altering, repairing, packing, finishing or cleaning of goods or produce is carried on for trade, sale or gain.	
9	A building of a public nature.	
	9A	A health care building, including those parts of the building set aside as a laboratory.
	9B	An assembly building, including a trade workshop, laboratory or the like, in a primary or secondary school, but excluding any other parts of the building that are of another class.
	9C	An aged care building.
10	A building of a public nature.	
	10A	A private garage, carport, shed or the like.
	10B	A structure being a fence, mast, antenna, retaining or free standing wall, swimming pool or the like.
	10C	A private bushfire shelter

▲ Table 15 – Classes of buildings and importance levels in Australia, NCC

6.4.3.2 Bangladesh

<table>
<tr><td>AUTHOR</td><td colspan="2">Housing and Building Research Institute</td></tr>
<tr><td>TITLE</td><td colspan="2">Bangladesh National Building Code. Volume 2/3 Structural Design</td></tr>
<tr><td>YEAR</td><td colspan="2">2014</td></tr>
<tr><td colspan="3">OCCUPANCY CATEGORY OF BUILDINGS AND OTHER STRUCTURES FOR FLOOD, SURGE, WIND AND EARTHQUAKE LOADS</td></tr>
<tr><td colspan="2">CATEGORY</td><td>NATURE OF OCCUPANCY</td></tr>
<tr><td colspan="2">I</td><td>Buildings and other structures that represent a low hazard to human life in the event of failure, including, but not limited to:
• Agricultural facilities
• Certain temporary facilities
• Minor storage facilities</td></tr>
<tr><td colspan="2">II</td><td>All buildings and other structures except those listed in Occupancy Categories I, III, and IV</td></tr>
<tr><td colspan="2">III</td><td>Buildings and other structures that represent a substantial hazard to human life in the event of failure, including, but not limited to:
• Buildings and other structures where more than 300 people congregate in one area
• Buildings and other structures with daycare facilities with a capacity greater than 150
• Buildings and other structures with elementary school or secondary school facilities with a capacity greater than 250
• Buildings and other structures with a capacity greater than 500 for colleges or adult education facilities
• Health care facilities with a capacity of 50 or more resident patients, but not having surgery or emergency treatment facilities
• Jails and detention facilities Buildings and other structures, not included in Occupancy Category IV, with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure, including, but not limited to:
• Power generating stations
• Water treatment facilities
• Sewage treatment facilities
• Telecommunication centers
• Buildings and other structures not included in Occupancy Category IV (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives) containing sufficient quantities of toxic or explosive substances to be dangerous to the public if released.</td></tr>
<tr><td colspan="2">IV</td><td>Buildings and other structures designated as essential facilities, including, but not limited to:
• Hospitals and other health care facilities having surgery or emergency treatment facilities
• Fire, rescue, ambulance, and police stations and emergency vehicle garages
• Designated earthquake, hurricane, or other emergency shelters
• Designated emergency preparedness, communication, and operation centers and other facilities required for emergency response
• Power generating stations and other public utility facilities required in an emergency
• Ancillary structures (including, but not limited to, communication towers, fuel storage tanks, cooling towers, electrical substation structures, fire water storage tanks or other structures housing or supporting water, or other fire-suppression material or equipment) required for operation of Occupancy Category IV structures during an emergency
• Aviation control towers, air traffic control centers, and emergency aircraft hangars
• Water storage facilities and pump structures required to maintain water pressure for fire suppression
• Buildings and other structures having critical national defense functions Buildings and other structures (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, or hazardous waste) containing highly toxic substances where the quantity of the material exceeds a threshold quantity established by the authority having jurisdiction.</td></tr>
<tr><td colspan="3">a Cogeneration power plants that do not supply power on the national grid shall be designated Occupancy Category II.</td></tr>
</table>

▲ Table 16 – Occupancy category of buildings in Bangladesh, BNBC

6.4.3.3 Philippines

AUTHOR	Association of Structural Engineers of the Philippines
TITLE	National Structural Code of the Philippines C101-10. Volume 1 – Buildings, Towers, and Other Vertical Structures
YEAR	2010
RISK CATEGORY OF BUILDINGS AND OTHER STRUCTURES	
OCCUPANCY CATEGORY	DESCRIPTION
I	Essential
II	Hazardous
III	Special Occupancy
IV	Standard Occupancy
V	Miscellaneous

▲ Table 17 – Risk category of buildings in the Philippines, NSCP C101-10

6.4.4 International Occupance Category of Buildings

AUTHOR	International Organization for Standardization
TITLE	ISO 16932 Glass in building - Destructive-windstorm-resistant security glazing - Test and classification
YEAR	2015
LEVELS OF PROTECTION	
LEVEL	DESCRIPTION
1	Level 1 is advised for unprotected buildings and other structures, which are expected to have low hazard to human life in a cyclones and other severe storms. Buildings in this level may include, but are not restricted to, agricultural houses, temporary facilities and storage facilities.
2	Level 2 is advised for protection of buildings and other structures which are expected to have moderate hazard to human life in cyclones and other severe storms. Buildings in this level may include, but are not restricted to, houses, commercial and industrial buildings.
3	Level 3 is advised for protection of buildings and other structures which are expected to have a substantial hazard to human life in cyclones and other severe storms. Buildings in this level may include, but are not limited to, major office buildings, schools, shopping centers, hotels and other buildings and structures where a significant number of people congregate in one area.
4	Level 4 is advised for enhanced protection of essential facilities. Buildings in this level may include, but are not limited to, hospitals and other health care facilities, fire, rescue, ambulance, and police stations, and buildings and other structures having critical national defense functions or designated as storm shelters during a severe storm.

▲ Table 18 – Levels of protection of buildings, ISO 16932

AUTHOR	International Code Council
TITLE	International Building Code
YEAR	2015

RISK CATEGORY OF BUILDINGS AND OTHER STRUCTURES	
RISK CATEGORY	NATURE OF OCCUPANCY
I	Buildings and other structures that represent a low hazard to human life in the event of failure, including but not limited to: • Agricultural facilities. • Certain temporary facilities. • Minor storage facilities.
II	Buildings and other structures except those listed in Risk Categories I, III and IV.
III	Buildings and other structures that represent a substantial hazard to human life in the event of failure, including but not limited to: • Buildings and other structures whose primary occupancy is public assembly with an occupant load greater than 300. • Buildings and other structures containing Group E occupancies with an occupant load greater than 250. • Buildings and other structures containing educational occupancies for students above the 12th grade with an occupant load greater than 500. • Group I-2 occupancies with an occupant load of 50 or more resident care recipients but not having surgery or emergency treatment facilities. • Group I-3 occupancies. • Any other occupancy with an occupant load greater than 5,000.a • Power-generating stations, water treatment facilities for potable water, wastewater treatment facilities and other public utility facilities not included in Risk Category IV. • Buildings and other structures not included in Risk Category IV containing quantities of toxic or explosive materials that: Exceed maximum allowable quantities per control area as given in Table 307.1(1) or 307.1(2) or per outdoor control area in accordance with the International Fire Code; and Are sufficient to pose a threat to the public if released.
IV	Buildings and other structures designated as essential facilities, including but not limited to: • Group I-2 occupancies having surgery or emergency treatment facilities. • Fire, rescue, ambulance and police stations and emergency vehicle garages. • Designated earthquake, hurricane or other emergency shelters. • Designated emergency preparedness, communications and operations centers and other facilities required for emergency response. • Power-generating stations and other public utility facilities required as emergency backup facilities for Risk Category IV structures. • Buildings and other structures containing quantities of highly toxic materials that: • Exceed maximum allowable quantities per control area as given in Table 307.1(2) or per outdoor control area in accordance with the International Fire Code; and • Are sufficient to pose a threat to the public if released. • Aviation control towers, air traffic control centers and emergency aircraft hangars. • Buildings and other structures having critical national defense functions. • Water storage facilities and pump structures required to maintain water pressure for fire suppression.
a. For purposes of occupant load calculation, occupancies required by Table 1004.1.2 to use gross floor area calculations shall be permitted to use net floor areas to determine the total occupant load.	
b. Where approved by the building official, the classification of buildings and other structures as Risk Category III or IV based on their quantities of toxic, highly toxic or explosive materials is permitted to be reduced to Risk Category II, provided it can be demonstrated by a hazard assessment in accordance with §1.5.3 of ASCE 7 that a release of the toxic, highly toxic or explosive materials is not sufficient to pose a threat to the public.	

▲ Table 19 – RIsk category of buildings, IBC

6.5 Codes for Cyclone Resistant Façades

The research activities identified 8 relevat building codes for cyclone-resistant façade requirements.

Each of them has been analyzed in order to verify if it contains information about 7 main topics.

7 topics:

- Testing apparatus
- Wind loads
- Wind-borne debris impact test
- Pressure cycling testing
- Testing procedure
- Technical report
- Wind speed maps

AUTHOR	International Code Council	International Code Council	Housing and Building Research Institute	Association of Structural Engineers of the Philippines	International Code Council	Australian/ New Zealand Standard	Queensland Government - Department of Public Works	2006 Texas Revisions to the 2006 IRC
TITLE	International Building Code	Florida Building Code	Bangladesh National Building Code	National Structural Code of the Philippines C101-10. Volume 1 – Buildings, Towers, and Other Vertical Structures	ICC 500 Guidelines for Hurricane Resistant Residential Construction	AS/NZS 1170.2:2011 Structural design actions - Part 2: Wind actions. Incorporating Amendment No. 4	Design Guidelines for Australian Public Cyclone Shelters	2006 Texas Revisions to the 2006 International Residential Code
YEAR	2015	2015	2014	2010	2014	2011 + 2016	2006	2006
Testing apparatus								
Wind loads	X	X	X	X		X	X	
Wind-borne debris impact test	X	X				X	X	
Pressure cycling testing	X	X					X	
Testing procedure			X	X	X		X	X
Technical report							X	
Wind speed maps	X	X	X	X				

▲ Table 20 – Information on the 7 Main Topics identified for cyclone-resistant façade design, list of the analyzed codes

6.5.1 Code Comparison

BUILDING CODE	TEST CRITERIA
International Code Council - international Building Code, 2015	• ASTM E1886 and ASTM E1996 *1. Glazed openings located within 30 feet (9144 mm) of grade shall meet the requirements of the large missile test of ASTM E1996.* *2. Glazed openings located more than 30 feet (9144 mm) above grade shall meet the provisions of the small missile test of ASTM E1996.* *3. Storage sheds that are not designed for human habitation and that have a floor area of 720 square feet (67 mq) or less are not required to comply with the mandatory windborne debris impact standard of this code.* *4. Openings in sunrooms, balconies or enclosed porches constructed under existing roofs or decks are not required to be protected provided the spaces are separated from the building interior by a wall and all openings in the separating wall are protected in accordance with §1609.1.2 above. Such spaces shall be permitted to be designed as either partially enclosed or enclosed structures.* *Exceptions:* *2. Glazing in Risk Category I buildings, including greenhouses that are occupied for growing plants on a production or research basis, without public access shall be permitted to be unprotected.* *3. Glazing in Risk Category II, III or IV buildings located over 60 feet (18288 mm) above the ground and over 30 feet (9144 mm) above aggregate surface roofs located within 1,500 feet (458 m) of the building shall be permitted to be unprotected.*
International Code Council - Florida Building Code, 2015	• ASTM E1886 and ASTM E1996 / TAS 201, TAS 202 and TAS 203 / AAMA 506 *1. Glazed openings located within 30 feet (9144 mm) of grade shall meet the requirements of the large missile test of ASTM E1996.* *2. Glazed openings located more than 30 feet (9144 mm) above grade shall meet the provisions of the small missile test of ASTM E1996.* *3. Storage sheds that are not designed for human habitation and that have a floor area of 720 square feet (67 mq) or less are not required to comply with the mandatory windborne debris impact standard of this code.* *4. Openings in sunrooms, balconies or enclosed porches constructed under existing roofs or decks are not required to be protected, provided the spaces are separated from the building interior by a wall and all openings in the separating wall are protected in accordance with §1609.1.2 above. Such spaces shall be permitted to be designed as either partially enclosed or enclosed structures.* *§1609.1.2.2. Application of ASTM E1996.* *The text of §6.2.2 of ASTM E1996 shall be substituted as follows:* *§6.2.2 Unless otherwise specified, select the wind zone based on the strength design wind speed, Vult, as follows:* *§6.2.2.1 Wind Zone 1—130 mph ≤ ultimate design wind speed, Vult < 140 mph.* *§6.2.2.2 Wind Zone 2—140 mph ≤ ultimate design wind speed, Vult < 150 mph at greater than one mile (1.6 km) from the coastline. The coastline shall be measured from the mean high water mark.* *§6.2.2.3 Wind Zone 3—150 mph (67 m/s) ≤ ultimate design wind speed, Vult ≤170 mph (76 m/s), or 140 mph (63 m/s) ≤ ultimate design wind speed, Vult ≤ 170 mph (76 m/s) and within one mile (1.6 km) of the coastline. The coastline shall be measured from the mean high water mark.* *§6.2.2.4 Wind Zone 4— ultimate design wind speed, Vult >170 mph (76 m/s).* *§1609.1.2.2.1 Modifications to ASTM E 1886 and ASTM E 1996.* *Table 1 of ASTM E 1886 and ASTM E 1996 - revise the third column to read as follows:* *Air Pressure Cycles* *0.2 to 0.5 Ppos (1)* *0.0 to 0.6 Ppos* *0.5 to 0.8 Ppos* *0.3 to 1.0 Pneg (2)* *0.5 to 0.8 Pneg* *0.0 to 0.6 Pneg* *0.2 to 0.5 Pneg* *Notes:* *(1) Ppos= 0.6 x positive ultimate design load in accordance with ASCE 7.* *(2) Pneg= 0.6 x negative ultimate design load in accordance with ASCE 7.* *Exceptions:* *2. Glazing in Risk Category I buildings, including greenhouses that are occupied for growing plants on a production or research basis, without public access shall be permitted to be unprotected.* *3. Glazing in Risk Category II, III or IV buildings located over 60 feet (18 288 mm) above the ground and over 30 feet (9144 mm) above aggregate surface roofs located within 1,500 feet (458 m) of the building shall be permitted to be unprotected.*

Housing and Building Research Institute - Bangladesh National Building Code, 2014	• ASTM E1886 and ASTM E1996 *Exceptions:* *i. Glazing in Category II, III, or IV buildings located over 18.3 m above the ground and over 9.2 m above aggregate surface roofs located within 458 m of the building shall be permitted to be unprotected.* *ii. Glazing in Category I buildings shall be permitted to be unprotected.*
Association of Structural Engineers of the Philippines - National Structural Code of the Philippines C101-10, 2010	• ASTM E1886 and ASTM E1996 *Exceptions:* *1. Glazing in category I, II or III buildings located over 18 m above the ground and over 9 m above aggregate surface roofs located within 458 m of the building shall be permitted to be unprotected.* *2. Glazing in category IV buildings shall be permitted to be unprotected.*
International Code Council - ICC 500 Guidelines for Hurricane Resistant Residential Construction, 2014	• ASTM E1886 and ASTM E1996 / SSTD 12-97 / AAMA506
AS/NZS 1170.2:2011 Structural design actions - Part 2: Wind actions. Incorporating Amendment No. 4, 2011 + 2016	• Technical Note No. 4, 'Simulated windborne debris impact testing of building envelope components', Cyclone Testing Station, James Cook University, 2017 Clause 2.5.8 Where windborne debris loading is required for impact resistance testing, the debris impact loading shall be— (a) a timber test member of 4 kg mass, of a density of at least 600 kg/m3, with a nominal cross-section of 100 mm × 50 mm impacting end on at 0.4 VR for the horizontal component of the trajectory, and 0.1 VR for the vertical component of the trajectory; and (b) a spherical steel ball 8 mm in diameter (approximately 2 grams mass) impacting at 0.4 VR for the horizontal component of the trajectory, and 0.3 VR for the vertical component of the trajectory, where VR is the regional wind speed given in Clause 3.2. NOTES: 1 Examples of the use of this Clause would be for the evaluation of internal pressure (see Clause 5.3.2), or the demonstration of resistance to penetration of the building envelope enclosing a shelter room. 2 The two test debris items are representative of a large range of windborne debris of varying masses and sizes that can be generated in severe wind storms. 3 The spherical ball missile is representative of small missiles, which could penetrate protective screens with large mesh sizes. 4 These impact loadings should be applied independently in time and location. 5 This Standard does not specify a test method or acceptance criteria. Acceptance criteria may vary according to the purpose of the test. An appropriate test method and acceptance criteria for debris tests are given in Technical Note No. 4, 'Simulated windborne debris impact testing of building envelope components', Cyclone Testing Station, James Cook University.

Queensland Government - Department of Public Works, Design Guidelines for Australian Public Cyclone Shelters, 2006	• AS/NZS1170.2 ***Large missile impact test:*** *a 100mm x 50mm piece of timber of 4 kg impacting end-on at 0.4 x $V_{10,000}$ for horizontal trajectories and 0.1 x $V_{10,000}$ for vertical trajectories.* ***Small missile impact test:*** *five spherical steel balls of 2 grams mass {8mm diameter} impacting at 0.4 x $V_{10,000}$ for horizontal trajectories and 0.3 x $V_{10,000}$ for vertical trajectories.* *Solid steel ball having a mass of 2 gm impacting between 0.40 and 0.75 of basic wind speed (number, size and impact speed specified by user).* ***Acceptance Criteria:*** *A test specimen shall:* *(a) prevent a debris missile from penetrating through the screen/cladding;* *(b) if perforated, have a maximum perforation width of less than 8mm;* *(c) in the case of a debris screen, not deflect more than 0.8 times the clear distance between the screen and the glazing, at any stage of the test.* *(d) be capable of resisting the specified wind load.* In Region C: the impact speeds are: 0.1 x $V_{10,000}$ = 8.5 m/s (30.6 km/h); 0.3 x $V_{10,000}$ = 25.5 m/s (91.8 km/h); 0.4 x $V_{10,000}$ = 34 m/s (122 km/h)
Texas Revisions to the 2006 International Residential Code, 2006	• ASTM E 1886 and ASTM E 1996 / ANSI/DASMA 115

▲ Table 21 – Comparison of the requirements for cyclone-resistant façades in the analyzed codes

6.6 Standards for Cyclone Resistant Façades

The research activities identified 11 relevat standards for cyclone-resistant façade requirements.

Each of them has been analyzed in order to verify if it contains information about 7 main topics.

7 topics:

- Testing apparatus
- Wind loads
- Wind-borne debris impact test
- Pressure cycling testing
- Testing procedure
- Technical report
- Wind speed maps

AUTHOR	American Society of Civil Engineers	International Organization for Standardization	International Code Council	International Code Council	International Code Council	ASTM	ASTM	Texas Department of Insurance	AAMA	Cyclone Testing Station - James Cook University
TITLE	ASCE 7-16 Minimum Design Loads and Associated Criteria for Buildings and Other Structures	ISO 16932 Glass in building - Destructive-windstorm-resistant security glazing - Test and classification	Testing Application Standard 201-94 - Impact Test Procedures. Florida Building Code Test Protocols for High-Velocity Hurricane Zones	Testing Application Standard 202-94 - Criteria For Testing Impact & Nonimpact Resistant Building Envelope Components Using Uniform Static Air Pressure. Florida Building Code Test Protocols for High-Velocity Hurricane Zones	Testing Application Standard 203-94 - Criteria For Testing Products Subject to Cyclic Wind Pressure Loading. Florida Building Code Test Protocols for High-Velocity Hurricane Zones	ASTM E 1886 Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Missile(s) and Exposed to Cyclic Pressure Differentials	ASTM E1996 Standard Specification for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Windborne Debris in Hurricanes	Standard TDI 1 - 98 Test for Impact and Cyclic Wind Pressure Resistance of Impact Protective Systems and Exterior Opening Systems. Building Code for Windstorm Resistant Construction	AAMA 506-16 Voluntary Specifications for Impact and Cycle Testing of Fenestration Products	TECHNICAL NOTE No.4. Simulated Windborne Debris Impact Testing of Building Envelope Components
YEAR	2016	2015	1994	1994	1994	2013	2014	1998	2016	2017
Testing apparatus		X	X	X	X	X	X	X	X	X
Wind loads	X	X				X	X			X
Wind-borne debris impact test	X	X	X				X	X	X	X
Pressure cycling testing	X	X		X	X	X	X	X	X	
Testing procedure	X	X	X	X	X	X	X	X	X	X
Technical report		X	X	X	X	X	X	X	X	X
Wind speed maps	X									

▲ Table 22 – Information on the 7 Main Topics Identified for cyclone-resistant façade design, list of the analyzed standards

6.6.1 Standard Comparison

STANDARD	TEST CRITERIA
American Society of Civil Engineers - ASCE 7-16 Minimum Design Loads and Associated Criteria for Buildings and Other Structures, 2016	• ASTM E1886 and ASTM E1996
International Organization for Standardization - ISO 16932 Glass in building - Destructive-windstorm-resistant security glazing - Test and classification, 2015	Large missile impact test Below 10 m: 50 x 100 mm timber weighing 4.1 kg impacting end-on at 15.3 m/s (two per specimen). Small missile impact test Above 10 m: 2 g steel balls impacting at 39.7 m/s (30 per specimen). Pressure cycles Each of the above impacts followed by 9,000 cycles of pressure representing hurricane wind gusts.
International Code Council - Florida Building Code, Test Protocols for High-Velocity Hurricane Zones - Testing Application Standard 203-94 - Criteria For Testing Products Subject to Cyclic Wind Pressure Loading; Testing Application Standard 201-94 - Impact Test Procedures, 1994	Large missile impact test Below 30 ft (9,144 mm): 2 x 4 in. timber weighing 9 lbs (4.08 kg) impacting end-on at 50 ft/s (15.24 m/s) (two per specimen). Small missile impact test Above 30 ft (9,144 mm): 2g steel balls impacting at 80 ft/s (15.24 m/s) (30 per specimen). Pressure cycles Each of the above impacts followed by 9,000 cycles of pressure representing hurricane wind gusts.
ASTM E 1886 and ASTM E 1996 Standard Test Method and Specification for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Missile(s) and Exposed to Cyclic Pressure Differentials, 2013 - 2014	Large missile impact test Below 30 ft (9,144 mm): 2 x 4 in. timber weighing 4.5 – 9 lbs (2.04 – 4.08 kg) impacting between 0.10 and 0.55 of basic wind speed (number, size and impact speed specified by user). Small missile impact test Above 30 ft (9,144 mm): Solid steel ball having a mass of 2 g impacting between 0.40 and 0.75 of basic wind speed (number, size and impact speed specified by user). Pressure cycles Each of the above impacts followed by 9,000 cycles of pressure representing hurricane wind gusts.
Texas Department of Insurance - Standard TDI 1 - 98 Test for Impact and Cyclic Wind Pressure Resistance of Impact Protective Systems and Exterior Opening Systems Building Code For Windstorm Resistant Construction, 1998	Large missile impact test 2 x 4 in. timber weighing 9 lbs (4.08 kg) impacting at 50 ft/s (15.24 m/s). Impact each of three specimens twice (center and corner) or each of six specimens once (three in the center, three in the corner). Small missile impact test 2 gm steel balls impacting at 130 ft/s (39.62 m/s). Each of three specimens receives 30 impacts in three groups of 10 (in the center, corner and center of long dimension). Pressure cycles Each of the above impacts followed by 9,000 cycles of pressure representing hurricane wind gusts.
AAMA 506-16 - Voluntary Specifications for Impact and Cycle Testing of Fenestration Products, 2016	• ASTM E1886 and ASTM E1996 *8.2.1 Mulled assemblies shall be qualified by this document if all of the following conditions are met:* *a) When required, the largest assembly with the longest mullion shall be impacted at its midpoint in accordance with ASTM E1996.* *b) The assembly shall satisfy the minimum requirements of AAMA 450* *c) Individual units making up the assembly shall also satisfy the minimum requirements of this specification* *Note 1: Some specifying authorities require impact of each unique mullion cross section at its midpoint.* *8.2.2 Impact resistant assemblies meeting the requirements of Section 8.2.1 shall be permitted to follow the same rules of unit substitution that are permitted by AAMA 450.* *8.2.3 Qualification of an assembly with the longest mullion shall qualify that mullion for other assemblies containing that same mullion at a shorter length with a tributary area less than or equal to the test specimen. Section 8.2.2 shall apply to these other assemblies.*

	All Buildings in Cyclonic Areas - The windborne debris impact test is an optional test for envelope components of all buildings in cyclonic regions. Clause 2.5.8 of AS/NZS 1170.2:2011 (Incorporating Amendment Nos 1, 2, 3 and 4), "Structural design actions – Part 2: Wind Actions" states that: "Where windborne debris impact loading is specified, the debris impact shall be equivalent to: *Large missile impact test* *a) timber member of 4 kg mass with a nominal cross section of 100 mm x 50 mm impacting end on at 0.4 VR for horizontal trajectories and 0.1 VR for vertical trajectories; and* *Small missile impact test* *b) spherical steel ball 8 mm diameter (approximately 2 grams mass) impacting at 0.4 VR for horizontal trajectories and 0.3 VR for vertical trajectories.* *where VR is the regional wind speed.* *Note: As this standard does not provide guidance to determine whether an impact test has passed, the CTS has developed acceptance criteria to provide consistency when assessing the results of impact tests."*
Cyclone Testing Station - James Cook University - Technical Note No.4, 'Simulated Windborne Debris Impact Testing of Building Envelope Components', 2017	The external fabric of public cyclone shelters is to be at least capable of resisting wind debris defined as: Large missile impact test a) Test Load A: A 100 mm x 50 mm cross-section piece of timber of 4 kg mass impacting end-on at 0.4 x V10,000 for horizontal trajectories and 0.1 x V10,000 for vertical trajectories. Small missile impact test b) Test Load B: Five spherical steel balls of 2 g mass and 8 mm diameter, successively impacting at 0.4 x V10,000 for horizontal trajectories and 0.3 x V10,000 for vertical trajectories. **Test:** Determine the gust wind speed in accordance with AS/NZS1170.2. *1. Impact test specimen at the specified locations with timber debris item.* *2. Inspect test specimen.* *a. If timber debris item did not penetrate and no obvious aperture is present →Pass* *b. If test specimen stops timber debris item but is left with an aperture smaller than 5000 mm2 → Pass* *c. If test specimen stops timber debris item but is left with an aperture greater than 5000 mm2 → Fail* *d. If test specimen stops timber debris item but timber debris item is visible from the inside (i.e. protruding through test specimen) → Fail* *3. If test specimen(s) passes the timber debris item test requirements at all critical locations, impact the same or an identical, new test specimen with five spherical steel balls at various random locations. For a given component and configuration, only one series of five spherical steel balls is required.* *4. Inspect test specimen.* *a. If none of the spherical steel balls penetrate through the test specimen → Pass* *b. If any of the spherical steel balls penetrates through the test specimen or test specimen is left with an aperture greater than 5000 mm2 → Fail* *6.1 Windows* *Windows shall be tested as an assembly consisting of the glass and its typical frame including any seals. Note that the frame itself is not being tested; however, the connection between the glass and the frame is being tested. Normally three impact tests are conducted on glass panels at different locations:* *1. Interface corner* *2. Interface edge* *3. Geometric center* *Where interior mullions or other glazed section joints and/or latches are present, additional impacts are to be performed at these locations:* *4. Centre of mullion* *5. Base of mullion*

▲ Table 23 – Comparison of the requirements for cyclone-resistant Façades in the analyzed standards

6.7 Tall Buildings and Typhoon Prone Façades – Generic Problems and Gaps in Standards

The first problem identified during the research is that many of the analyzed jurisdictions do not have any standard testing requirements for curtain wall in their national building code. This lack of regulations can have a very negative result on the local façade market. The tender contracts for the façade supplier normally contain an international or foreign jurisdiction's regulations and standards. This means every single project is the result of a negotiation happening between the client, the general contractor and the façade supplier. The discussion normally aims to find a compromise between cost, responsibility and reliability of building product.

That being said, there are jurisdictions in the Asia Pacific region in which tall buildings envelope started to be taken into account. Since 1997, Thailand requirements have specified that the glass in the external façade of high-rise buildings must be laminated safety glass. This requirement is not directly related to typhoon resistance, but has an indisputable repercussion on environmental effects due to typhoon events. As mentioned before, if the break occurs and the glass is not laminated, pieces of glass could fall and injure people. If the building is a tall building the results of this kind of event are very dangerous for people because of the impact force that a piece of glass could reach by the time it reaches the ground; it could reach missiles' speeds. If the glass is laminated and it breaks it will stay together thanks to the interlayer, avoiding this kind of danger.

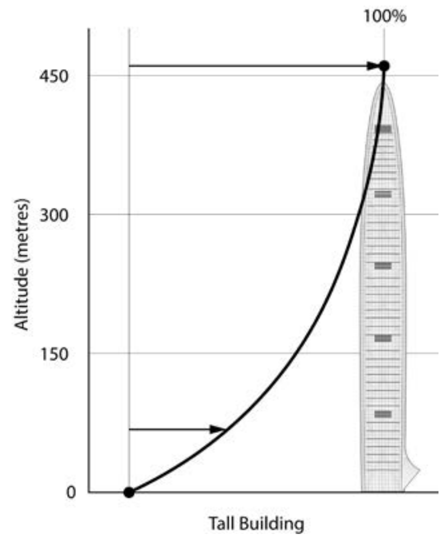
Australian Standard AS 1288 (AS, 2006. Incorporating Amendment No. 2, 2011) also recognizes the potential danger represented by the spontaneous breakage of glass. It especially recognizes the danger of toughened glass breakage. That is the reason why heat soaked toughened glass or laminated glass is required to be used in buildings above a height of 5 meters.

These two are the only codes that recognize the potential danger represented by spontaneous breakage of toughened glass in the 12 Asia Pacific analyzed jurisdictions.

The Asia Pacific jurisdiction, which has had major problems related with spontaneous breakage of glass, is China. Many times the spontaneous breakage of toughened glass caused injuries. However, China still does not have any requirement for laminated glass.

Focusing on the research topic, in Australia and in New Zealand, the requirements for cyclone resistant glazing solutions significantly changed in the last six years. There is still no pressure cycling test after the missile impact one, even if it is well representative of the cyclone natural phenomena and even if in the US this second step was identified as a tricky phase in the product approval process procedure.

This final testing phase (clearly request for the ASTM E 1886, 2013 and ASTM E 1996,2014) is not even mentioned for the cyclone-resistant windows product approval process. Furthermore, the actual wind speeds for the impact testing are extremely high and this regulation decision produced negative consequences in the design choices. It is very arduous for the façade system to withstand to the very demanding impact test and, as a result many of these building components are now commonly transferring their cyclone resistance to additional systems, to the



▲ Figure 15 – Height vs. relative wind speeds increasing on the building

shutters.

The purpose of the ASTM E1886 (ASTM, 2013) and ASTM E1996 (ASTM, 2014) standards is to safeguard human life and public and private property and directly refer to cyclone resistances for the glazing building envelope.

If a disaster event affects an urbanized territory, the most important thing is that the primary health care activities are not affected and could be available in helping people that were injured by a cyclone event. Beginning from the primary activities as hospitals, schools, etc., all the cyclone-prone jurisdictions should have to introduce minimum safety (impact and pressure cycling testing) requirements for curtain wall performances.

A gap recognized during the research activities, which took into account many post-disaster event assessments and surveys, is that small impact test requirements for the upper floors, present in all the standards analyzed, is not enough when it comes to tall buildings.

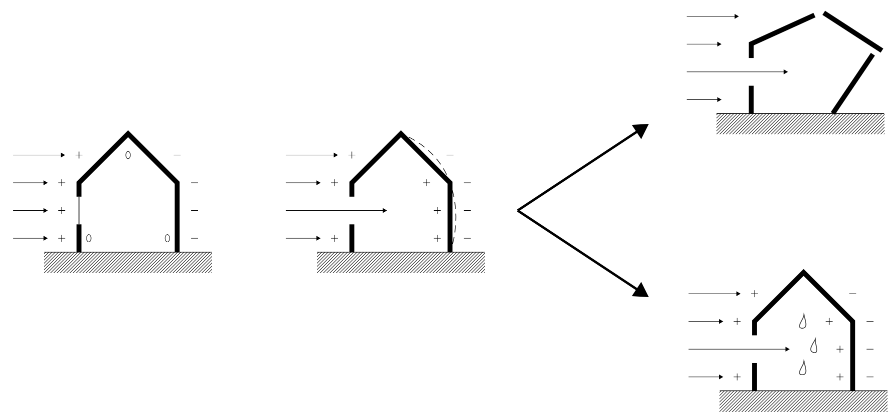


Figure 16 – Building envelope failure due to pressure differentials can lead to failure of the structure and water penetration problems.

It is unusual that a skyscraper does not have other tall buildings in the surrounding area and it is very common to find a cluster of buildings in the urban setting. If a cyclone event occurs, debris could be generated by the nearby tall building component failure and by objects left on tall building balconies. These objects are not necessarily always small and the small missile impact test simulations may not even be adequate for testing façades to prevent damage from these objects. Consequently, for tall building construction, the large missile impact tests should be mandatory for the entire glazed envelope, especially for clusters of tall buildings.

Building envelope failure caused by a typhoon event can also have consequences on interior damage, internal pressurization, interruption of business during the renovation period, and can cause potential mold problems. Another gap identified by the research project is that the performance that the facade has to resist to penetrate pressurized water during a cyclonic event is not well governed.

While US standards are appropriate with regard to the resistance required by the impact glass and the "dry" positive/negative pressure cycling testing there is, however, no representative test for “real conditions” that take into account the penetration of water for areas subject to hurricanes. There are already standards that the scientific community recognizes as suitable for the simulation of such conditions, but there is no demand for it to be carried out following impact and pressure/depression tests; they are, rather, voluntary. An example is the standard AAMA 520-12 (AAMA, 2012. Voluntary Specification for Rating the Severe Wind-Driven Rain Resistance of Windows, Doors and Unit Skylights). The international and US standard test methods for typhoon/hurricane resilience don’t take this into account, even though during a typhoon event there are huge amounts of wind-driven rain.

For example, in Biloxi, in 2005, despite the apparent integrity of the building envelope of MGM Mirage’s Beau Rivage Hotel and Casino, after Hurricane Katrina there was extensive damage due to internal mold problems.

6.8 Final remarks

The curtain wall is a building component that continues to undergo numerous innovations in recent years. In many contemporary buildings, the glazed surfaces represent the only “skin” of the building, the only barrier between the interior and the outdoor

Figure 17 – Biloxi. Despite the apparent integrity of the building envelope of MGM Mirage’s Beau Rivage Hotel and Casino, after Hurricane Katrina there were many extensive damages.

environment.

Undoubtedly, façades in new building construction and re-cladding processes in building renovations should begin to provide more safety for users as well as for the property, especially in typhoon-prone areas. Upgrading the performances of this building component, it is possible to reduce users and property vulnerability during natural disasters.

Now it is time to react to natural disasters and to prevent their consequences in our life by improving our infrastructure's resilience. We could start working on specific aspects we can easily control, like the resistance of the building components and the resistance of their assembly in the building.

Resistance to penetration by missile impact is determined by the interlayer type and the thickness of the interlayer.

- The interlayer thickness relates to missile impact speed, not to design wind load.
- Resistance to interlayer tearing in the ASTM pressure cycling test is influenced by interlayer stiffness and cut-resistance.

Building envelope failure caused by a typhoon event can have consequences on:

- safeguard the people;
- interior damage ;
- internal pressurization;
- interruption of business during the renovation period;
- potential mold problems.

New constructions have to follow the best practices for typhoon resistant glazing because, in addition to interior damage, the potential effect to the external area and urban environment due to storms is invaluable.

In the Miami-Dade County, the effectiveness of cyclone-resistant building components have proven to be hurricane resistant.

The local authorities of Asia Pacific jurisdictions must specify a timeline for aligning there façade requirements with that of the most developed jurisdictions on the specific issue. This could lead at least to these new construction representing a new image of safety by serving as a refuge for local residents during disaster events. The most desirable result is that building managers of old construction, taking these new safe models as an example, will upgrade their façade systems in order to withstand a typhoon.

7.0 Appendix A - Code and Standard Analysis

7.0 Appendix A - Code and Standard Analysis

7.1 Code Analysis

7.1.1 IBC International Building Code

AUTHOR	International Code Council
TITLE	International Building Code
YEAR	2015

This document is an extensive and effective building code, which is mainly adopted for the United States. It aims to enhance the protection of life and property thanks to minimum requirements for: building structural design; component design; construction process; approval process; and building component test requirements.

In Chapter 16, the minimum structural loading and structural component requirements for use in the design and construction of buildings are explained, as well as the different risk categories of buildings.

The chapter references and relies on many nationally recognized design standards. A key standard recognized is the American Society of Civil Engineer's Minimum Design Loads for Buildings and Other Structures (ASCE 7). Maps are provided of rainfall, seismic, snow and wind criteria in different regions, as the structural design needs to address the conditions of the site and location.

Information about:

- Testing apparatus
- ✓ Wind loads
- ✓ Wind-borne debris impact test
- ✓ Pressure cycling testing
- Testing procedure
- Technical report
- ✓ Wind speed maps

Strengths / Limitations

Refer to ASTM E 1886 and ASTM E 1996 strengths/limitations.

7.1.2 Florida Building Code

AUTHOR	International Code Council
TITLE	Florida Building Code
YEAR	2015

This document is an extensive and effective building code, which is mainly adopted for the United States. It aims to enhance the protection of life and property thanks to minimum requirements for the building's structural design, component design, construction process, approval process, and testing.

In Chapter 16 the minimum structural loading and structural component requirements for use in the design and construction of buildings are explained, as well as the risk categories. The chapter references and relies on many nationally recognized design standards. A key standard recognized is the American Society of Civil Engineer's Minimum Design Loads for Buildings and Other Structures (ASCE 7). Maps are provided of rainfall, seismic, snow and wind criteria in different regions, as the structural design needs to address the conditions of the site and location.

The Florida Building Code requires wind loads to be calculated according to ASCE-7, but all glazing in hurricane-prone areas (defined by county within the code) must meet the testing requirements of the Dade County protocols.

Information about:

- Testing apparatus
- ✓ Wind loads
- ✓ Wind-borne debris impact test
- ✓ Pressure cycling testing
- Testing procedure
- Technical report
- ✓ Wind speed maps

Strengths / Limitations

This is the most restrictive building code in the US for the design and construction of hurricane resistant glazing systems. The effectiveness of the indications and of the test procedures in the Building Code have been proved by the demonstrated resilience of the building components during Hurricane Wilma in 2006.

7.1.3 BNBC Bangladesh National Building Code

AUTHOR	Housing and Building Research Institute
TITLE	Bangladesh National Building Code
YEAR	2014

This is an effective building code for building design and construction. This code is implemented with many requests for more safe construction and it also considers recent climate changes and related disaster events.

It is a very comprehensive document where cyclone-proof glazing systems are considered, which have to withstand the United States ASTM standards requirements.

The building code contains indications for the main wind-force resisting systems, special wind regions, importance factors, wind-borne debris prone regions, and a wind speed map of Bangladesh.

Information about:

- Testing apparatus
- ✓ Wind loads
- Wind-borne debris impact test
- Pressure cycling testing
- ✓ Testing procedure
- Technical report
- ✓ Wind speed maps

Strengths / Limitations

The document is a very comprehensive code for calculation of wind speed and wind pressure. It indicates wind-borne debris regions testing requirements and clearly identifies the "Special Wind Regions". Also, it refers to ASTM E 1886 and ASTM E 1996 for levels of missile tests and wind zones in order to identify the impact resistance.

Refer to ASTM E 1886 and ASTM E 1996 for both strengths and limitations.

7.1.4 National Structural Code of the Philippines C101-10

AUTHOR	Association of Structural Engineers of the Philippines
TITLE	National Structural Code of the Philippines C101-10
YEAR	2010

This document is the national building code for buildings, towers and other vertical structures of the Philippines. It is designed to meet these needs through various model codes/regulations, generally from the United States, to safeguard the public health and safety nationwide.

The structural design actions are identified in it. It contains a section dedicated to wind loads, which takes into account testing requirements for glazing systems in wind-borne debris regions.

Information about:

- Testing apparatus
- ✓ Wind loads
- Wind-borne debris impact test
- Pressure cycling testing
- ✓ Testing procedure
- Technical report
- ✓ Wind speed maps

Strengths / Limitations

The document is a very comprehensive code for calculation of wind speed, wind pressure. It indicates wind-borne debris regions testing requirements. It clearly identify the "Special Wind Regions" and it refers to ASTM E 1886 and ASTM E 1996 both for levels of missile levels and wind zones in order to identify the levels of impact resistance. The Code takes into account the height of the aggregate surface roofs located within 458 m of the building in order to decide if the glazing systems has to be protected from wind-borne debris.

Refer to ASTM E 1886 and ASTM E 1996 for both strengths and limitations.

7.1.5 ICC 500 Guidelines for Hurricane Resistant Residential Construction

AUTHOR	International Code Council
TITLE	ICC 500 Guidelines for Hurricane Resistant Residential Construction
YEAR	2014

The document is a referenced standard in the International Codes. It provides codes for design and operative construction requirements for storm shelters (hurricanes; tornadoes). It also provides minimum design requirements in order to guarantee safety and public health relative to design, construction, and installation of windproof shelters. The standard could be adopted both for residential storm shelters (that serve occupants of dwelling units and has an occupant load not exceeding 16 people) and for community storm shelters.

It specifies testing requirements to be conducted on the glazing systems building components for missile impact and for pressure cycling.

Information about:

- Testing apparatus
- Wind loads
- Wind-borne debris impact test
- Pressure cycling testing
- ✓ Testing procedure
- Technical report
- Wind speed maps

Strengths

The document is very a comprehensive guideline for designing and testing of hurricane shelters. It contains wind speed maps and clear references to standard requirements. It contains information for glazing systems and suggests testing using requirements from ASTM E 1886 and ASTM E 1996, or SSTD 12, or AAMA 506. For hurricane shelter glazing system after the missile impact testing, the pressure cycling testing is required.

Limitations

Refer to ASTM E 1886 and ASTM E 1996 strengths/limitations.

7.1.6 AS/NZS 1170.2:2011 Structural design actions - Part 2: Wind actions. Incorporating Amendment No. 4

AUTHOR	Australian/New Zealand Standard
TITLE	AS/NZS 1170.2:2011 Structural design actions - Part 2: Wind actions. Incorporating Amendment No. 4
YEAR	2011 + 2016

The document AS/NZS 1170 is a building code where the structural design actions are identified. The second part of the document provides information about the design of wind actions on buildings. In 2016 - with the Amendment No. 4 - the requirements for tropical cyclone prone provinces changed. The code explains calculation of wind-borne debris speed for various regions and it gives references about test method requirements for the product approval process.

Information about:

- Testing apparatus
- ✓ Wind loads
- ✓ Wind-borne debris impact test
- Pressure cycling testing
- Testing procedure
- Technical report
- Wind speed maps

Strengths / Limitations

The document is a very comprehensive code for the calculation of wind speed, wind pressure, and regional wind-borne debris speed for cyclonic regions (C and D). In this way, the wind-borne debris loading requirements are explained, which helps in conducting the impact tests. Calculation of regional wind speed and then of regional wind-borne debris loading is very clearly explained. In 2016, the Amendment No. 4 updated wind-borne debris speed requirement which now consistently increased.

Before 2016, the wood missiles had to impact the glass with a speed of 15 m/s (comparable to ASTM E1886, ASTM E1996) whereas now it has to be calculated. For example, missile speed for region C doubled. It means that the energy to be absorbed, raising the speed to the second power, changes in magnitude. It is for these requirements that many buildings are not following the product approval process for cyclone-proof glazed building components anymore.
Furthermore, no pressure cycling is requested after the missile impact tests. The committee involved in the ASTM E 1886 and ASTM E 1996 requirements identified the pressure cycling test as a critical part of the product approval process.

7.1.7 Design Guidelines for Australian Public Cyclone Shelters

AUTHOR	Queensland Government - Department of Public Works
TITLE	Design Guidelines for Australian Public Cyclone Shelters
YEAR	2006

This document aims to provide guidelines for design requirements of public cyclone shelters in Queensland, Australia. It incorporates the recommendations of the Queensland Tropical Cyclone Coordination Committee (QTCCC). Public cyclone shelters are buildings that provide shelter during a severe tropical cyclone (these are different from post-cyclone event recovery centers). The guidelines are categorized in the following sections: shelter location; structure; human factors; and other factors.

It has references for pressure cycling requirements but they are not for private/public common buildings, as this document is specifically made for public cyclone shelters.

Information about:

- Testing apparatus
- ✓ Wind loads
- ✓ Wind-borne debris impact test
- ✓ Pressure cycling testing
- ✓ Testing procedure
- ✓ Technical report
- Wind speed maps

Strengths

This document clearly indicates what kind of load the building structure has to be capable to resisting. The structures of the public cyclone shelters include windows and doors.
This document requires that, after the wind-borne debris impact test, the window specimen has to carry on the pressure cycling test. This is the main difference from typical requirements for tropical cyclone-proof windows.

Limitations

The mentioned requirements in the guidelines only refer to public cyclone shelters construction. The effect of cyclic pressures on the glazing construction component is well representative of a real cyclone event and has been identified in the US as a critical part of the testing protocol.
These pressure cycling requirements are not for private/public common buildings, but just for public cyclone shelters. This pressure cycling requirements has to be extended to cyclone-proof windows.

7.1.8 2006 Texas Revisions to the 2006 International Residential Code

AUTHOR	2006 Texas Revisions to the 2006 IRC
TITLE	2006 Texas Revisions to the 2006 International Residential Code
YEAR	2006

This Revision of the International Residential Code clearly identifies test requirements for impact tests in wind-borne debris prone regions of Texas.

Wind-borne debris requirements:

- Seaward of the Intracoastal Canal - All unprotected exterior openings are required to be impact resistant and are designed to accommodate 130 mph 3-second gusts;
- Inland I (inland of the Intracoastal Canal) 120 mph 3-second wind gust design - All glazed exterior opens shall be protected or impact resistant;
- Inland II (inland of the 120 mph contour) - No impact requirements.

Information about:

Testing apparatus
Wind loads
Wind-borne debris impact test
Pressure cycling testing
✓ Testing procedure
Technical report
Wind speed maps

Strengths

This revision clearly identifies regions that have to guarantee wind-borne debris protection for openings. It refers to ASTM standard requirements and to ANSI/DASMA standard requirements. Refer to ASTM E 1886 and ASTM E 1996 strengths/limitations.

Limitations

Refer to ASTM E 1886 and ASTM E 1996 strengths/limitations.
No protection is needed for glazing systems above 60 ft (20 m) for Category II, III and IV of buildings.

7.2 Standard Analysis

7.2.1 ASCE 7-16 Minimum Design Loads and Associated Criteria for Buildings and Other Structures

AUTHOR	American Society of Civil Engineers
TITLE	ASCE 7-16 Minimum Design Loads and Associated Criteria for Buildings and Other Structures
YEAR	2016

This document is a very comprehensive standard that provides minimum loads, hazard levels, associated criteria, and intended performance goals for buildings and other structures subject to building code requirements. The explained loads, load combinations, and associated criteria have to been used with design strengths contained in design specifications for conventional structural materials.

Chapter 26 regards the wind load provisions: definitions, basic wind speed, exposure categories, internal pressures, elevation effects, enclosure classification, gust effects, and topographic factors.
In the 2016 last edition of the ASCE 7, the wind speed maps are updated, also taking into account to hurricane and tornadoes zones.

Information about:

- Testing apparatus
- ✓ Wind loads
- ✓ Wind-borne debris impact test
- ✓ Pressure cycling testing
- ✓ Testing procedure
- Technical report
- ✓ Wind speed maps

Strengths / Limitations

Refer to ASTM E 1886 and ASTM E 1996 strengths/limitations.
Wind-borne debris protection requirements for glazing systems building components are very comprehensive.
The wind speed maps have been updated and now they take into account tornado disaster events probability. There are similarities between hurricane- and tornado-proof building glazing components and they both use the ASTM testing procedures (impact and pressure testing).

7.2.2 ISO 16932 Glass in building - Destructive-windstorm-resistant security glazing - Test and classification

AUTHOR	International Organization for Standardization
TITLE	ISO 16932 Glass in building - Destructive-windstorm-resistant security glazing - Test and classification
YEAR	2015

This International Standard determines resistance of security glazing products to natural threats characterized by simulated destructive-windstorm events. Classification is intended as a basis for judging the ability of glazing to remain without openings during a tropical cyclone with wind speeds of 50 m/s or greater. Impact by missile(s) and subsequent cyclic static-pressure differentials simulate conditions representative of windborne debris and pressures in a destructive windstorm.

Information about:

- ✓ Testing apparatus
- ✓ Wind loads
- ✓ Wind-borne debris impact test
- ✓ Pressure cycling testing
- ✓ Testing procedure
- ✓ Technical report
- Wind speed maps

Strengths / Limitations

Refer to ASTM E 1886 and ASTM E 1996 strengths/limitations. It has the same characteristics.
It also has information about basic wind speed zones.

7.2.3 Testing Application Standard 201-94 - Impact Test Procedures

AUTHOR	International Code Council
TITLE	Testing Application Standard 201-94 - Impact Test Procedures. Florida Building Code Test Protocols for High-Velocity Hurricane Zones
YEAR	1994

The TAS 201-94 covers procedures for conducting the impact tests for wall cladding, exterior windows, glazing, exterior doors, skylights, glass block, shutters and any other similar devices used as external protection on the envelope of a building, as required by §1626 of the Florida Building Code, Building. The tests demand a sufficient grade of resiliency from wind-borne debris.

This standard was developed in 1994 after Hurricane Andrew hit the Miami-Dade and Palm Beach County. After this standard development, the Florida Building Commission recognized a need for a state wind code.

Information about:

- ✓ Testing apparatus
- Wind loads
- ✓ Wind-borne debris impact test
- Pressure cycling testing
- ✓ Testing procedure
- ✓ Technical report
- Wind speed maps

Strengths

This test is recognized by the scientific community as the best practice for wind-borne debris impact testing requirements and the testing is representative of the natural phenomena of a real cyclone. After hurricane Wilma in 2006, it has been proved that buildings with glazing systems that were certified with the NOA (Notice of Acceptance) and passed the TAS had no significant damages.

Limitations

During major storm events, there is often heavy rain. Despite this, the TAS tests do not take into account the water penetration tests. TAS are mandatory for the hurricane-proof glazing system building components NOA certification, but no water penetration requirements are taken into account. The scientific community agrees that there is need for water penetration tests after the pressure cycling tests.

Also, the request for big missile impact tests has to be extended in height, especially in areas with clusters of tall buildings. If, during a hurricane event, some objects from tall buildings break off, they can break surrounding glazing that was only tested for small missile impacts.

7.2.4 Testing Application Standard 202-94 - Criteria For Testing Impact & Nonimpact Resistant Building Envelope Components Using Uniform Static Air Pressure

AUTHOR	International Code Council
TITLE	Testing Application Standard 202-94 - Criteria For Testing Impact & Nonimpact Resistant Building Envelope Components Using Uniform Static Air Pressure. Florida Building Code Test Protocols for High-Velocity Hurricane Zones
YEAR	1994

The standard TAS 202-94 covers procedures for conducting a uniform static air pressure test for materials and products such as wall cladding, glass blocks, exterior doors, garage doors, skylights, exterior windows, storm shutters, and any other external component that help maintain the integrity of the building envelope (§1620 Florida Building Code, Buildings). It has to be conducted after the impact test TAS 201-94.

This standard was developed in 1994 after Hurricane Andrew hit the Miami-Dade and Palm Beach County. After the standard development, the Florida Building Commission recognized a need for a state wind code.

Information about:

- ✓ Testing apparatus
- Wind loads
- Wind-borne debris impact test
- ✓ Pressure cycling testing
- ✓ Testing procedure
- ✓ Technical report
- Wind speed maps

Strengths

The scientific community agrees on the need of conducting this test after the impact test in order to approve hurricane-proof glazing systems building components. In fact, during a hurricane event, there is high probability of wind-borne debris impacts and of a strong turnover of positive and negative pressure.
After hurricane Wilma in 2006, it has been proved that buildings with glazing systems which were certified with the NOA (Notice of Acceptance) and passed the TAS had no significant damage.

This test has to be conducted both for impact and non-impact resistant building envelope components and is not specific for impact resistant windows and curtain walls.

Limitations

During major storm events, there is often heavy rain. Despite this, the TAS tests do not take into account the water penetration tests. TAS are mandatory for the hurricane-proof glazing system building components NOA certification, but no water penetration requirements are taken into account. The scientific community agrees that there is need for water penetration tests after the pressure cycling tests.
Also, the request for big missile impact tests has to be extended in height, especially in areas with clusters of tall buildings. If, during a hurricane event, some objects from tall buildings break off, they can break surrounding glazing that was only tested for small missile impacts.

7.2.5 Testing Application Standard 203-94 - Criteria For Testing Products Subject to Cyclic Wind Pressure Loading

AUTHOR	International Code Council
TITLE	Testing Application Standard 202-94 - Criteria For Testing Impact & Nonimpact Resistant Building Envelope Components Using Uniform Static Air Pressure. Florida Building Code Test Protocols for High-Velocity Hurricane Zones
YEAR	1994

The TAS 203-94 covers procedures for conducting the cyclic wind pressure loading test required by the Florida Building Code, Building and TAS 201-94.

This standard was developed in 1994 after Hurricane Andrew hit the Miami-Dade and Palm Beach County. After the standard development, the Florida Building Commission recognized a need for a state wind code.

Information about:

- ✓ Testing apparatus
- Wind loads
- Wind-borne debris impact test
- ✓ Pressure cycling testing
- ✓ Testing procedure
- ✓ Technical report
- Wind speed maps

Strengths

The scientific community agrees on the need of conducting this test after the impact test in order to approve hurricane-proof glazing systems building components. In fact, during a hurricane event, there is high probability of wind-borne debris impacts and of a strong turnover of positive and negative pressure.
After hurricane Wilma in 2006, it has been proved that buildings with glazing systems which were certified with the NOA (Notice of Acceptance) and passed the TAS had no significant damage.

This test has to be conducted both for impact and non-impact resistant building envelope components and is not specific for impact resistant windows and curtain walls.

Limitations

During major storm events, there is often heavy rain. Despite this, the TAS tests do not take into account the water penetration tests. TAS are mandatory for the hurricane-proof glazing system building components NOA certification, but no water penetration requirements are taken into account. The scientific community agrees that there is need for water penetration tests after the pressure cycling tests.
Also, the request for big missile impact tests has to be extended in height, especially in areas with clusters of tall buildings. If, during a hurricane event, some objects from tall buildings break off, they can break surrounding glazing that was only tested for small missile impacts.

7.2.6 ASTM E 1886 Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Missile(s) and Exposed to Cyclic Pressure Differentials

AUTHOR	ASTM E 1886
TITLE	ASTM E 1886 Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Missile(s) and Exposed to Cyclic Pressure Differentials
YEAR	2013

This test method is applicable to the design of the entire fenestration or impact protection systems assemblies and their installation. The performance is determined by this test method and determines the ability of elements of the building envelope to avoid being breached during a windstorm. This standard, and the ASTM E 1996 standard, aims to test the hurricane resistance of building glazing system assemblies. They specify testing requirements for vertical glazing and skylights based on wind zones, as determined in ASCE 7. They test the resistance of glazing system building components against wind-borne debris impact, followed by the effects of repeated or cyclic wind loading.

Information about:

- ✓ Testing apparatus
- ✓ Wind loads
- Wind-borne debris impact test
- ✓ Pressure cycling testing
- ✓ Testing procedure
- ✓ Technical report
- Wind speed maps

Strengths

This standard and the ASTM E 1996 standard were developed after the introduction of standards TAS 201, TAS 202, TAS 203 in 1994 in the Miami-Dade County. The ASTM standards are based on these and the scientific community agrees they are the best standards to test glazing building components for their resistant against disaster effects. The pressure cycling testing, after the impact testing, submits the specimen to a well representative simulation of the natural effects of cyclones.

Limitations

During major storm events, there is often heavy rain. Despite this, the ASTM E 1886 and ASTM E 1996 tests don't take into account the water penetration tests. ASTM E 1886 and ASTM E 1996 are mandatory for the hurricane-proof glazing system building component's certification, but no water penetration requirements are taken into account. The scientific community agrees that there is need for water penetration tests after the pressure cycling tests.
Also, the request for big missile impact tests has to be extended in height, especially in areas with clusters of tall buildings. If, during a hurricane event, some objects from tall buildings break off, they can break surrounding glazing that was only tested for small missile impacts.

7.2.7 ASTM E1996 Standard Specification for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Windborne Debris in Hurricanes

AUTHOR	ASTM E 1996
TITLE	ASTM E1996 Standard Specification for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Windborne Debris in Hurricanes
YEAR	2014

This specification covers exterior windows, glazed curtain walls, doors, and impact protective systems used in buildings located in geographic regions that are prone to hurricanes. This specification provides the information required to conduct Test Method E 1886. This standard, and the ASTM E 1996 standard, aim to test the hurricane resistance of building glazing systems assemblies. They specify testing requirements for vertical glazing and skylights based on wind zones determined in ASCE 7. They test the resistance of glazing systems building components against wind-borne debris impacts, followed by the effects of repeated or cyclic wind loading.
While this standard was developed for hurricanes, it may be used for other types of similar windstorms capable of generating windborne debris.
This test method is applicable to the design of entire fenestrations or impact protection system assemblies and their installation.

Information about:

- ✓ Testing apparatus
- ✓ Wind loads
- ✓ Wind-borne debris impact test
- ✓ Pressure cycling testing
- ✓ Testing procedure
- ✓ Technical report
- Wind speed maps

Strengths

This standard and the ASTM E 1996 standard were developed after the introduction of standards TAS 201, TAS 202, TAS 203 in 1994 in the Miami-Dade County. The ASTM standards are based on these and the scientific community agrees they are the best standards to test glazing building components for their resistant against disaster effects. The pressure cycling testing, after the impact testing, submits the specimen to a well representative simulation of the natural effects of cyclones.

Limitations

During major storm events, there is often heavy rain. Despite this, the ASTM E 1886 and ASTM E 1996 tests don't take into account the water penetration tests. ASTM E 1886 and ASTM E 1996 are mandatory for the hurricane-proof glazing system building component's certification, but no water penetration requirements are taken into account.
The scientific community agrees that there is need for water penetration tests after the pressure cycling tests.
Also, the request for big missile impact tests has to be extended in height, especially in areas with clusters of tall buildings. If, during a hurricane event, some objects from tall buildings break off, they can break surrounding glazing that was only tested for small missile impacts.

7.2.8 Standard TDI 1 - 98 Test for Impact and Cyclic Wind Pressure Resistance of Impact Protective Systems and Exterior Opening Systems. Building Code for Windstorm Resistant Construction

AUTHOR	Texas Department of Insurance
TITLE	Standard TDI 1 - 98 Test for Impact and Cyclic Wind Pressure Resistance of Impact Protective Systems and Exterior Opening Systems. Building Code for Windstorm Resistant Construction
YEAR	1998

The purpose of this Standard is to minimize public and private losses due to wind and windborne debris damage to impact protective systems and exterior opening systems. This standard provides general guidance for impact locations and cyclic wind pressure loading requirements for impact protective systems and exterior opening systems.

Wind-borne Debris requirements:

- Seaward of the Intracoastal Canal:
  All unprotected exterior openings are required to be impact resistant and are designed to accommodate 130 mph 3-second gusts.
- Inland I (inland of the Intracoastal Canal):
  120 mph 3-second wind gust design and all glazed exterior opens shall be protected or impact resistant.
- Inland II (inland of the 120 mph contour):
  No impact requirements.

Information about:

- ✓ Testing apparatus
- Wind loads
- ✓ Wind-borne debris impact test
- ✓ Pressure cycling testing
- ✓ Testing procedure
- ✓ Technical report
- Wind speed maps

Strengths

The document is a very comprehensive standard for calculation of wind-borne debris proof building testing requirements for buildings located in hurricane prone areas. The pressure cycling testing after the missile (large/small) impact testing is universally recognized as the best practice. In fact, the hurricanes are characterized by strong succession of positive and negative pressure, which is represented in these tests.

Limitations

The scientific community agreed that the hurricane event is not a dry event and so one limitation of this standard is that it is not 100% representative of the natural phenomena. There could be an improvement of this standard by adding additional water penetration testing in the end of the sequence.

7.2.9 AAMA 506-16 Voluntary Specifications for Impact and Cycle Testing of Fenestration Products

AUTHOR	AAMA
TITLE	AAMA 506-16 Voluntary Specifications for Impact and Cycle Testing of Fenestration Products
YEAR	2016

This specification uses existing ASTM test methods to qualify windows, doors, and skylights as impact resistant. It implements the ASTM E 1886 and ASTM E 1996 with requirements for components to be tested and certified by an AAMA Laboratory.
Refer to ASTM E 1886 and ASTM E 1996.

Information about:

- ✓ Testing apparatus
- Wind loads
- ✓ Wind-borne debris impact test
- ✓ Pressure cycling testing
- ✓ Testing procedure
- ✓ Technical report
- Wind speed maps

Strengths / Limitations

Refer to ASTM E 1886 and ASTM E 1996 strengths/limitations.

7.2.10 Technical Note No.4. Simulated Windborne Debris Impact Testing of Building Envelope Components

AUTHOR	Cyclone Testing Station - James Cook University
TITLE	Technical Note No.4. Simulated Windborne Debris Impact Testing of Building Envelope Components
YEAR	2017

The Cyclone Testing Station (CTS) is an independent authority on the effects of high wind and related damage to low-rise building systems in Australia, South East Asia, and the Pacific. The CTS provides a service to the building industry for testing the effects of wind forces on buildings and building components.

The CTS has the equipment and technical expertise to test existing and new building envelope components to comply with Australian and International standards.

Information about:

- ✓ Testing apparatus
- ✓ Wind loads
- ✓ Wind-borne debris impact test
- Pressure cycling testing
- ✓ Testing procedure
- ✓ Technical report
- Wind speed maps

Strengths

The document is a very comprehensive standard procedure to follow for wind-borne debris resisting glazing systems certified in Australia and New Zealand.

Limitations

The scientific community agreed that the updated wind-borne debris speed requirement are too strict – Amendment No. 4, 2016. Before 2016, the wood missiles had to impact the glass with a speed of 15 m/s (comparable to ASTM E1886, ASTM E1996) whereas now it has to be calculated. For example, missile speed for region C doubled. It means that the energy to be absorbed, raising the speed to the second power, changes in magnitude. It is for these requirements that many buildings are not following the product approval process for cyclone-proof glazed building components anymore.

Furthermore, no pressure cycling is requested after the missile impact tests. The scientific community identifies the pressure cycling test as a critical part of the product approval process which follows the ASTM E 1886 and ASTM E 1996 standards.

8.0 Appendix B - Asia Pacific Jurisdictions Tabs

8.0 Appendix B - Asia Pacific Jurisdictions Tabs

This Section of the document aims to give to the Lector, which is interested in one specific of the analyzed jurisdictions, the quick overview on the local requirements and on the size of the problem of tall buildings in tropical cyclone prone area.

8.1 Australia

TALL BUILDINGS and CYCLONE EVENTS	
Tall buildings in 1995	399
Tall buildings in 2005	591
Tall buildings in 2017	962
Tall building in cyclone prone area	170
Tall building affected by cyclone	68
Taller than 150m in 1995	34
Taller than 150m in 2005	55
Taller than 150m in 2017	99
Taller than 150m in cyclone prone area	12
Taller than 150m affected by cyclone	1

ECONOMIC DATA	
GDP (2016, million US$)	$ 1,204,616.44
GDP per capita (2016, US$)	$49,927.00
GDP, PPP per capita (2016, US$)	$46,789.90
GDP, PPP per capita (2016, world ranking)	17

POPULATION DATA	
Population 2016	24,127,000
Urban population 1960	81.52%
Urban population 2016	89.55%
Urban population increase (from 1960 to 2016)	13,228,485

CODE/STANDARD REQUIREMENTS	AS/NZS 1170.2

Locations of buildings taller than 150 m in 1995, cross-referenced with typhoon events occurred before 2016. The purple dots represent the location of a city with at least one 150m+ building.

Locations of buildings taller than 150 m in 2017, cross-referenced with typhoon events occurred before 2016. The purple dots represent the location of a city with at least one 150m+ building.

8.2 Bangladesh

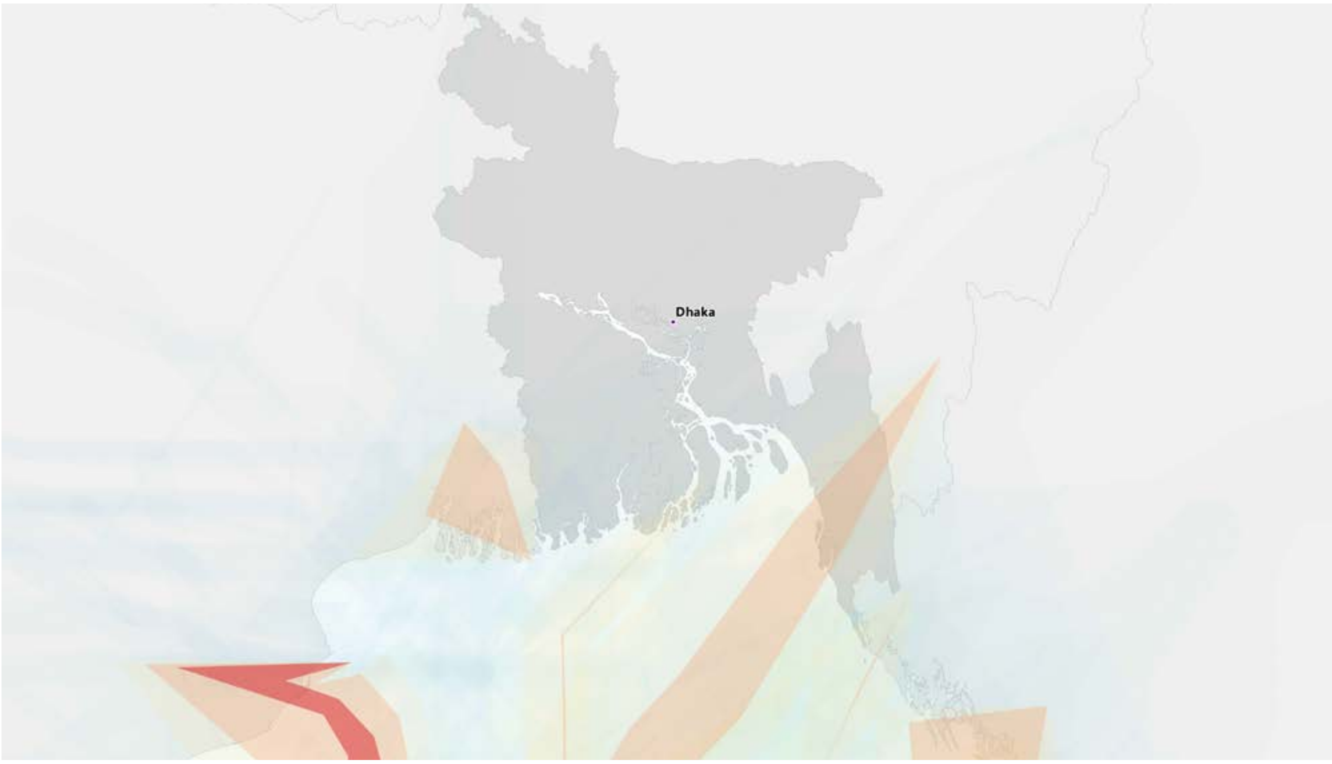
TALL BUILDINGS and CYCLONE EVENTS	
Tall buildings in 1995	1
Tall buildings in 2005	1
Tall buildings in 2017	5
Tall building in cyclone prone area	5
Tall building affected by cyclone	1
Taller than 150m in 1995	0
Taller than 150m in 2005	0
Taller than 150m in 2017	1
Taller than 150m in cyclone prone area	1
Taller than 150m affected by cyclone	0

ECONOMIC DATA	
GDP (2016, million US$)	$ 221,415.28
GDP per capita (2016, US$)	$1,358.00
GDP, PPP per capita (2016, US$)	$3,580.70
GDP, PPP per capita (2016, world ranking)	137

POPULATION DATA	
Population 2016	162,952,000
Urban population 1960	5.13%
Urban population 2016	35.04%
Urban population increase (from 1960 to 2016)	54,617,432

CODE/STANDARD REQUIREMENTS	ASTM E 1886 and ASTM E 1996

RANK BY POP.	MEGACITY	COMBINED POPULATION	AREA (SQ. KM)	DENSITY (PPL/SQ. KM)	NUMBER OF 200 M+ BUILDINGS	CITIES & ADMINISTRATIVE AREAS WITHIN
13	Dhaka	24,952,038	9,353	2,668	0	Districts of Dhaka, Gazipur, Munshiganj, Mymensingh, and Narayanganj within Dhaka Division



Locations of buildings taller than 150 m in 1995, cross-referenced with typhoon events occurred before 2016. The purple dots represent the location of a city with at least one 150m+ building.

Locations of buildings taller than 150 m in 2017, cross-referenced with typhoon events occurred before 2016. The purple dots represent the location of a city with at least one 150m+ building.

8.3 China

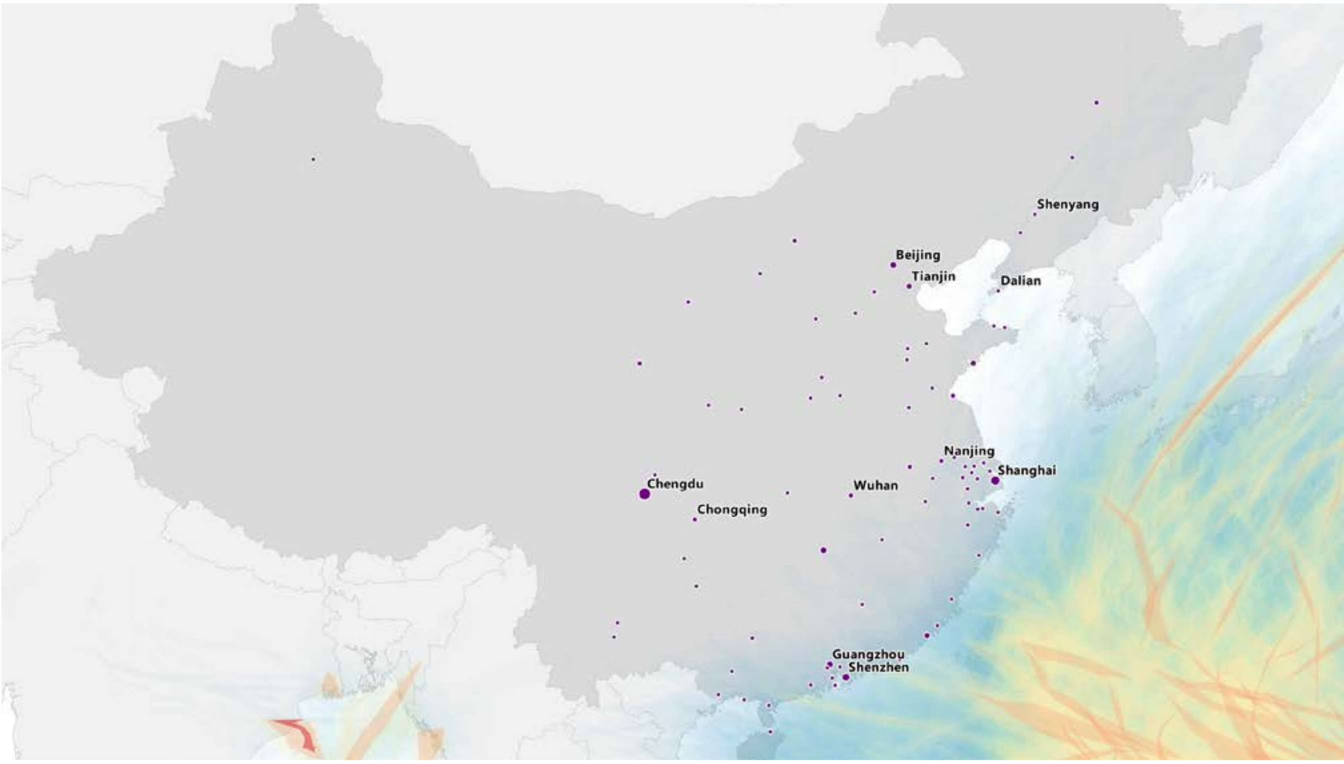
TALL BUILDINGS and CYCLONE EVENTS	
Tall buildings in 1995	231
Tall buildings in 2005	601
Tall buildings in 2017	2124
Tall building in cyclone prone area	1675
Tall building affected by cyclone	300
Taller than 150m in 1995	43
Taller than 150m in 2005	317
Taller than 150m in 2017	1316
Taller than 150m in cyclone prone area	994
Taller than 150m affected by cyclone	194

ECONOMIC DATA	
GDP (2016, million US$)	$ 11,199,145.16
GDP per capita (2016, US$)	$8,123.00
GDP, PPP per capita (2016, US$)	$15,534.70
GDP, PPP per capita (2016, world ranking)	70

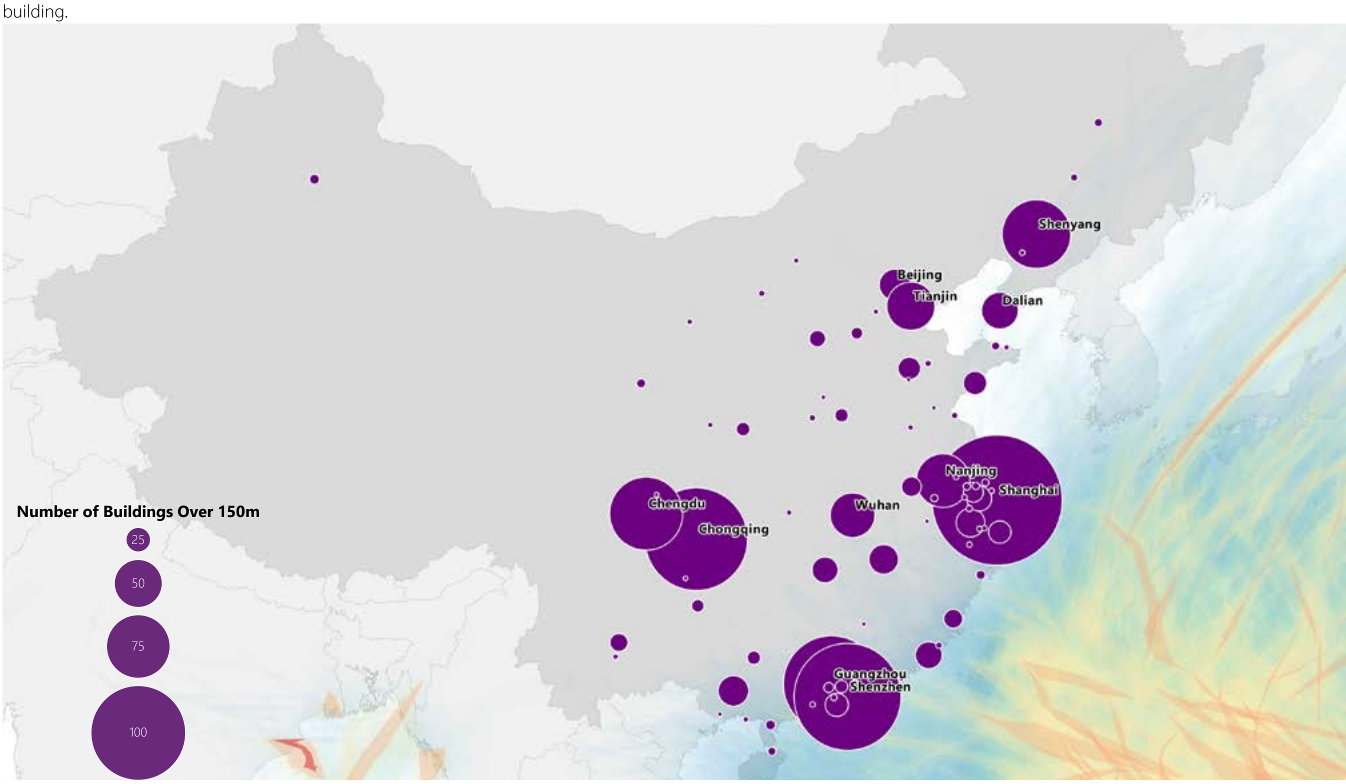
POPULATION DATA	
Population 2016	1,378,665,000
Urban population 1960	16.20%
Urban population 2016	56.77%
Urban population increase (from 1960 to 2016)	674,602,781

CODE/STANDARD REQUIREMENTS	No

RANK BY POP.	MEGACITY	COMBINED POPULATION	AREA (SQ. KM)	DENSITY (PPL/SQ. KM)	NUMBER OF 200 M+ BUILDINGS	CITIES & ADMINISTRATIVE AREAS WITHIN
1	Pearl River Delta	64,899,778	56,217	1,154	220	Dongguan, Foshan, Guangzhou, Hong Kong, Huizhou, Jiangmen, Macau, Shenzhen, Zhaoqing, Zhongshan, and Zuhai
2	Shanghai-Changzhou	50,302,212	28,010	1,796	90	Changzhou, Jiaxing, Shanghai, Suzhou, and Wuxi
4	Beijing-Tianjin	40,594,839	34,588	1,174	50	Beijing, Langfang, and Tianjin
7	Chongqing	30,165,500	82,403	366	46	Chongqing Province
17	Hangzhou-Ningbo	21,218,301	34,936	607	24	Hangzhou, Ningbo, Shaoxing
25	Chengdu	17,663,383	18,115	975	24	Chengdu, Deyang
26	Xiamen	16,469,863	25,792	639	20	Quanzhou, Xiamen, Zhangzhou
31	Shantou	13,943,141	10,660	1,308	0	Chaozhou, Jieyang, and Shantou
43	Wuhan	10,834,056	10,088	1,074	29	Ezhou and Wuhan
45	Shenyang	10,244,261	24,132	425	41	Fushun and Shenyang



Locations of buildings taller than 150 m in 1995, cross-referenced with typhoon events occurred before 2016. The purple dots represent the location of a city with at least one 150m+ building.



Locations of buildings taller than 150 m in 2017, cross-referenced with typhoon events occurred before 2016. The purple dots represent the location of a city with at least one 150m+ building.

8.4 Hong Kong

TALL BUILDINGS and CYCLONE EVENTS	
Tall buildings in 1995	238
Tall buildings in 2005	582
Tall buildings in 2017	821
Tall building in cyclone prone area	821
Tall building affected by cyclone	575
Taller than 150m in 1995	61
Taller than 150m in 2005	247
Taller than 150m in 2017	317
Taller than 150m in cyclone prone area	317
Taller than 150m affected by cyclone	276

ECONOMIC DATA	
GDP (2016, million US$)	$ 320,912.24
GDP per capita (2016, US$)	$43,681.00
GDP, PPP per capita (2016, US$)	$58,552.70
GDP, PPP per capita (2016, world ranking)	8

POPULATION DATA	
Population 2016	7,347,000
Urban population 1960	85.20%
Urban population 2016	100.00%
Urban population increase (from 1960 to 2016)	4,726,280

CODE/STANDARD REQUIREMENTS	No

RANK BY POP.	MEGACITY	COMBINED POPULATION	AREA (SQ. KM)	DENSITY (PPL/SQ. KM)	NUMBER OF 200 M+ BUILDINGS	CITIES & ADMINISTRATIVE AREAS WITHIN
1	Pearl River Delta	64,899,778	56,217	1,154	220	Dongguan, Foshan, Guangzhou, Hong Kong, Huizhou, Jiangmen, Macau, Shenzhen, Zhaoqing, Zhongshan, and Zuhai

Locations of buildings taller than 150 m in 1995, cross-referenced with typhoon events occurred before 2016. The purple dots represent the location of a city with at least one 150m+ building.

Locations of buildings taller than 150 m in 2017, cross-referenced with typhoon events occurred before 2016. The purple dots represent the location of a city with at least one 150m+ building.

8.5 India

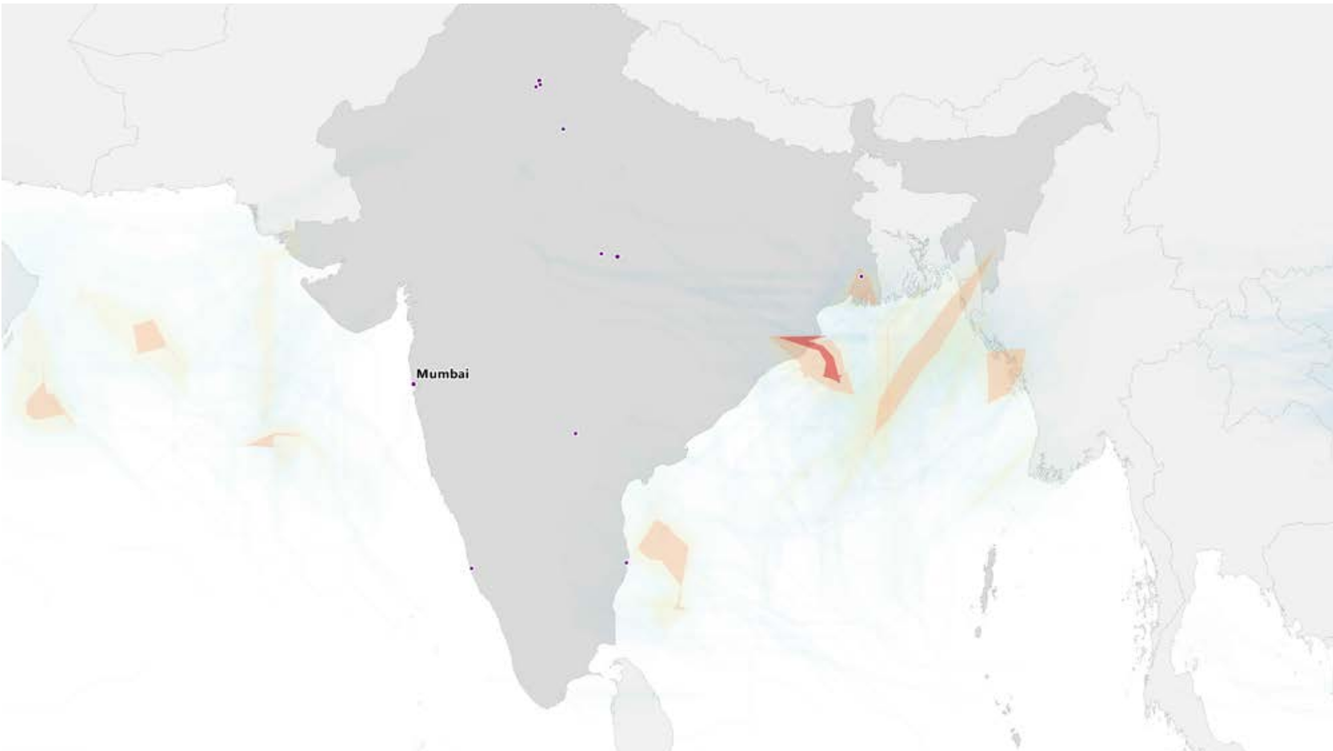
TALL BUILDINGS and CYCLONE EVENTS	
Tall buildings in 1995	35
Tall buildings in 2005	52
Tall buildings in 2017	181
Tall building in cyclone prone area	25
Tall building affected by cyclone	6
Taller than 150m in 1995	3
Taller than 150m in 2005	4
Taller than 150m in 2017	56
Taller than 150m in cyclone prone area	10
Taller than 150m affected by cyclone	1

ECONOMIC DATA	
GDP (2016, million US$)	$ 2,263,522.52
GDP per capita (2016, US$)	$1,709.00
GDP, PPP per capita (2016, US$)	$6,572.30
GDP, PPP per capita (2016, world ranking)	113

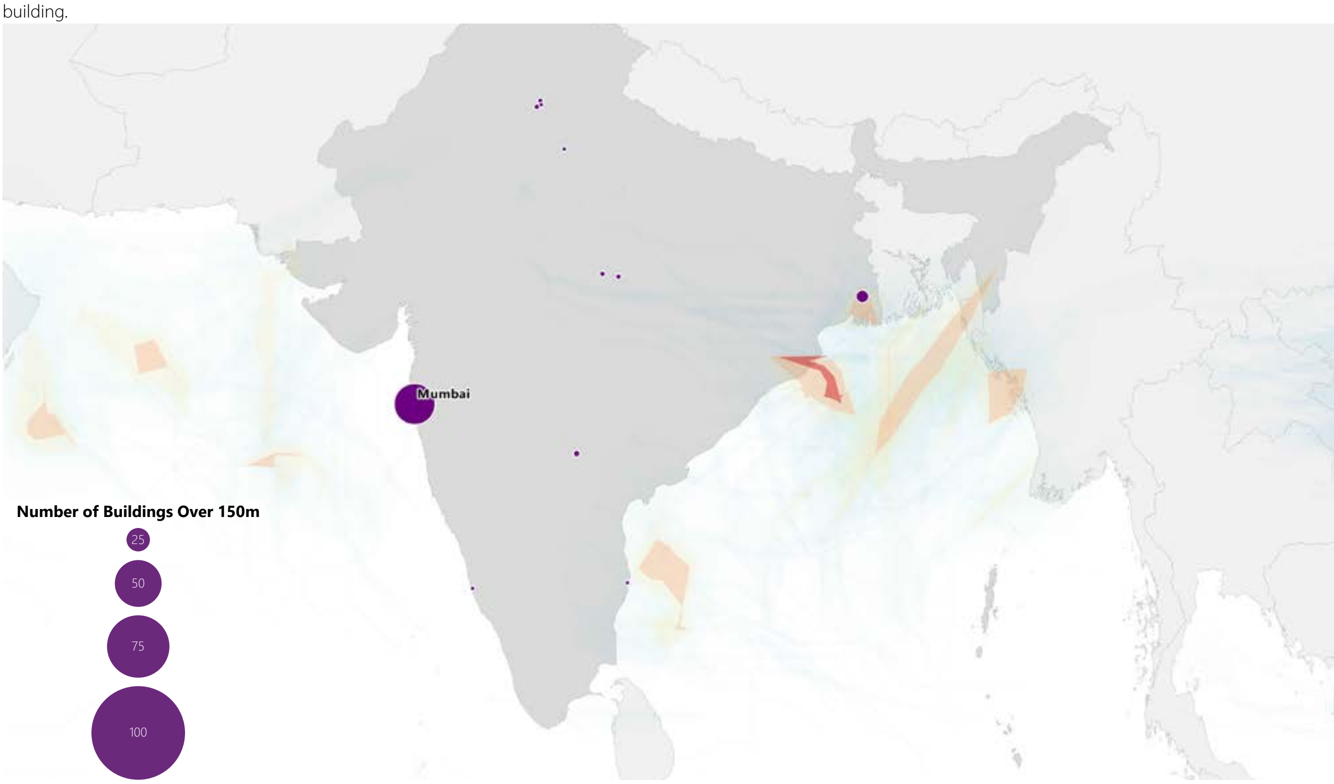
POPULATION DATA	
Population 2016	1,324,171,000
Urban population 1960	17.92%
Urban population 2016	33.13%
Urban population increase (from 1960 to 2016)	358,151,043

CODE/STANDARD REQUIREMENTS	No

RANK BY POP.	MEGACITY	COMBINED POPULATION	AREA (SQ. KM)	DENSITY (PPL/SQ. KM)	NUMBER OF 200 M+ BUILDINGS	CITIES & ADMINISTRATIVE AREAS WITHIN
5	Delhi	34,397,873	15,562	2,210	3	Delhi, Nodia, Gurgaon, Ghaziabad, Rohtak, and Meerut
10	Mumbai	26,136,721	17,313	1,510	38	Districts of Mumbai, Mumbai Suburban, Pulghar & Raigad, Thane
19	Kolkata	20,608,327	18,885	1,091	1	Districts of Hooghly, Howrah, Kolkata, North 24 Parganas, Parganas, and South 24
33	Bangalore	13,093,168	13,139	1,297	0	Districts of Bangalore, Krishnagiri Districts, and Ramanagara
39	Chennai	12,373,088	8,052	705	0	Districts of Chennai, Kancheepuram Districts, and Thiruvallur
40	Hyderabad	12,273,352	17409	1,005	0	Districts of Hyderabad, Medak, and Rangareddy



Locations of buildings taller than 150 m in 1995, cross-referenced with typhoon events occurred before 2016. The purple dots represent the location of a city with at least one 150m+ building.



Locations of buildings taller than 150 m in 2017, cross-referenced with typhoon events occurred before 2016. The purple dots represent the location of a city with at least one 150m+ building.

8.6 Japan

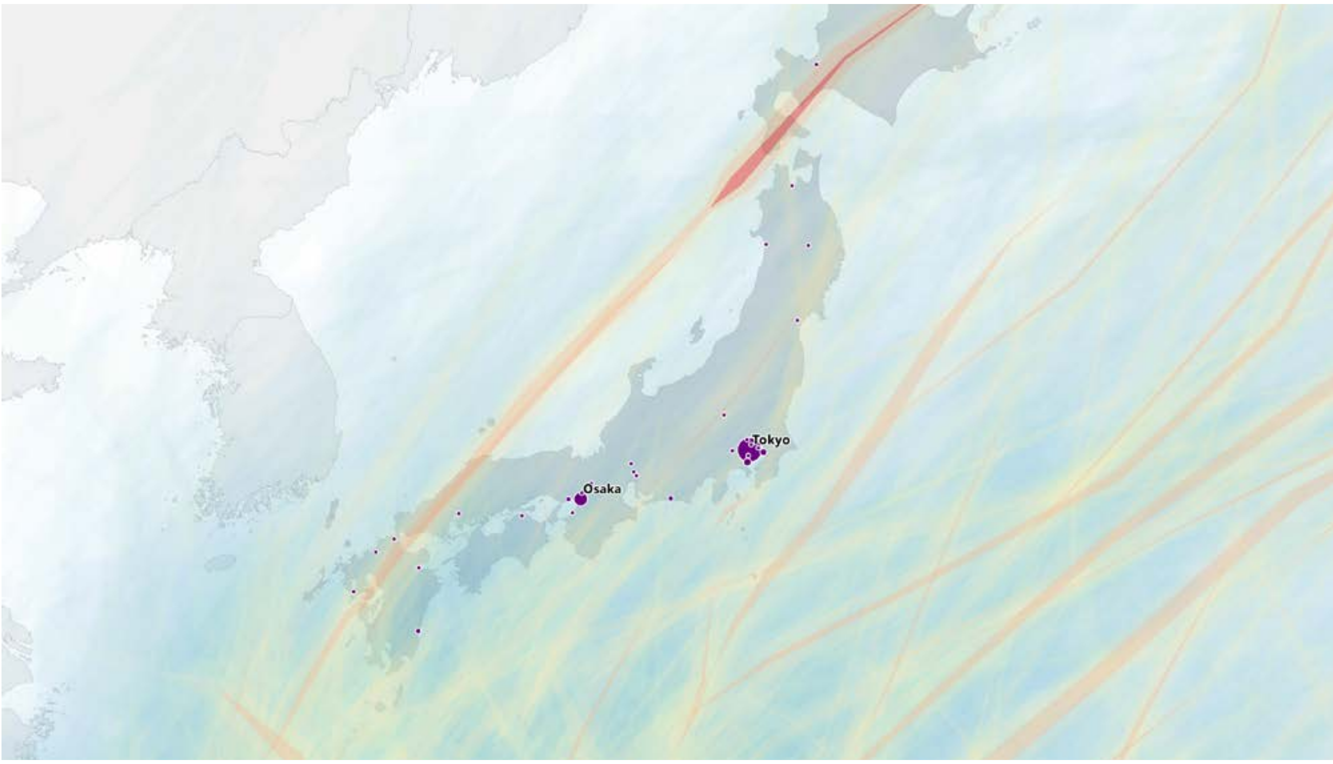
TALL BUILDINGS and CYCLONE EVENTS	
Tall buildings in 1995	146
Tall buildings in 2005	330
Tall buildings in 2017	564
Tall building in cyclone prone area	564
Tall building affected by cyclone	470
Taller than 150m in 1995	45
Taller than 150m in 2005	107
Taller than 150m in 2017	240
Taller than 150m in cyclone prone area	240
Taller than 150m affected by cyclone	186

ECONOMIC DATA	
GDP (2016, million US$)	$ 4,939,383.91
GDP per capita (2016, US$)	$38,894.00
GDP, PPP per capita (2016, US$)	$41,469.90
GDP, PPP per capita (2016, world ranking)	22

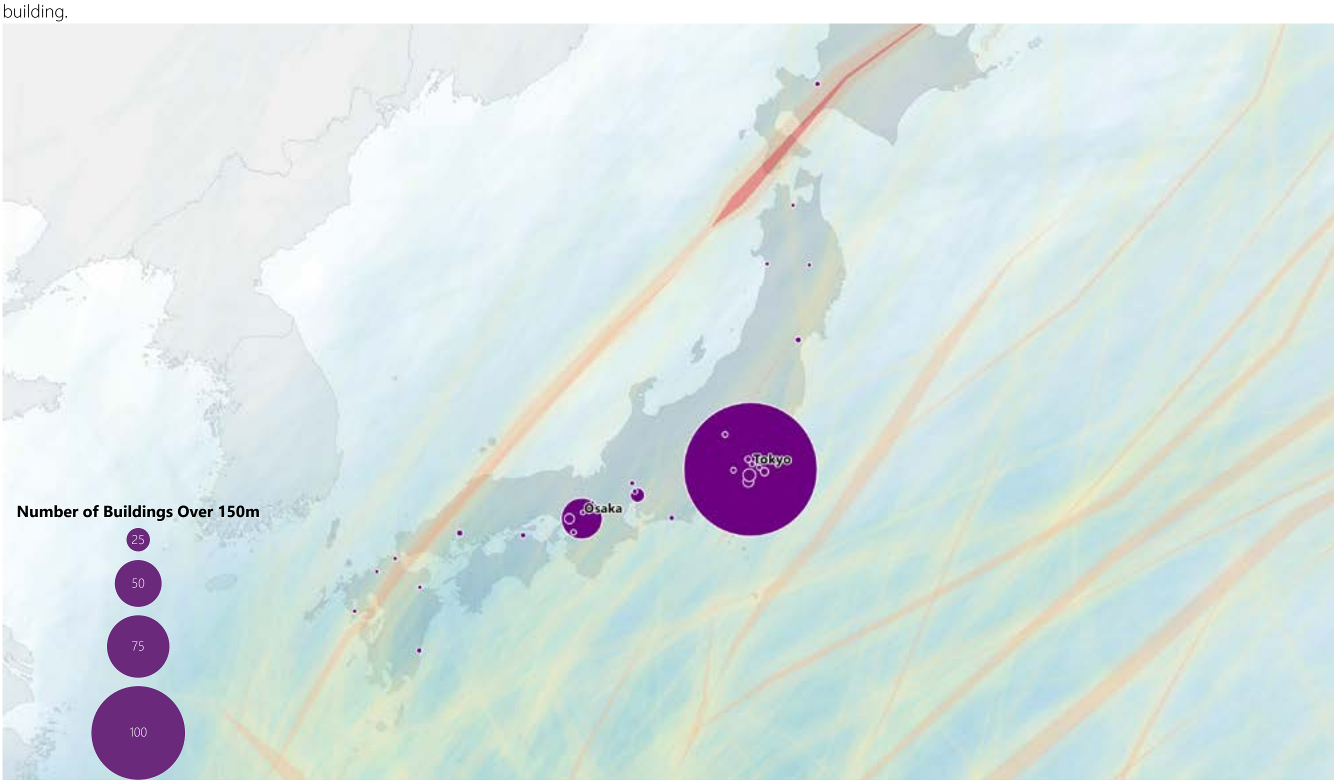
POPULATION DATA	
Population 2016	126,995,000
Urban population 1960	63.27%
Urban population 2016	93.92%
Urban population increase (from 1960 to 2016)	60,748,133

CODE/STANDARD REQUIREMENTS	No

RANK BY POP.	MEGACITY	COMBINED POPULATION	AREA (SQ. KM)	DENSITY (PPL/SQ. KM)	NUMBER OF 200 M+ BUILDINGS	CITIES & ADMINISTRATIVE AREAS WITHIN
3	Tokyo (Kanto Region)	42,797,000	32,424	1,320	29	Prefectures of Chiba, Gunma, Ibaraki, Kanagawa, Saitama, Tochigi, and Tokyo
18	Osaka	20,750,000	27,351	759	6	Prefectures of Hyogo, Kyoto, Osaka, Nara, Shiga, and Wakayama; including the cities of Hemeji, Izumisano, and Kobe
42	Nagoya	11,321,000	21,567	525	4	Prefectures of Aichi, Gifu, Mie; including the cities of Nagoya, Toyohashi, and Tsu



Locations of buildings taller than 150 m in 1995, cross-referenced with typhoon events occurred before 2016. The purple dots represent the location of a city with at least one 150m+ building.



Locations of buildings taller than 150 m in 2017, cross-referenced with typhoon events occurred before 2016. The purple dots represent the location of a city with at least one 150m+ building.

8.7 New Zealand

TALL BUILDINGS and CYCLONE EVENTS	
Tall buildings in 1995	37
Tall buildings in 2005	51
Tall buildings in 2017	60
Tall building in cyclone prone area	10
Tall building affected by cyclone	5
Taller than 150m in 1995	0
Taller than 150m in 2005	2
Taller than 150m in 2017	2
Taller than 150m in cyclone prone area	0
Taller than 150m affected by cyclone	0

ECONOMIC DATA	
GDP (2016, million US$)	$ 185,017.32
GDP per capita (2016, US$)	$39,426.00
GDP, PPP per capita (2016, US$)	$39,058.70
GDP, PPP per capita (2016, world ranking)	24

POPULATION DATA	
Population 2016	4,693,000
Urban population 1960	75.99%
Urban population 2016	86.32%
Urban population increase (from 1960 to 2016)	2,248,408

CODE/STANDARD REQUIREMENTS	AS/NZS

Locations of buildings taller than 150 m in 1995, cross-referenced with typhoon events occurred before 2016. The purple dots represent the location of a city with at least one 150m+ building.

Locations of buildings taller than 150 m in 2017, cross-referenced with typhoon events occurred before 2016. The purple dots represent the location of a city with at least one 150m+ building.

8.8 Philippines

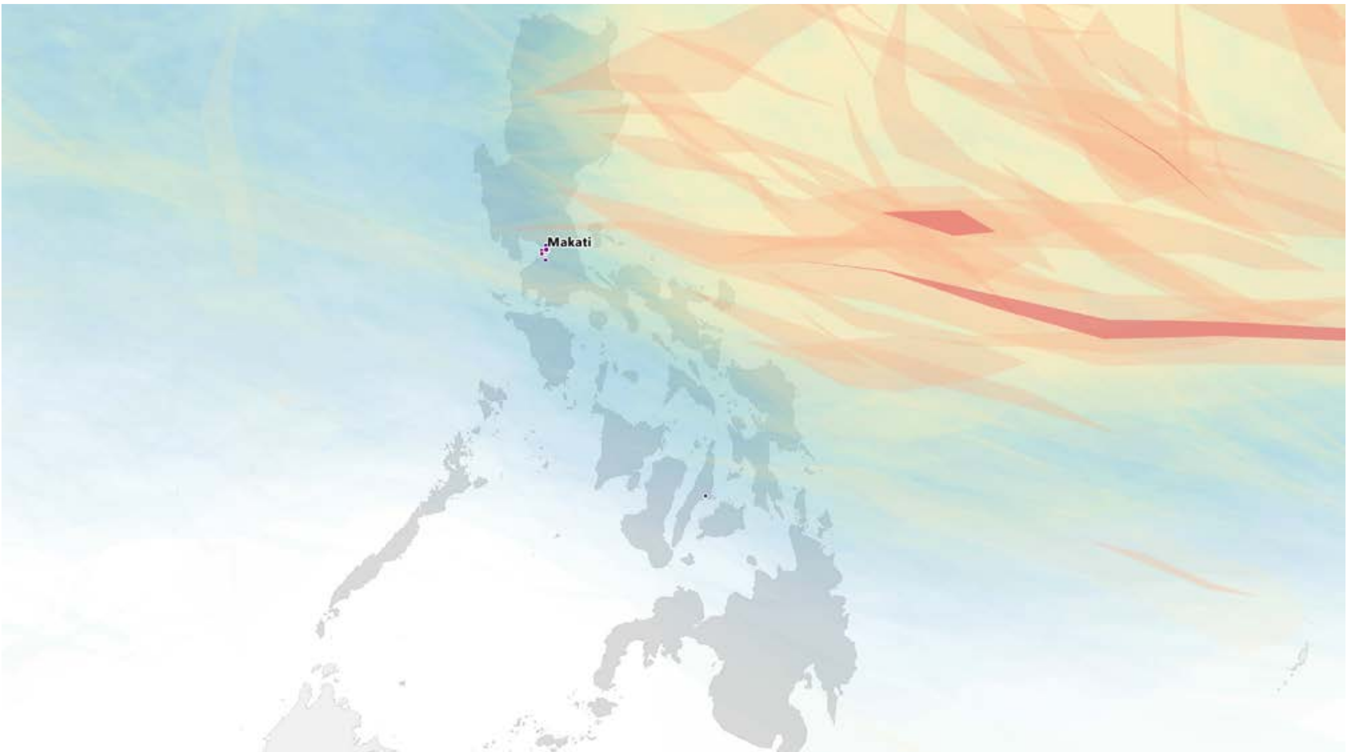
TALL BUILDINGS and CYCLONE EVENTS	
Tall buildings in 1995	15
Tall buildings in 2005	57
Tall buildings in 2017	142
Tall building in cyclone prone area	142
Tall building affected by cyclone	74
Taller than 150m in 1995	3
Taller than 150m in 2005	27
Taller than 150m in 2017	78
Taller than 150m in cyclone prone area	78
Taller than 150m affected by cyclone	43

ECONOMIC DATA	
GDP (2016, million US$)	$ 304,905.41
GDP per capita (2016, US$)	$2,951.00
GDP, PPP per capita (2016, US$)	$7,806.20
GDP, PPP per capita (2016, world ranking)	111

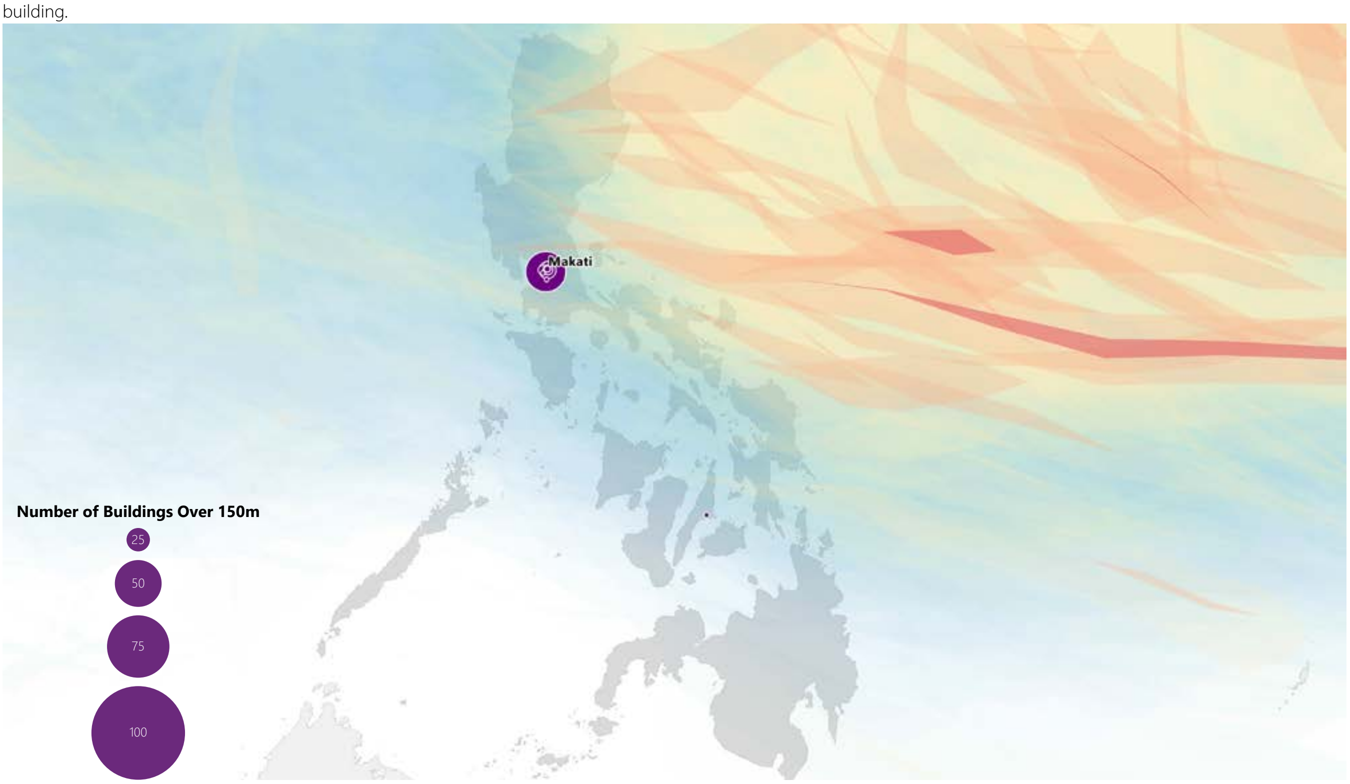
POPULATION DATA	
Population 2016	103,320,000
Urban population 1960	30.29%
Urban population 2016	44.28%
Urban population increase (from 1960 to 2016)	37,792,093

CODE/STANDARD REQUIREMENTS	ASTM E 1886 and ASTM E 1996

RANK BY POP.	MEGACITY	COMBINED POPULATION	AREA (SQ. KM)	DENSITY (PPL/SQ. KM)	NUMBER OF 200 M+ BUILDINGS	CITIES & ADMINISTRATIVE AREAS WITHIN
12	Manila	25,169,197	8,113	3,102	30	Provinces of Bulacan,Cavite, Leguna, Rizal, and the National Capitol Region



Locations of buildings taller than 150 m in 1995, cross-referenced with typhoon events occurred before 2016. The purple dots represent the location of a city with at least one 150m+ building.



Locations of buildings taller than 150 m in 2017, cross-referenced with typhoon events occurred before 2016. The purple dots represent the location of a city with at least one 150m+ building.

8.9 South Korea

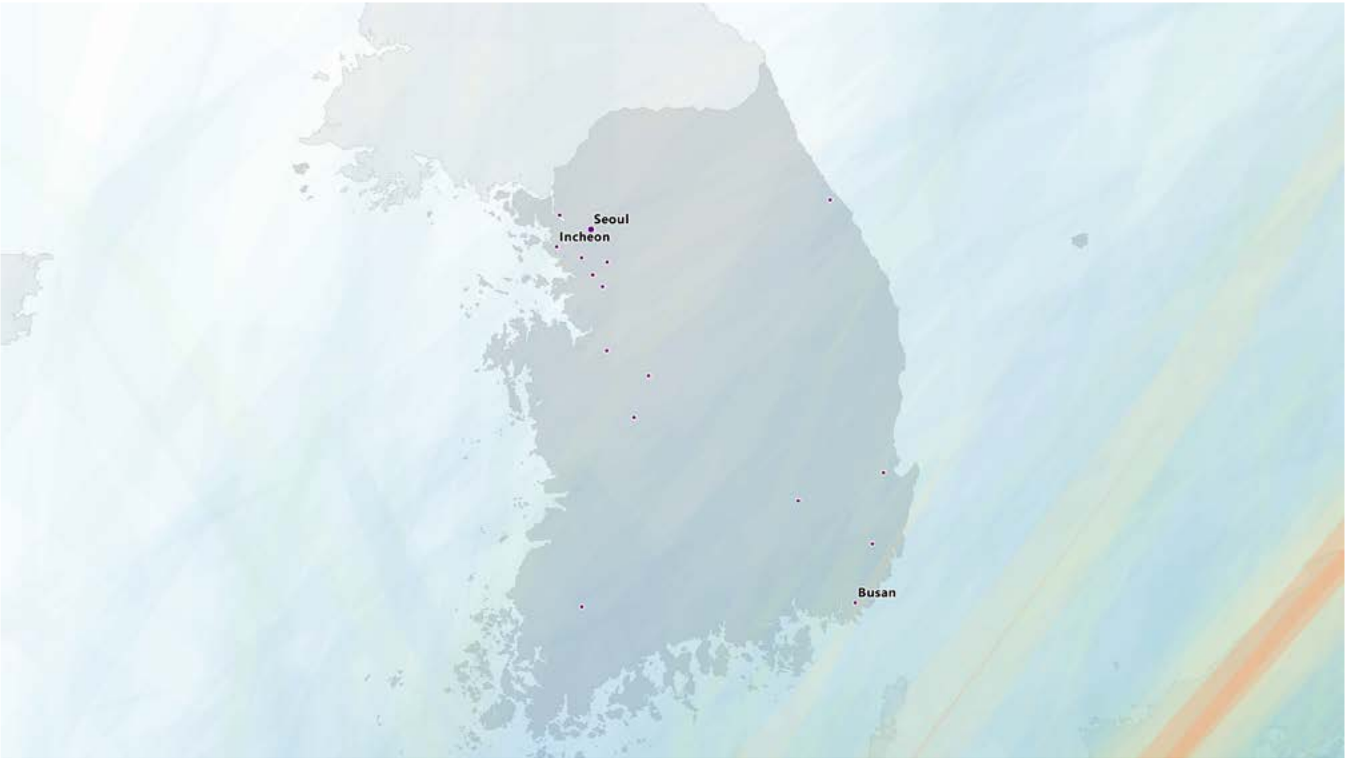
TALL BUILDINGS and CYCLONE EVENTS	
Tall buildings in 1995	17
Tall buildings in 2005	109
Tall buildings in 2017	376
Tall building in cyclone prone area	371
Tall building affected by cyclone	192
Taller than 150m in 1995	3
Taller than 150m in 2005	45
Taller than 150m in 2017	216
Taller than 150m in cyclone prone area	214
Taller than 150m affected by cyclone	92

ECONOMIC DATA	
GDP (2016, million US$)	$ 1,411,345.59
GDP per capita (2016, US$)	$27,538.00
GDP, PPP per capita (2016, US$)	$35,750.80
GDP, PPP per capita (2016, world ranking)	29

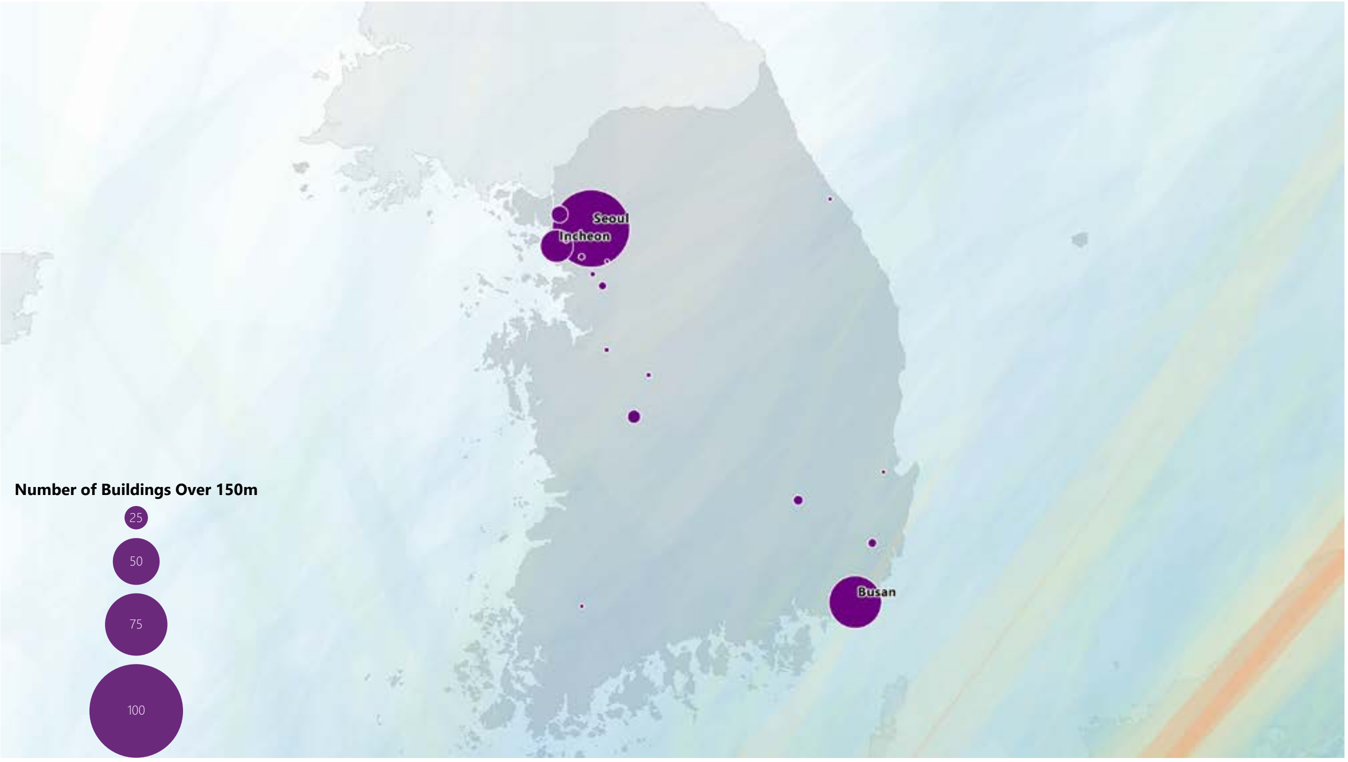
POPULATION DATA	
Population 2016	51,246,000
Urban population 1960	27.71%
Urban population 2016	82.59%
Urban population increase (from 1960 to 2016)	35,392,904

CODE/STANDARD REQUIREMENTS	No

RANK BY POP.	MEGACITY	COMBINED POPULATION	AREA (SQ. KM)	DENSITY (PPL/SQ. KM)	NUMBER OF 200 M+ BUILDINGS	CITIES & ADMINISTRATIVE AREAS WITHIN
11	Seoul-Incheon	25,524,572	11,807	2,162	39	Gyeonggi Province, Incheon, and Seoul



Locations of buildings taller than 150 m in 1995, cross-referenced with typhoon events occurred before 2016. The purple dots represent the location of a city with at least one 150m+ building.



Locations of buildings taller than 150 m in 2017, cross-referenced with typhoon events occurred before 2016. The purple dots represent the location of a city with at least one 150m+ building.

8.10 Taiwan

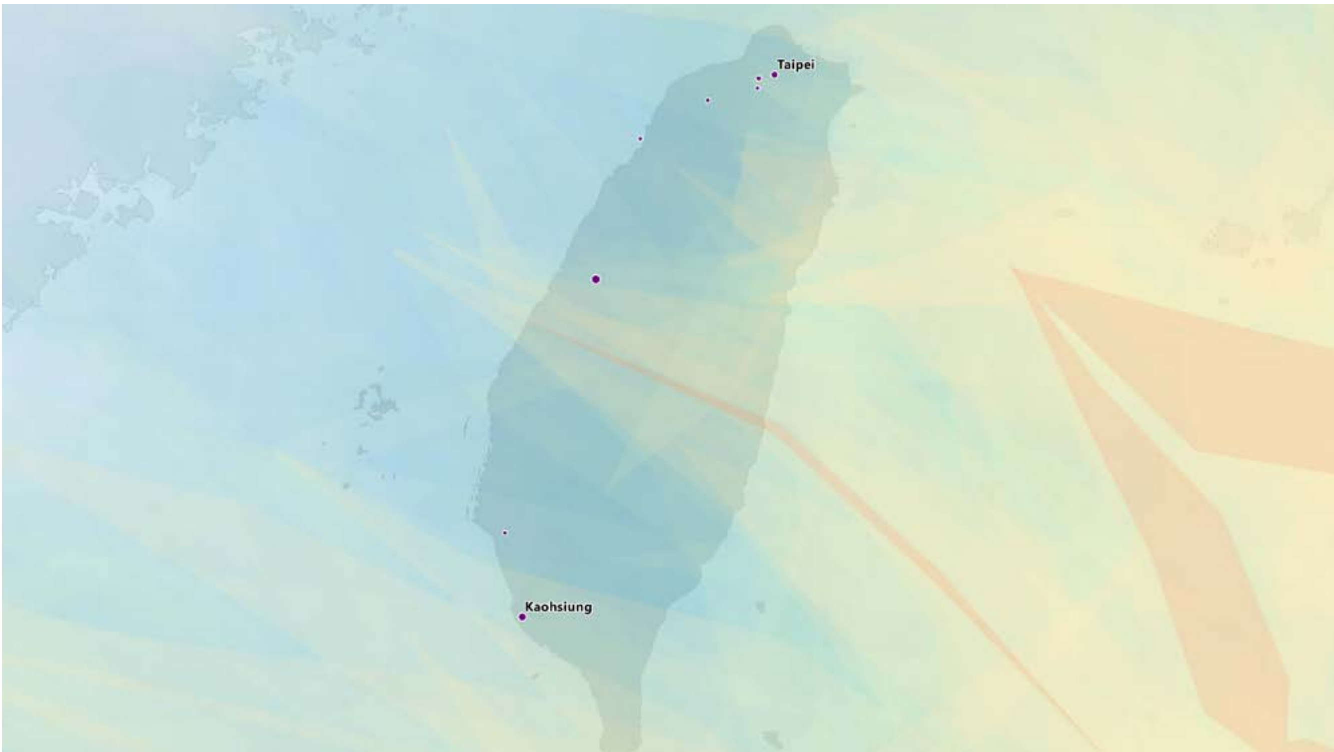
TALL BUILDINGS and CYCLONE EVENTS	
Tall buildings in 1995	35
Tall buildings in 2005	73
Tall buildings in 2017	102
Tall building in cyclone prone area	102
Tall building affected by cyclone	78
Taller than 150m in 1995	13
Taller than 150m in 2005	18
Taller than 150m in 2017	40
Taller than 150m in cyclone prone area	40
Taller than 150m affected by cyclone	26

ECONOMIC DATA	
GDP (2016, million US$)	$ 1,411,345.59
GDP per capita (2016, US$)	$27,538.00
GDP, PPP per capita (2016, US$)	$35,750.80
GDP, PPP per capita (2016, world ranking)	29

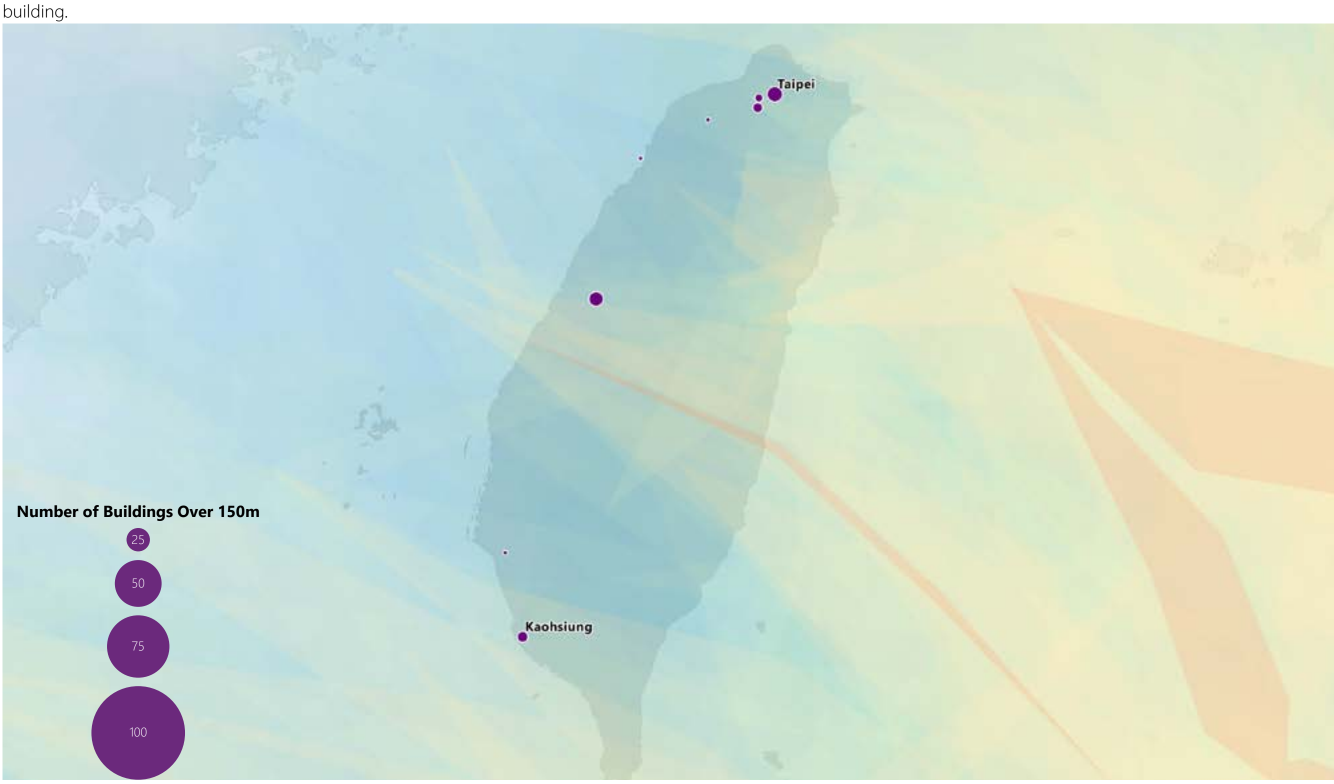
POPULATION DATA	
Population 2016	51,246,000
Urban population 1960	27.71%
Urban population 2016	82.59%
Urban population increase (from 1960 to 2016)	35,392,904

CODE/STANDARD REQUIREMENTS	No

RANK BY POP.	MEGACITY	COMBINED POPULATION	AREA (SQ. KM)	DENSITY (PPL/SQ. KM)	NUMBER OF 200 M+ BUILDINGS	CITIES & ADMINISTRATIVE AREAS WITHIN
44	Taipei	10,280,569	5,209	1,974	6	Hsinchu, Keelung, New Taipei City, Taipei, and Taoyuan



Locations of buildings taller than 150 m in 1995, cross-referenced with typhoon events occurred before 2016. The purple dots represent the location of a city with at least one 150m+ building.



Locations of buildings taller than 150 m in 2017, cross-referenced with typhoon events occurred before 2016. The purple dots represent the location of a city with at least one 150m+ building.

8.11 Thailand

TALL BUILDINGS and CYCLONE EVENTS	
Tall buildings in 1995	27
Tall buildings in 2005	58
Tall buildings in 2017	139
Tall building in cyclone prone area	0
Tall building affected by cyclone	0
Taller than 150m in 1995	7
Taller than 150m in 2005	26
Taller than 150m in 2017	75
Taller than 150m in cyclone prone area	0
Taller than 150m affected by cyclone	0

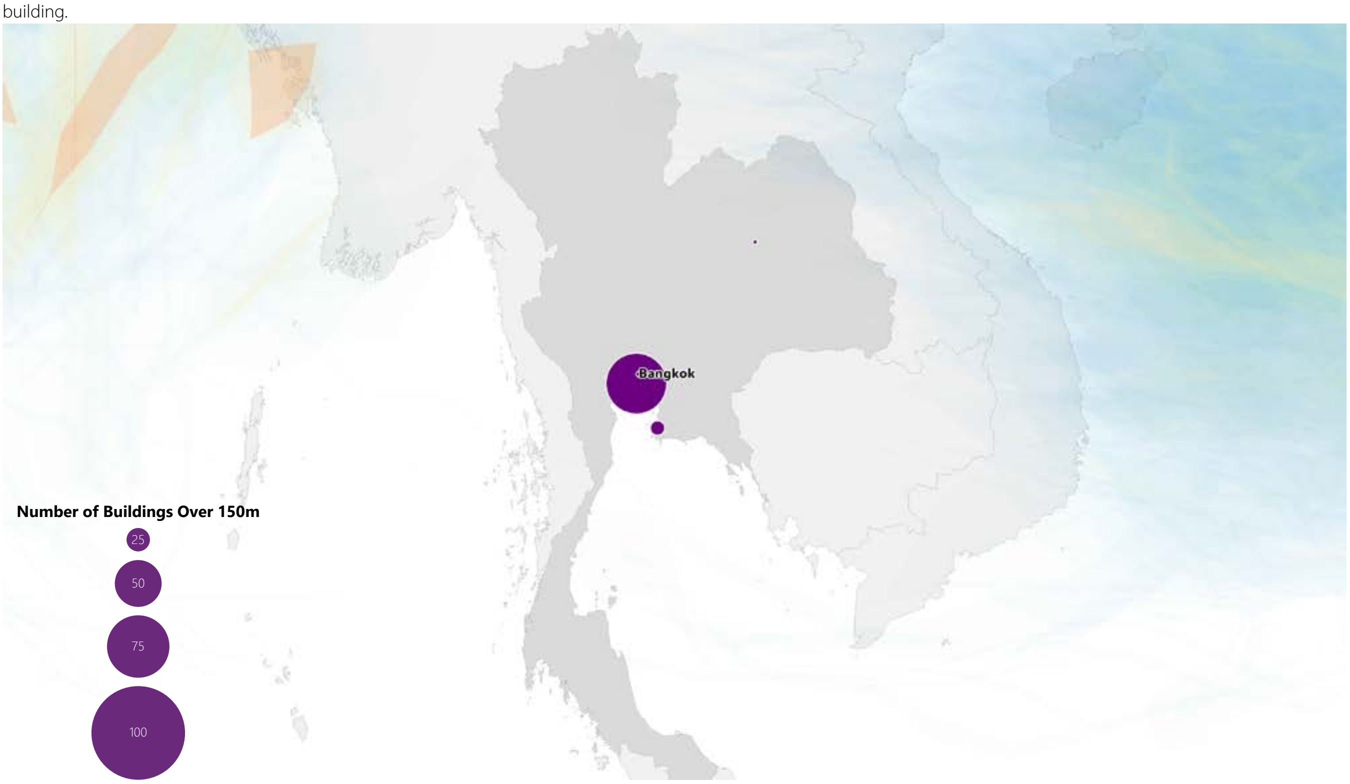
ECONOMIC DATA	
GDP (2016, million US$)	$ 406,839.68
GDP per capita (2016, US$)	$5,907.00
GDP, PPP per capita (2016, US$)	$16,916.50
GDP, PPP per capita (2016, world ranking)	64

POPULATION DATA	
Population 2016	68,864,000
Urban population 1960	19.67%
Urban population 2016	51.54%
Urban population increase (from 1960 to 2016)	30,103,230

CODE/STANDARD REQUIREMENTS	No

RANK BY POP.	MEGACITY	COMBINED POPULATION	AREA (SQ. KM)	DENSITY (PPL/SQ. KM)	NUMBER OF 200 M+ BUILDINGS	CITIES & ADMINISTRATIVE AREAS WITHIN
24	Bangkok	17,718,258	21,028	843	20	Provinces of Bangkok, Chachoengsao, Chon Buri, Nakhon Patham, Nonthaburi,Pathum Thani, Rayong, Samout Prakan, and Samut Sakhon

Locations of buildings taller than 150 m in 1995, cross-referenced with typhoon events occurred before 2016. The purple dots represent the location of a city with at least one 150m+ building.



Locations of buildings taller than 150 m in 2017, cross-referenced with typhoon events occurred before 2016. The purple dots represent the location of a city with at least one 150m+ building.

8.12 Vietnam

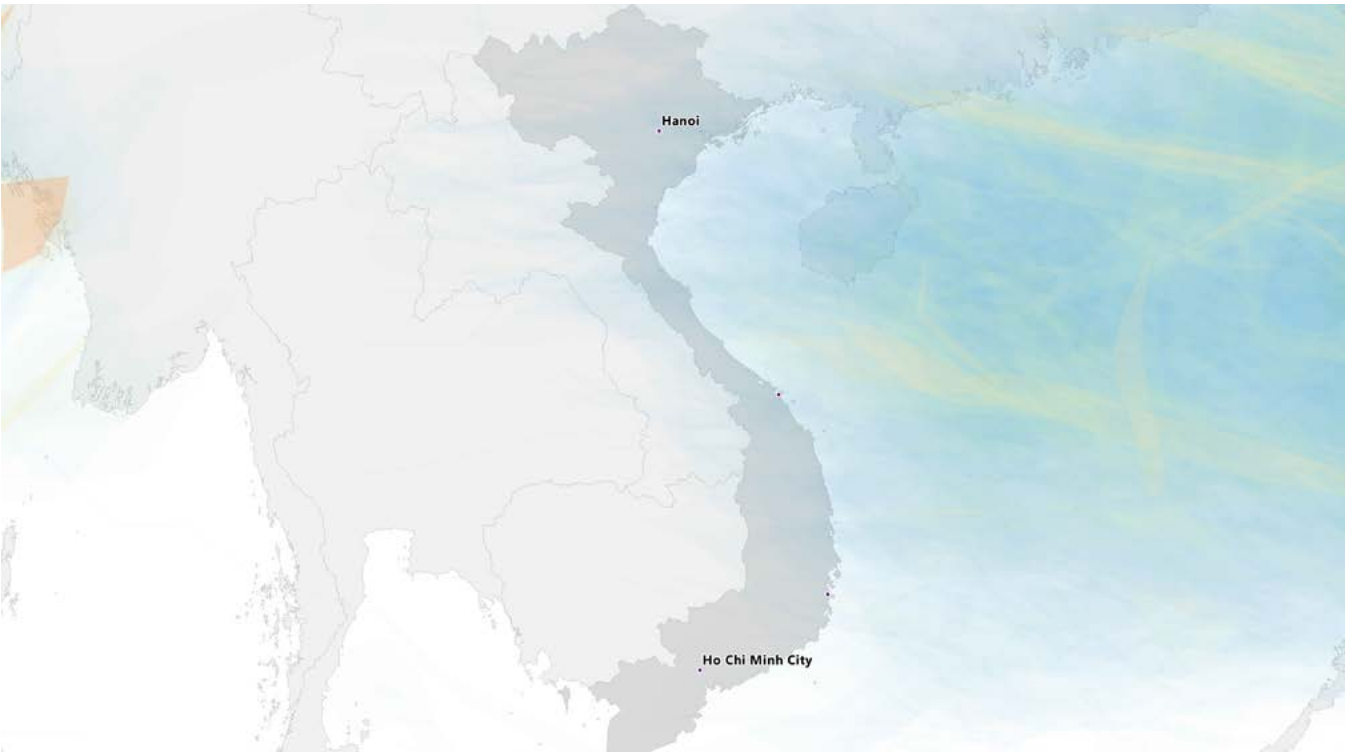
TALL BUILDINGS and CYCLONE EVENTS	
Tall buildings in 1995	0
Tall buildings in 2005	6
Tall buildings in 2017	78
Tall building in cyclone prone area	78
Tall building affected by cyclone	9
Taller than 150m in 1995	0
Taller than 150m in 2005	0
Taller than 150m in 2017	26
Taller than 150m in cyclone prone area	26
Taller than 150m affected by cyclone	0

ECONOMIC DATA	
GDP (2016, million US$)	$ 202,615.89
GDP per capita (2016, US$)	$2,185.00
GDP, PPP per capita (2016, US$)	$6,424.10
GDP, PPP per capita (2016, world ranking)	117

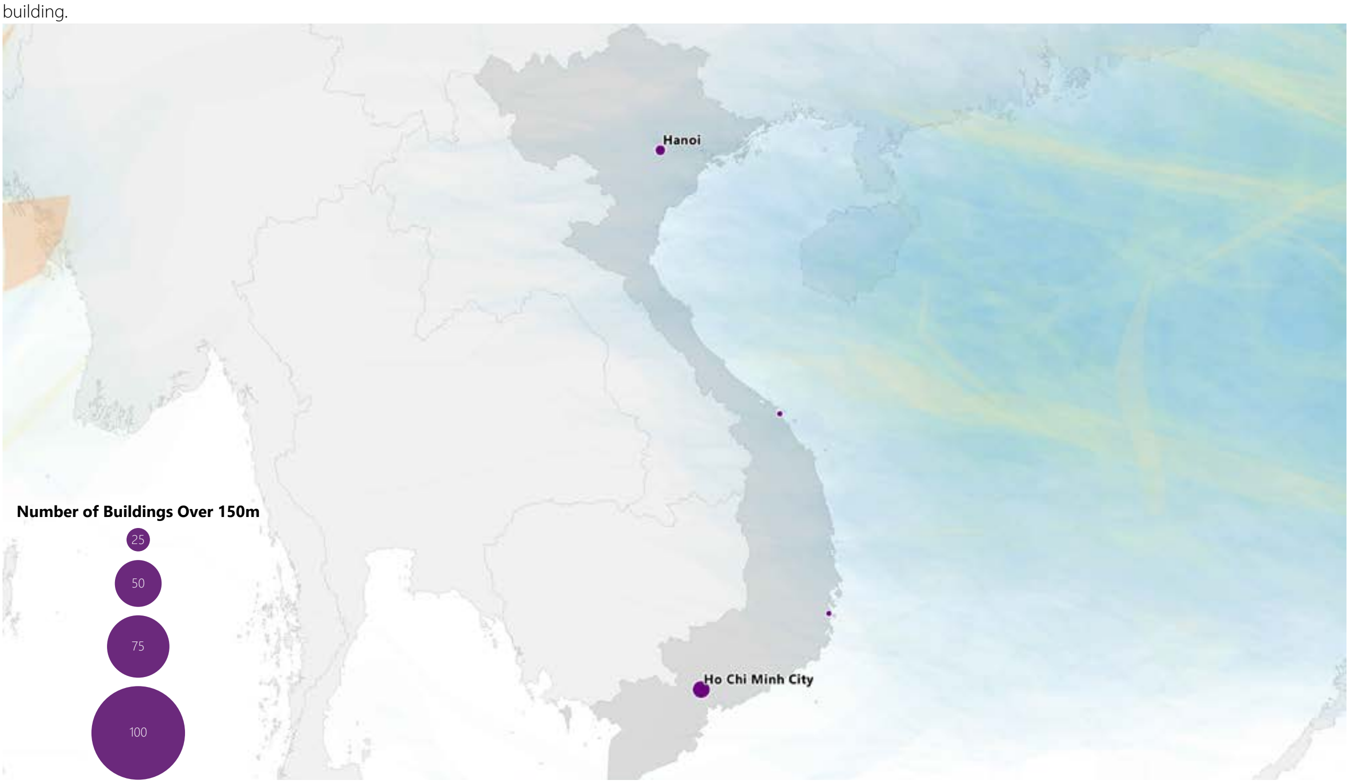
POPULATION DATA	
Population 2016	92,701,000
Urban population 1960	14.70%
Urban population 2016	34.23%
Urban population increase (from 1960 to 2016)	26,624,366

CODE/STANDARD REQUIREMENTS	No

RANK BY POP.	MEGACITY	COMBINED POPULATION	AREA (SQ. KM)	DENSITY (PPL/SQ. KM)	NUMBER OF 200 M+ BUILDINGS	CITIES & ADMINISTRATIVE AREAS WITHIN
23	Ho Chi Minh	18,051,200	23,724	761	7	Ho Chi Minh City and Provinces of Ba Ria-Vung Tau, Binh Duong, Dong Nai, Long An, Tay Ninh, and Tien Giang



Locations of buildings taller than 150 m in 1995, cross-referenced with typhoon events occurred before 2016. The purple dots represent the location of a city with at least one 150m+ building.



Locations of buildings taller than 150 m in 2017, cross-referenced with typhoon events occurred before 2016. The purple dots represent the location of a city with at least one 150m+ building.

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